Electric cars on the 100% renewable energy island of Samsø

Abstract

2011 marks the first year when a number of major car manufacturers are launching a number of models of electric cars, and the Danish island of Samsø is looking a new ways to integrate transport into its energy system

This case study shows that care must be paid to designing energy systems from a technical as well as institutional perspective.

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Foreword

This constitutes the final thesis in the M.Sc. programme in Sustainable Energy Planning and Management at Aalborg University, Department of Development and Planning. The study has been conducted during the period 1^{st} February 2011 – 9^{th} June 2011, under the supervision of associate professor Brian Vad Mathiesen.

The topic of the thesis has been chosen in connection with the 10 years of development and evaluation of the 100% renewable energy system on, and owned by, the island of Samsø as it prepares to look at the electrification of light vehicle transport a second time. The arrival on the market of a number of electric car models by major manufacturers, and electric car leasing companies is significant. Therefore the importance of understanding the implications of electric cars for energy systems as well as the societies they serve is timely.

I wish to express my thanks to my supervisor Brian Vad Mathiesen for his precious insight to the topic, always illustrated with the relevant documentation, valuable comments and suggestions and not least for being understanding and guiding during the difficult times.

I would like to thank Dansk Elbil Komite, Grønn Bil (Norway), for sharing their experiences and knowledge as well as making it possible to learn and work with this interesting issue. Special thanks to Søren Hermansen of Samsø Energi Akademi, Professor Willett Kempton, PhD candidate Nathaniel Pearre of the University of Delaware for receiving me, and teaching me about V2G, wind policy and planning, and much more.

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Chapter 1: Introduction

1.1 Overview

Samsø is well known in renewable energy circles, as a special place. It is an island of 114 square kilometers and 3885 souls off the coast of Denmark (making it one of the smallest municipalities, as it is 96th out of 98 in terms of population size in Denmark, and with 25 percent of the population over the age of 65). Its prime industry being agriculture, and major employers being the social and health care system as well as the hospitality and trade industry, it also has one of the lowest incomes per capita in Denmark (Kommune 2010) (Energiakademi 2007).

In 1997, Samsø won a competition by the Danish Government to become self sufficient in energy, using renewable energy sources, and now the island has a claim to having a 100% renewable energy supply, which is owned mostly locally by the islanders and the municipality. and a share of profits accrue to the island. (Energiakademi 2007)

Samsø was not always as it is now. During the period from 1997 until 2005, the energy system was transformed both technologically and institutionally. Firstly, the system changed in terms of energy sources (going from fossil fuels to renewable), energy transformation technology (different heating systems, like district heating, energy savings, etc) and energy services, and now renewable energy supply meets 99.6 percent of demand (Energiakademi 2007). Secondly the system was changed in terms of its ownership model, going from fossil fuel owned by utilities to a 50-30-20 percent model, with 50 percent owned by the municipality, 30 percent by households and 20 percent corporate. (Energiakademi 2007)

Samsø attributes its success to implementing a “100 percent” renewable energy system to the implementation of “off the shelf” renewable engineering technologies and local citizen involvement. However, while the island successfully built on and offshore wind turbines for a renewable electricity supply, straw based district heating for renewable heating, demand side energy savings, it failed on transport and its planned electrification. Instead, to counter this, it built the offshore wind farm to offset transport CO_2 emissions from a 100% fossil fuel powered motorized transport sector, including ferries, private cars, trucks, lorries, etc. (Energiakademi 2007)

1.2 Why does transport matter and why change the energy system?

Since the 1970s, Danish energy planning has had some success at stabilising greenhouse gas emissions while increasing GDP. It has done so by including renewable energy sources like wind power on a large scale into electricity production, improving energy production efficiency by for instance the use of combined heat and power, and decreasing energy demand by demand side measures and district heating. (Danish Association of Engineers 2010)

While transport is one the largest sectors of the energy system in Denmark, and therefore one of the most important, it has followed a different trend. Transport is almost 100% fossil fuel based, and since the 1970s has represented a large and growing share of energy consumed in Denmark.

Despite one of the highest tax rates on cars in the world, a combination of a legacy of 19th century combustion engine technology with rising incomes in a 20th century of personal travel are responsible. However, possible technological change is finally at hand, with electric vehicles coming onto the mass market this year and the next

1.3 Potential for Samsø

Electrifying the light vehicle sector on Samsø has the potential to make several impacts. Firstly it would make a big cut in CO2 emissions on the island. Secondly it would use some of the excess electricity produced by wind turbines on the island, thereby helping in a theoretical manner to stabilize the system. Thirdly, using locally produced surplus electricity may be cheaper than buying fossil fuels, and the savings thus made could be greater than the income from the export of the excess electricity. This argument is one made by Preben Maegaard of the Nordisk Folkecenter for Vedvarende Energi as a general case for locally produced energy in Denmark (Maegaard 2011).

Looking at the transport by relative share for Samsø (see Figure 1), almost a third of the total energy consumed is represented by the light vehicle fleet, namely cars. Busses, trucks and tractors, represent the almost a quarter, while ferries represent almost half.

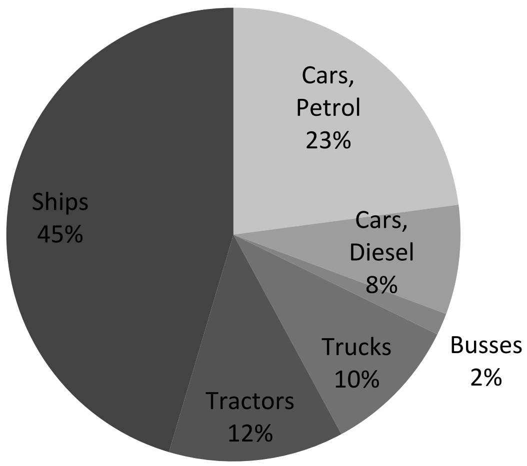

Figure 1: transport in Samsø by type in 2005 (Source: (Energiakademi 2007))

Figure 1 shows that the transportation problem in Samsø is a multifaceted one, involving different technologies and social settings, transporting both people and goods, on and to the island. Cars are one such facet – they are the second largest single category after the ferry, and secondly, they are ubiquitous, widespread, of relevance to each and every household. In terms of cars, it is interesting to see how energy use would change if cars were electric. While there are no figures for the CO2 emissions by type of combustion-engined land transport

There are 1591 cars (personbiler) in Samsø (January 2010 figures); 1563 of which were for private driving purposes (privatkørsel) (Danmarks Statistik 2011). Of the 28 others, 1 is a taxi, 3 are ambulances, 15 are “residential”, 1 is for the fire service and 8 have another purpose. In addition, there are 8 busses (all tourist transport) and 475 vans (most of which in commercial ownership, possibly by tradesmen) which theoretically could be electrified. The rest of the system, including trucks, road tractors, semi-trailers, motorcycles, scooters, tractors, camping cars and emergency trucks is shown in Figure 2 below. (Danmarks Statistik 2011)

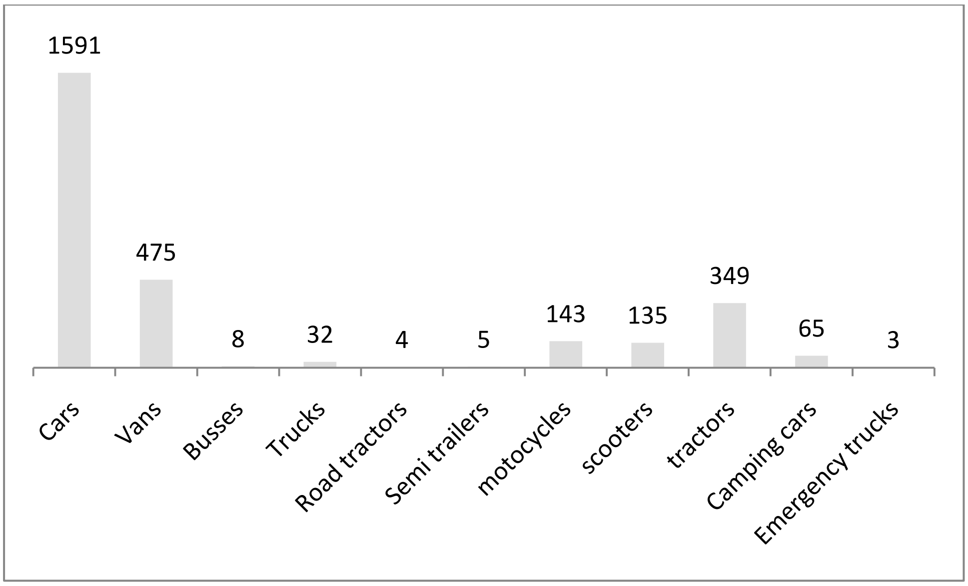

Figure 2: Vehicles of all kinds on Samsø (Source (Danmarks Statistik 2011))

Cars are ubiquitous, with almost two-thirds families owning one, but few owning more than one. Out of a total of 2231 families on the island, 1415 own a vehicle of some kind, 816 families no vehicles of any kind. 1213 families have a total of one vehicle, 185 families a total of two vehicles, and 17 families have a total of three vehicles. 1164 families have a car, 153 families have two cars. (Danmarks Statistik 2011)

So theoretically electrifying the car sector has the potential to reduce CO2 emissions and use locally produced electricity. 1563 electric cars would have the potential to displace most of the 19.8 TJ of fossil fuel used by combustion engine cars and use some of the 286 TJ of renewable electricity exported from the island. (Energiakademi 2007). (THINK Norway u.d.) (THINK Norway u.d.)

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Chapter 2
The problem's context

Having introduced the potential for electric cars on Samsø, this chapter presents some of the background to the issue. The focus is organizational and institutional, starting with the broader picture and focusing closer to home through the chapter: and going from live world examples to the broader picture of current research. The chapter concludes by drawing on the real world cases and the state of current academic research to define a research question and explain the contribution of the project to the global body of knowledge.

2.1 The state of current academic research

Researching electric cars is important, from technical, socio-economic and public regulation perspectives. Indeed much academic research exists on electric car systems, namely how they are engineered, but little exists on actual integration. Secondly, much of the engineering research uses theoretical modeling, and there is little research based on real cases. Thirdly, there is little research looking at the integrated technical, socio-economic and public regulation perspectives.

Researching electric vehicles from a technical perspective is important to energy planning. From a technical perspective, integrating transport is often seen as a challenge in energy planning, alongside integrating fluctuating renewable energy. The challenge can be solved by building suitable flexibility in the system to accommodate the fluctuation. There is a body of research showing that electric transport provides this flexibility.   This includes the choice of drive train in the system (Mathiesen, Lund og Nørgaard 2008), the charging scheme (Lund og Kempton 2008), etc.

For instance, (Mathiesen, Lund og Nørgaard 2008) show that the nature of the complete energy system has an impact on the electrification of transport. They present a system where transport is not 100% electric, because of the demands of the national energy system. In contrast, (Mathiesen 2009) shows by a feasibility study that BEVs are the best technological choice for all electric energy systems with a lot of excess electricity production.

In addition, that relationship works in the inverse. The flexibility of the energy system, in terms of the electricity supply system, can be enhanced by having cars feed power back into the grid, known as Vehicle –to-Grid, and there is research on the impact of this in Denmark (Lund og Kempton 2008), as well as how it works

From a socio-economic perspective, (Mathiesen 2009) undertakes a feasibility study of different drive trains, where he compares ICE vehicles, BEVs and HFCVs (representing a comparison of electric drive trains, hybrid fuel cells, and diesel, gasoline and biofuel) technically and socio-economically for Denmark, using different scenarios, and including V2G. He finds that BEVs have the lowest energy consumption, the lowest CO_2 emissions; as well as the lowest socio-economic costs, of all drive trains. He further finds that the latter holds true at low, medium and high energy prices, concluding that BEVs are the least vulnerable to fluctuating energy prices.

While they represent a tax revenue loss to the government, their socio-economic effects are positive, by means of a redistribution of which players receive income and have expenditure and advantageous private costs. (Vad Mathiesen 2008)

Something about the current research on technical scenarios (including V2G) for electric cars – what they tell us (macro level technical feasibility) and what they don't (micro level socioeconomic feasibility).

There is research to suggest that in a flexible energy system, large utilities with centralized energy production at a distance have a lesser reason to exist and therefore increase efforts to preserve the old system. The time is right to investigate possible feasibility of electric cars in different systems, providing alternatives to Better Place and centralized utilities (so that the whole is considered).

The implications of this research for this project are that technically, as the energy system on Samsø is electricity-focussed, BEVs are the choice of study in this project.

The first section starts by taking a world view of electric car implementation, looking at numbers from a manufacturer perspective, in terms of numbers of cars produced, forecast to be produced, or pre-ordered. It then takes a country specific view, examining the specific case of Norway in figures and trying to understand organizationally and institutionally why implementation has been successful there. Specific reference is made to the cases of Oslo and Trondheim. The next section looks at the situation in Denmark, contrasting it at the organizational and institutional level and comparing outcomes. It illustrates Denmark's different approach by looking at the EDISON project on Bornholm.

The next, second, section goes beyond electric cars and introduces Danish energy planning from a historical and technical perspective. It then illustrates it with the example of Samsø. The Samsø model in integrating large scale renewable energy to the island is then introduced, along with why it came to be successful.

Having presented the background to cars and energy systems in Denmark, the state of current energy research in Denmark is presented, with particular reference to energy system analysis (technical and institutional) and cars.

This provides, in the third section, the context for the formulation of a research problem in the following section, as well as the contribution this piece of research makes. The chapter concludes by putting forward a framework for analyzing and solving the problem.

2.2 Electric cars: a worldwide overview

There are no figures for the total number of electric cars in use worldwide in 2010 or, and estimates, which have been around since the 1970s, are typically wide off the mark, having been based on the wrong technological and economic assumptions. With several models coming to the global market in 2011, there are, however, figures available on planned worldwide production, as well as pre-orders, for some models. For instance, according to one source, there were 26000 preorders for the Nissan Leaf in the US and Japan (Savov 2010). The Leaf has production worldwide of 250,000 units per year (50,000 at Oppama in Japan, and 200,000 in Tennessee in the US) with additional future production envisaged in the UK and Portugal (Orecchini and Santiangeli 2010). General Motors production figures give 10,000 Chevrolet Volts (a hybrid, extended range model which will be known as the Opel Ampera in Europe when it comes to market in 2011) in 2010; 25,000 in 2011; and a prediction of 60,000 in 2012. (Wikipedia u.d.). The Volt is one of the best known electric models in the US (though its range is gas extended), and monthly sales figures show 1703 Volts were sold in the US in 2011 so far. (General Motors 2011).

More recently, the Obama administration in the US has announced plans to have one million electric cars in the US by 2015. China has announced plans to produce one million electric cars per year by 2015. (DB 2011)

Production predictions, however, are generally a function of predicted vehicle demand, and therefore economic growth. Another view is necessary, looking at success rates for electric cars in different countries. The stance of organizational and institutional frameworks towards electric cars differs from country to country, leading to differences in adoption rates.

Illustrative cases are presented in the following sections. Starting with public regulation in different countries, it is interesting to look at the varying incentives for electric cars between countries. Electric cars are definitely not equal geographically. Figure 3 shows this.

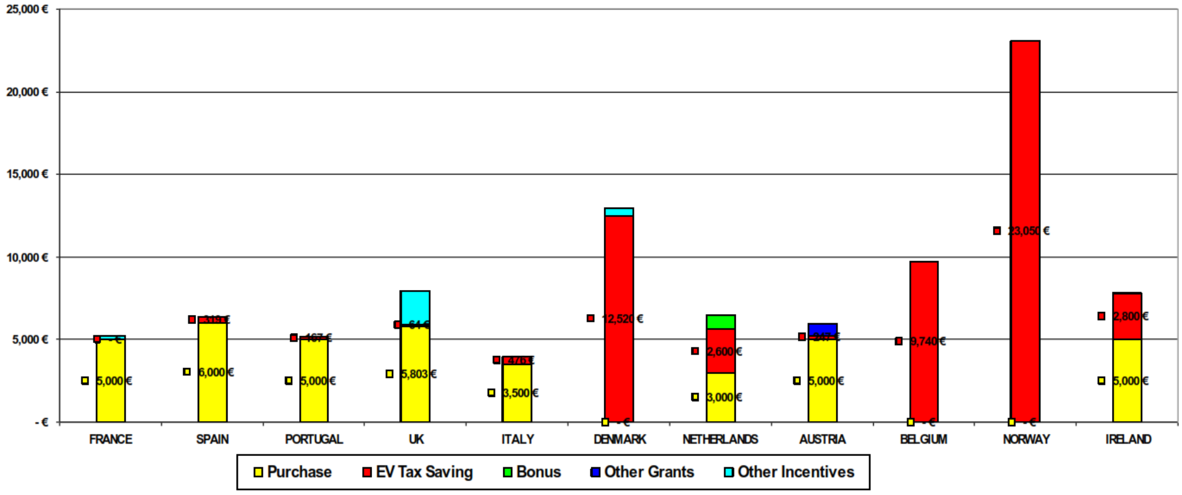

Figure 3: incentives internationally (Secondary source: (Grønn Bil 2009), primary source Nissan-Renault February 2011)

According to Figure 3, the countries of Norway, Denmark (which traditionally heavily tax cars) and Belgium, have taxation-based favourable conditions for electric cars, while the countries of France, Spain, the UK, where car purchase is not so heavily taxed, favour a one off subsidy. The US, a country with a strong connection to the automobile, is not represented, but typically offers a combination of federal and state incentives towards electric car purchase. (US Department of Energy n.d.) (US Department of Energy n.d.)

The next section presents the success story for electric cars that is Norway. It looks at why it has high private ownership of electric cars, well developed state and municipal funding for charging network provision outside the home, and public regulation that is in favour of electric cars. The Norwegian example will then be contrasted with the Danish example.

2.3 The road to success– the case of Norway

In Scandinavia, Norway has seen a lot of success with electric cars. Norway describes itself as the country with perhaps the best public regulation conditions and the best charging infrastructure in the world for electric car owners (Grønn Bil 2009). There are also claims it is one of the places in the world with the highest number of electric cars. (NRK1 Kveldsnytt 25.oktober 2010, "om at Norge er helt i verdenstoppen hva angår antall elbiler") (Grønn Bil 2009)

For a population of about 4.5 to 5 million people (slightly less than Denmark at 5.3 million, and similar to Sydney, Australia at 4.5 million), there are almost 4,000 electric cars on Norwegian roads (at the end of Q1 2011, an increase of almost 500 cars on the previous quarter), about half of which are in the capital, Oslo; and about half THINKs and Buddys which are made in Norway (Grønn Bil 2009). Figures for the total amount of cars sold in Norway were hard to find, but in May 2010, almost 10,000 new cars were sold (Skogstadt 2010). By 2020, Norway hopes to have electrified or replaced with hybrid electric 10% of its light vehicle fleet, or 200,000 cars (EnergiNorge 2009). However one should note that not everyone supports this as feasible (the Norwegian Car Importers Association do not believe it feasible – (EnergiNorge 2009)).

Which regard to charge points, by the end of 2011, Trondheim expects to have installed 300 public charge points, Oslo 400 charge points, Tromsø 100 charge points. (Grønn Bil 2009)

This success is, however, attributed to a combination of factors: funding for public charging spots, two domestic electric car manufacturers (THINK, makers of the City, and Pure Mobility, makers of the Buddy), an electric car friendly tax system, a very active electric car association, special driving allowances such as toll free roads on electric cars, and work with individual as well as fleet owners (for instance with municipalities, by providing state grants to them for chargers) amongst other things. There is also work with energy suppliers. Norway relies heavily on hydropower, and therefore considers electric cars to be sustainable form of transport. It is part of the NordPool energy market, connected to Denmark and the rest of the NordPool area, where it supplies baseload electricity from hydropower.

Electric cars are popular in Norway because of their relative value for money compared to ICE cars. In Norway, ICE cars are heavily taxed at the point of sale, with a 180% tax on them. Electric cars on the other hand are sales tax free, and have more incentives such as no congestion tax, free parking, etc. Fossil fuel is also heavily taxed, and therefore much more expensive to run a car on than electricity.

The number of public charging spots is high, because municipalities have been able to obtain funding for them from Transnova. Transnova is a new agency, created in 2009, because an agency was deemed necessary that would specifically to complement existing climate public regulation (such as taxes on fuel, etc) with climate measures in transport. It has an interesting three year mandate, from a technical and institutional standpoint. Its purpose is not to increase transport infrastructure (another ministry's mandate), but in light of its goal to have a climate neutral energy system in Norway by 2050, as part of the Norwegian Climate Goals ("Norske Klimameldinga", described in St. meld. nr. 34 (2006-2007) (Miljøverndepartementet 2007)), to enable the removal and overcoming of institutional and practical barriers to technological change. It does so by removing "technology lock" (say by investing in a distribution infrastructure such as chargers), by taking risk (the lack of information on future environmental policy, prices, costs, and properties by immature technologies is risky to all, and Transnova, by investing, can build knowledge – the opposite of risk – which helps the work of other agencies too), by being technologically neutral, by taking the medium and long term view, and generally trying to invest in projects that are business-wise sustainable after the three year evaluation period. Therefore, chargers are not the only outcome of the work of the agency. (Hannisdahl 2011). Business, NGOs, research institutions and local and regional authorities can apply for project funding from Transnova. However, while Transnova has a yearly budget of 50 million NOK for the first three year period (2009-11 inclusive), it has an additional 50 million NOK for 2010 specifically for chargers which resulted in the installation of 2000 chargers. (Transnova 2010)

While electric car implementation in Norway is generally seen to have been successful everywhere (and improving all the time), it is generally seen as most successful in the cities of Oslo and Trondheim. Cases include in Trondheim an electric car co-operative making cars available in housing blocks (Dahlbom 2011), a number of municipalities and companies owning electric car fleets, as well as civil organizations promoting electric cars (such as Grønn Bil, Norstart, etc), all of which receive funding from Transnova. (Hannisdahl 2011)

2.4 The case of Denmark

Like in Norway, the electric car market offering in Denmark includes a number of vehicle models available for purchase, now and later this year. However, only 497 electric cars were registered as privately owned in the whole of Denmark in the past 25 years (Schwartz 2009), despite favourable tax benefits similar to Norway. And a quick look around reveals that things are different from Norway. While in Norway, chargers are a common sight in shopping centres, electric cars a common sight on Norwegian roads and parked in the capital, Oslo, they are not so obvious in Denmark at this time. This may change, but it is helpful to look at how Denmark compares with Norway, in terms of policy and implementation.

2.4.1 Danish EV policy

Denmark, as a member of the EU, is aiming like Norway to reduce CO2 emissions in transport by half by 2020, this time in compliance with EU directives; as well as emissions from the energy system. As a result, a number of national Danish energy plans have been the result of the Danish political process, and the movement to integrate renewable energy sources into the Danish energy system since the 1970s. As a result, while Danish GDP has continued growing, Danish energy use has been fairly stable since then in all sectors except transport, where it has increased. (Danish Association of Engineers 2010)

Looking at 2050, the Danish Association of Engineers (IDA) 2050 national energy plan for Denmark, is the first energy plan to include transport for a 100% renewable Danish energy system by 2050. In the plan, electric cars are recommended as part of a Danish energy system that incorporates 70% of its energy generation from wind, as they can be used to stabilize the grid, providing the flexibility needed in an energy system with a large share of fluctuating renewables; both storing cheap surplus electricity and feeding electricity back to the grid in times of shortage (at a higher price). (Danish Association of Engineers 2010)

The IDA 2050 energy plan in essence makes three recommendations regarding transport for reducing CO2 emissions: reduce the total quantity of transport by better planning, switch transport to the transport modes with the lowest CO2 emissions, and implement a number of measures designed to reduce CO2 emissions for individual modes of transport (for instance with a more sustainable national energy system). With regard to electric vehicles, it advocates a change in the taxation system on cars, changing vehicle registration fees and imposing a green tax on mileage driven to encourage take up; recommends municipalities and the Ministry of Transport to work together to implement electric cars in cities.

How is this implemented and by whom in practice? In Denmark, at national level, the Danish Ministry of Transport ("Transportministeriet"), of which the Danish Energy Agency ("Energistyrelsen", or DEA) is part, and the Danish Climate and Energy Ministry ("Klima- og Energiministeriet") directly propose policy on electric vehicles. (The Danish names are added for clarity, but the English names will be used from now). The scope of each's mandate with regard to electric car policy was not clear, in particular how they fit with each other, but there are differences with Norway.

Like in Norway, fossil-fuelled cars are an expensive proposition in Denmark, typically being taxed with a registration tax, introduced in 1997, on the purchase price of new vehicles of 180% (above 8428 DKK), including VAT of 25%. In addition, owners pay circulation tax, and a yearly "owners green tax" on the vehicle efficiency, typically from 520 DKK for petrol cars with a vehicle efficiency of over 20 km/litre, to 18460 DKK for a vehicle efficiency below 4.5 km/litre; and from 600 DKK (for over 32 km/litre) to 25060 DKK (for less than 5.1 km/litre) for diesel cars. (www.skat.dk 2011). The Danish Climate and Energy Ministry's policy is that EVs are to be tax-free until and including 2015, after which the tax rate will be normalized.

The difference with Norway is about engaging people, whereas in Denmark its about engaging the big players with subsidies. The Danish Ministry of Transport's official policy on EVs is to bring together and work with players in the field. This includes users, importers, retailers, project actors, municipalities, relevant authorities and research bodies. They collate and give out material to those players. They also hold talks with the car industry, consumer organizations, the Danish EV Alliance (Dansk Elbil Alliance), amongst others. They have a special group, the Følgegruppe" from January 2011 to 2013.

The Danish Energy Agency is allocating 35 million DKK for EV research over the period 2008 to 2012. (Energistyrelsen 2009). This represents a very small grant, for an official view that EVs can meet Danish and EU goals on CO2 as well as help stabilize the electricity grid, and one of the main beneficiaries is Better Place and DONG Energy. (Møller 2011)

2.4.2 Danish EV demonstration projects in practice

In terms of practical implementations, a number of demonstration projects are currently underway. For instance, much of the focus by NRGi, a utility company, for instance is on driver behavior and Smart Grid implementation in the area of Horsens (NRGi 2011). Another well known project is the EDISON demonstration project, a good example of an electric car project classified as a demonstration project, which tests technology for large scale deployment, but does not look into further questions of economics or institutional matters. There are also six (6) EcoCities in Denmark, namely Kolding, Skive, Copenhagen, Århus, Herning and Albertslund. The City of Copenhagen has a programme for electric and hydrogen cars and busses. (EcoCities u.d.)

The EDISON project (Electric vehicles in a Distributed and Integrated market using Sustainable energy and Open Networks) is one of several projects on the island of Bornholm (another being EcoGrid.eu, a demonstration project of demand flexibility, again software based, related to EcoGrid.dk, a project to develop power system architecture for demand management in Denmark. It is noted that the project is described as potentially contributing to realize a Danish Energy Policy goal of 50% wind energy by 2025, but not which Danish energy plan (Danish Energy Industries Federation. Partnership for intelligent energy systems 2010)). The project is a consortium of Danish and international partners. It is partly funded by the Danish public sector (Energinet.dk 's FORSKELL programme) and is managed by the Danish Energy Association. ? (Danish Energy Industries Federation. Partnership for intelligent energy systems 2010)

Municipality cars will be exchanged for electric cars. A test center will be built where visitors will be able to try out electric cars and receive advice. (Bornholm Municipality u.d.) ? (Danish Energy Industries Federation. Partnership for intelligent energy systems 2010)

The project is a consortium between IBM, DTU, Siemens, DONG Energy, Østkraft, Eurisco and Dansk Energi, the aim of which, it says, is to find the best way to integrate fluctuating wind power by developing software for charging in times of surplus on the Grid and discharging in times of shortage (a form of V2G). Most of the information on the Bornholm Municipality website is about IBM, which will develop Smart Grid software at a research centre in Zurich and provide a hardware platform at DTU for real time simulations. Even the contact for the project is the PR manager for IBM. (Bornholm Municipality u.d.) ? (Danish Energy Industries Federation. Partnership for intelligent energy systems 2010)

The EDISON project includes research, concept and technology development and demonstration. ? (Danish Energy Industries Federation. Partnership for intelligent energy systems 2010)

Bornholm was picked because it is an isolated system, and therefore was seen as a good place to test the interaction of wind and EVs. (Danish Energy Industries Federation. Partnership for intelligent energy systems 2010)

2.4.3 Danish EV commercial players

A feature of Danish EV policy is the link between some commercial players, such as Better Place, and the state. While in Norway there are also funding links between the funding agency Transnova and private, commercial offerings; they differ substantially from those in Denmark.

Like in Norway, there are a number of offering available for driving an electric car. As well as direct ownership, and car co-operatives where one buys a share and leases; leasing options range from only leasing the vehicle (Dansk Elbil Komite 2009) to leasing the vehicle, the battery, a charger, and buying an electricity purchase plan and additional perks such as battery swapping etc. Companies that offer such packages are ChoosEV , ClearDrive and Better Place.

ChoosEV is a Danish electric car leasing company based in Copenhagen backed by SE a.m.b.a., SEAS-NVE a.m.b.a. and Sixt Danmark A/S. ChoosEV offers three standard leasing contracts (private, corporate, and public) and a subscription for access to chargers, electricity, etc. They do not have institutional ties to the energy system, being backed by a hire car company. They are also responsible for setting up public chargers.

Better Place is another option, involving direct car purchase, battery swap, and a subscription for electricity and other services. The Renault Fluence Z.E. "Prime Time", bought directly from Better Place will cost from 205,000 DKK including VAT. Renault's economic model is that the electric Fluence will cost the same as the diesel version, excluding the battery and the subscribers plan (market driven pricing) (Globes u.d.). Five mileage packages will be available from Better Place. (Business Wire 2011)

Services included in the subscription: access to Better Place charge spots and battery switch stations, electricity consumption, "personalized energy management and navigation services via in-car and network software, an inventory of batteries with a guaranteed service level agreement, 24-hour access to customer service and support, and a private charge spot". (Business Wire 2011)

2.5 The scope of the problem

2.5.1 Why does it all matter?

From the comparison of the implementation cases of Norway with Denmark, several things stand out. This includes problems at the car ownership level, as well as the energy system level.

At the car level, in contrast to Norway, where a successful framework exists to help municipalities fund public chargers, and where electric cars have a good consumer support organization, the lack of this in Denmark has meant the following impacts: much lower take up of privately owned electric cars, and therefore a more feasible technical option to the consumer of leasing, since leasing companies like Better Place offer the charger option to individuals and municipalities.

At the energy system level, in contrast to Norway, where electric car ownership or leasing is not tied to energy production, in Denmark the Better Place model represents an institutional and organizational tie between mobility services and a particular energy mix. For instance, Better Place is part-owned by DONG Energy, which is owned at 73% by the Danish State, and institutional investors, mostly in Israel. On the one hand, DONG Energy wants to bring electric cars to Denmark, but on the other hand DONG Energy produces 85 percent of its heat and power from fossil fuels – mainly coal, but also natural gas. And while it has pledged to increase wind power supply, it is also increasing its activities in natural gas. (DONG Energy 2011)

The financial flows behind the car and energy system do not stop there. Better Place's technological model relies on car owners not wanting to spend time recharging, preferring to swap batteries using fast swap technology (Ungerleider 2010). Better Place, in a consortium with other organizations in Europe and Israel has been awarded 3 billion euro until 2012 by the European Union (European Commission 2011) to research its battery swapping technology, which incidentally is derived from the Israeli Air Force's procedure for loading missiles in fighter jets, a case of technology reuse. So the Better Place option is one involving very specific proprietary technology and institutional investors. There is also a perception that the leasing offering is expensive as a result.

In addition, necessary to the Better Place model, has been its business strategy. Better Place Denmark is bringing to market its pricing model, with the first leases available this year (Business Wire 2011). Better Place Denmark has just opened this month (March 2011) its showroom in Copenhagen as part of its marketing drive year (Business Wire 2011), and recruited a new CEO with a background in transportation, signaling a strategic change from capital raising to an aggressive market share acquisition strategy (Better Place 2011). It has already signed agreements with a number of Danish municipalities.

The tax exemption on electric cars is important to Better Place. Its partner Renault threatened to withdraw from providing cars unless the tax break was confirmed. (The Copenhagen Post 2010)

Better Place is an international concern. Outside Denmark, there are partnerships with EDF in France, Australia, Japan, Hawaii (where in Hawaii alone, it is promising 100,000 charging spots)

When it comes to links with energy industry, Better Place has partnerships with GE Electric (for chargers, no information could be found for electricity), and in Denmark, Better Place Denmark has a partnership with DONG Energy (Danish Oil and Natural Gas). Through DONG Energy, it has an agreement with the Danish government (Ungerleider 2010). That agreement is for 103 million euro (770 Million DKK) (Willis 2009). It also has agreements with a growing number of Danish municipalities including Kalundborg, Fredrikshavn, Aalborg, etc for chargers. No details found.

The chargers market for Better Place is valued at 100 million USD, and it is planned to build battery swap stations, at a cost of one million dollars per battery swap station (Schwartz 2009). Better Place Denmark promised 100,000 charging spots and several thousands of cars on the road by 2010. There are only 55 charging spots so far (NY times), and no known cars since sale should start later this year (Schwartz 2009).

Concerns over technology lock, that other battery types and manufacturers are not offered (Schwartz 2009), and even over its ethics. As Israel has an automotive industry worth 800 million USD in exports of components for big car brands (and which has always been close to the defense industry), one wonders if that played a part in the partnership with Renault (Borochkov 2011). Better Place Israel is Harvard Alumnus Major General Mosche Kaplinsky, formally of the Israeli Army, and considered by some to be a war criminal for his involvement in the 2006 Israel war with Lebanon, being responsible for the bombing of Southern Lebanon with 3.5 million cluster bombs in the last 3 days of the war (GSAS Alliance for Justice in the Middle East (AJME), a student group at Harvard University n.d.). Major General Kaplinsky has responsibilities for R&D (Better Place n.d.), so may be behind the F-16 missile loading mechanism-based battery swap technology (no confirmation could be had), and he is working on a deal whereby Better Place Israel would provide infrastructure for the Israeli army (Autoblog 2009). In addition, there are claims of a strategy by Israel to “green” its defence industry since Obama came to power, but the balance of the sources could not be verified . And, a number of high-ranking Israeli military personnel currently wanted by the Hague International War Crimes Tribunal recently graduated from Harvard Business School, and whether they were funded by their home country or offered scholarships by HBS would make for interesting knowledge. Details are scant, and this would need verifying (and the scope and timeframe of this project did not allow this), but the implications are that if it is true then the reality of Better Place may be to do with something quite other than building a sustainable society. (Loewenstein 2010)

On the financial flows front, major backers include a fund owned by Wolfensohn (formally of the World Bank, and a member of "the Quartet"). Chairman of the Board is another prominent Israeli who provided financial assets. Other backers are capital funds. Better Place has the distinction of having the largest start up funding ever. . (Loewenstein 2010)

How does a company like Better Place, with material and financial flows on a global scale, answer questions about ethics? . (Loewenstein 2010) asked the Australian government, and the answer was that as a private company, it was Better Place's business (and its Australian subsidiaries). In other words, their status as a private company and their structure made them less accountable.

2.5.2 The Samsø case

Much has been said about electric cars, as a technology, and as a market in Denmark. However, it transpires that electric cars being part of the total energy system, both technically and institutionally, has implications for implementation. This consideration is an important one for Samsø, as it has achieved a very unique position in becoming "100%" renewable, building and owning its own energy production facilities.

As previously mentioned, Samsø is well known for aiming to become a 100% renewable energy island, thereby reducing its dependence on expensive, imported, polluting and non-sustainable fossil fuel. It has done so by implementing a combination of measures, including demand-side savings via efficiency measures, as well as straw based district heating (and a little solar thermal too) and wind-based electricity. (Energiakademi 2007)

In that regard, Samsø is no different from a number of renewable energy projects, even if it was one of the first, using existing technology, to "go renewable". It even encountered some failures, such as electric transportation. However, what is really interesting about the Samsø case is the nature of the involvement of its citizens in energy planning.which is what makes it different (Energiakademi 2007) , both financially, and as project actors. There is a high degree of local citizen involvement in energy affairs through public meetings, on a wide range of projects, including district heating, wind, etc, and this was reflected in the implementation of renewable energy.

The institutional and organizational path taken to develop renewable energy on Samsø is shown in Figure 4. The organizations are separated into project coordination, energy facilities ownership, and political organizations at local and national level.

Samsø Municipality, the municipality of Samsø, set up several agencies. These include the Samsø Development Office, with promotes settlement, industry and tourism on Samsø, and Samsø Renewable Energy Limited ("APS" in Danish) to own five offshore wind turbines, as Danish law prevents municipalities from directly earning income from energy. The Samsø Development Office also helped the Samsø Energy Academy secure funding.

Project coordination of energy projects, such as the windmills and the district heating, was done by the Samsø Energy Company, a limited liability company which existed from 1998 to 2005. The company coordinated both the design and realization of projects in offshore and onshore wind and district heating.

At the national political level, Region Midtjylland, a government agency, provided the funding to build the co-operation network between research bodies, industry and renewable energy organizations to facilitate the project; and helped secure EU funding for Samsø Energy Academy.

Denmark is a member of the EU, and the EU funds a number of institutions and programmes at local level. The Samsø Energy Agency is a Regional EU Energy Office (i.e. it is funded by the EU), whose mandate is to share knowledge about renewable energy, notably with Iceland and Spain.

The Samsø Energy Service offers guidance and advice to individuals, schools and artisans on the island; while the Samsø Energy and Environment Office is a citizen's association with 100 members. It is the voice of citizens regarding their wishes about renewable energy on the island.

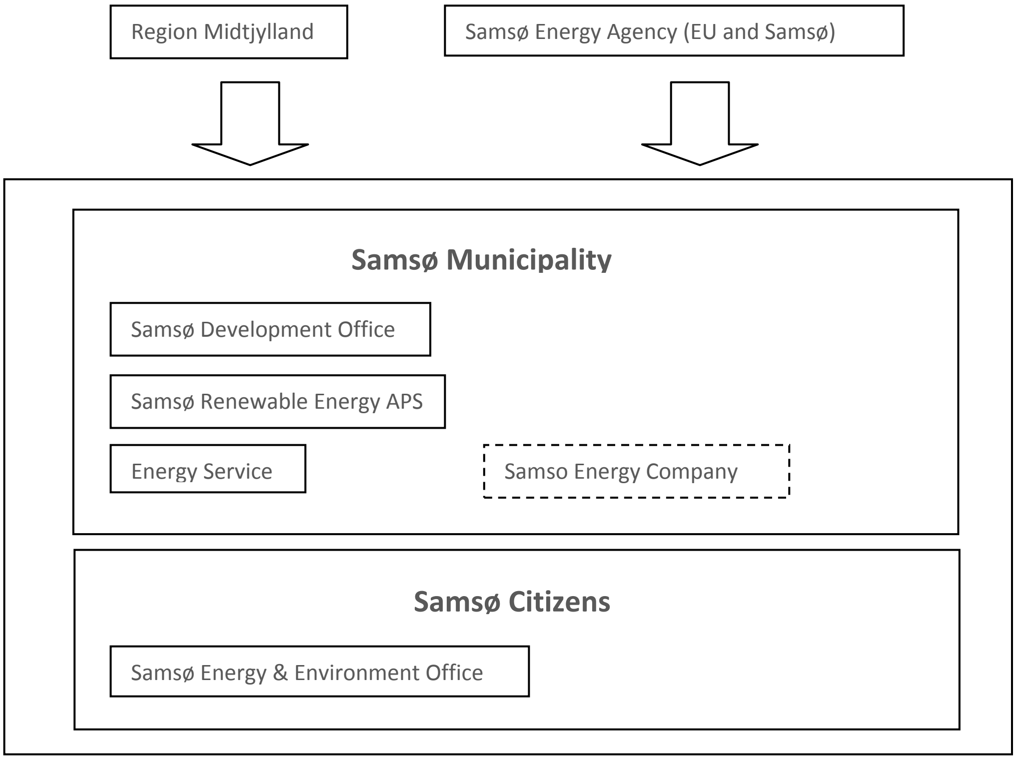

Figure 4: Organization and financing of RE projects on Samsø. Source: (Energiakademi 2007)

The energy system now depends on money from Samsø Renewable Energy APS for investments.

As a result of its 10 year evaluation, Samsø Energiakademi has formulated the wish for electric cars on the island for the future – it would like to see implementation of a successful test project in the form of a co-operative and a system for charging/replacing batteries. (Energiakademi 2007)

2.6 Contribution of this project

This piece of research aims to raise questions about current thinking in the field of electric cars, energy planning, and technology and public policy and provide possible answers.

The research aims to show that technical demonstration projects for electric cars do not have the scope to provide answers as to whether they are the best possible solution for society, or whether an alternative would be better. This is because they do not demonstrate the socio-economic or public regulation aspects of the technology in society.

The usual claim: if transportation switches to electric, then emissions problem will be at the least mitigated. But that is not really sustainable without taking into account the energy system. Therefore it is necessary to look not just at the energy system from a technical point of view, but in order to bring it about look at the governance systems underpinning it. Research and experience show that technically RE integrates well with electric cars - from dump charge to V2G, for regulatory power, peak load management, etc. The case of Samsø is therefore especially interesting as it has already 100% renewable energy and it is community owned.

There have been a number of studies done at national level, energy plans, etc. The problem is they fail to start from the ground up, instead favouring those technologies with economies of scale, or power. They may also not really give answers for local implementation (such as for instance in transport in the IDA Climate Plan 2050, giving instead broad directions of increase in train traffic, increase in cycling, etc (Danish Association of Engineers 2010)). National studies involving energy plans (such as that on "local" energy markets (Lund, Østergaard, et al. 2004)) do not tackle local imlementations.

While Cowan and Hulten (2000) claim that technological evolution is what will save the EV from its failures in the past, this project argues that it is not. Instead, the institutional, organizational infrastructure with regard to renewable energy is.

2.7 Research question

The previous sections in this chapter have presented an overview of the situation regarding electric cars in Denmark and abroad. From this presentation, several points stand out:

- There are huge differences in the way electric cars are implemented in different countries, especially in the institutional and organizational aspects of the cars, the technology behind the cars, etc. Denmark is about to embark on the implementation of electric cars, and must make choices.
- the Samsø energy system, with its specific institutional form, reflects a set of institutional connections, power flows that is very different from that presented by the rest of Denmark, which raises specific challenges and opportunities for the implementation of electric cars.

Therefore, in this context, it seems appropriate to ask the following:

Are electric vehicles technically and economically feasible for the island of Samsø? Which public regulation schemes can be recommended in the context of the Samsø model?

As part of the research question, a number of secondary questions must be answered. These are:

- Are electric cars technically feasible for the 100 percent renewable energy island of Samsø?
- Are electric cars feasible to society in Samsø?
- Can the special institutional form of energy ownership on Samsø play a role and be extended to electric car implementation?

2.8 The framework for answering the question

2.8.1 Structure of analysis

To answer the research question, the following research framework is used.

In the first instance, the technical feasibility of electric cars on Samsø must be determined. This is best done by an energy system analysis, with the aim of determining the best electric car in technological terms for the system. It proposes to calculate the electricity consumed by electric car model assuming all cars are electric for the island, and whether the energy system on Samsø can meet the expected demand. It also proposes to evaluate the amount of fuel and CO2 that would be foregone for every kind of electric car, and the wind capacity that may be needed for an electric car. From this, it can be calculated what wind energy capacity the demand represents.

In the second instance, having evaluated the technical feasibility of implementing electric cars on Samsø, the project proposes to evaluate the socio-economic feasibility. It will do this by calculating the socio-economic costs to the island of electric cars; that is the cost to society on the island. Building on, and taking the technical results, it proposes to compare these costs to society of electric cars with the cost of fossil-fuelled cars. This includes the cost of fuels (both electric and fossil foregone), the cost of CO2 emissions, the cost of the vehicles, etc. The idea is that quantifying those costs can be used as a basis for comparison between different implementation models.

Thirdly, several implementation alternatives are to be compared. This means the comparison could be between say, the Samsø model (privately owned cars, island owned 100% renewable energy system) and another alternative (a "Better Place" model, where the cars might be privately owned, but the energy system is not 100% renewable? Or where regulation favours fossil fuel?)

A business economic comparison of alternatives (commercial, private, from inside and outside Samsø) under the current public regulation framework will be made to see which is the best alternative in terms of absolute costs. Futhermore, a comparison of alternatives will be made with an analysis of money flows (based on the socio-economic findings).

The analytical framework is shown in Figure 5

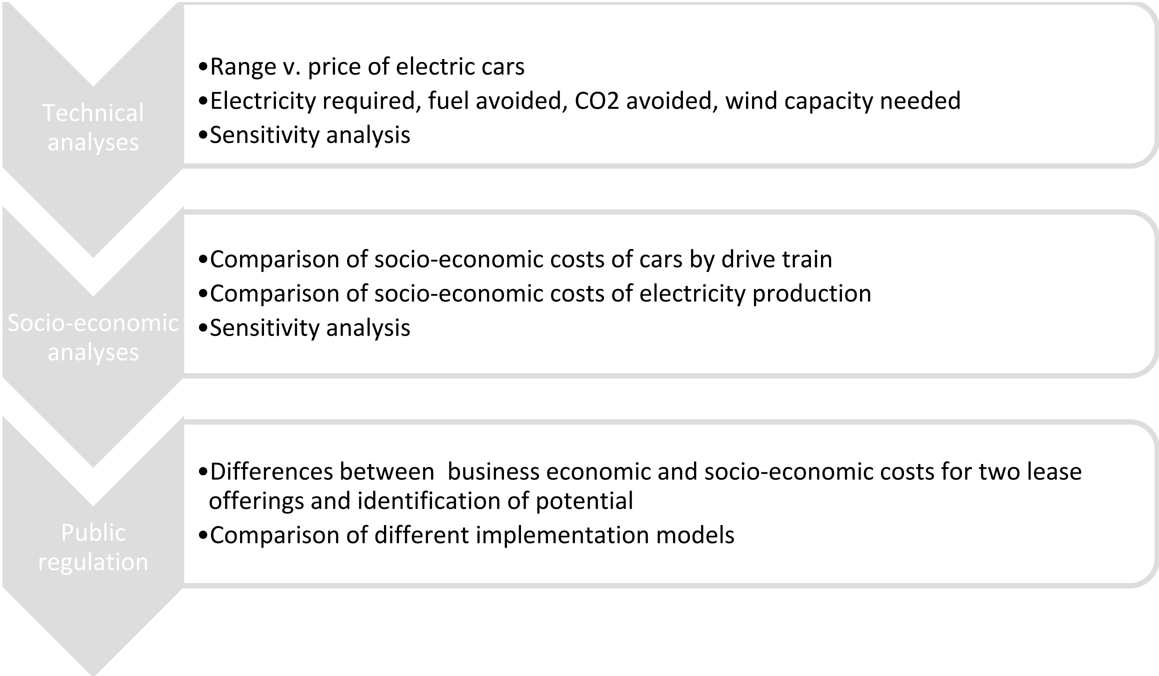

Figure 5: structure of analysis

2.8.2 Limitations

This section describes the broad limitations to the scope of the project. Limitations in the methodology of the actual research (such as, for instance, limitations in data gathering, obstacles encountered to the research, etc) are described in the next section.

This project is about the evaluation of different models for implementation. As a result, it uses projects as Better Place and ChoosEV as institutional and organizational examples of electric car offerings. This purely a theoretical tool for the study, and not intended to reflect on any individual choices citizens in Samsø may make to lease an electric car from those companies.

While a number of electric vans and trucks are available on the market in Denmark, the study will be limited to cars, and exclusively battery-electric, gasoline and diesel cars. The reasons for this are multiple. Time constraints on the project, uncertainty about commercial availability of trucks (Modec, who sell trucks in Denmark, went ceased trading in April) meant leaving trucks out of the scope. Furthermore, carrying out a technical analysis of vans and trucks in the Samsø energy system would have involved factoring in a different driving pattern and goods load to cars, and making the calculations accordingly. .

While IDA 2050 points to hybrid cars, in practice this study will focus purely on Battery Electric Vehicles (BEVs). As such, they represent a radical technological change, requiring a change in the energy system institutional and organizational framework in order to be supported. In short, no stopping at the fuel station for a quick fill up when needed. Instead, range, charging facilities, and the implications for electricity production become of importance. Futhermore, biofuelled, hydrogen fuel-celled, and other hybrids are also outside the scope. Samsø does not produce enough biofuel for cars, so cannot sustain a biofuel fuelled car pool. Hydrogen-fuel cells are still not mass produced in cars, and therefore outside the scope.

The focus of this project was not energy system modeling, so no energy system calculation was done. In particular, no hourly modeling of the energy system (over a year) was done (as would be done using EnergyPLAN); and no detailed specific hourly analysis such as load flow etc. was performed either. Any changes in the energy system required in terms of electricity production are assumed to be provided by means of a change in wind capacity, and no attempt is made to optimize the system for wind, solar, additional energy savings, etc. Likewise, no specific consideration was given to the electric connection to the mainland, and infinite capacity for transfer was assumed. This was deemed to be outside the scope of this project in the time frame given, and deemed to be a project in itself, so it was purposefully left out.

Finally, Vehicle-to-Grid, while having the potential to bring a lot of benefits to Samsø, is specifically outside the focus of this project. The reason is the focus of the project is on existing technologies, as sold openly on the market and widely available. While technically working and at a demonstration stage, it is not yet openly deployed, so its organizational and institutional framework cannot be analysed yet. It would be very interesting though, to evaluate it in the Samsø institutional context

2.8.3 Data gathering limitations and other considerations

Background information and data was collected from a variety of sources. This included books, peer-reviewed academic papers, manufacturers, official bodies, consumer associations, magazines, email correspondence with officials and much more

When choosing data for calculations, several sets were available. However, not all were compatible with each other, being built with different assumptions or using different years (for costs). This meant differences in measurements of technical characteristics such as efficiency, range, etc and in the economic characteristics.

One set of data available from the Danish Energy Authority (DEA, "Energistyrelsen" in Danish) uses a methodology based on comparing a modelised electric car with other modelised drive train technologies, in terms of technical and economic performance. While it provides economic data for socio-economic analysis, it also provides data for technological analysis. However, it makes a certain number of assumptions about that data to modelize by technology. Another set of data covered general parameters for socio-economic calculations.

The problem is this is in contrast to the range of technical data found for cars. For instance, not all cars are equally efficient, even with the same drive train (for instance, not all electric cars have the same efficiency). This is because differences exist in the ratios of energy in and energy out (the efficiency), due to differences in weight, battery size, battery chemistry (hence energy density and range).

For the technical analysis, the problem seemed to be to reconcile the calculations needs from a physics point of view (what was needed to be calculated) and the data that was available in the time frame, in accordance with a general methodology for the project. For instance, the question arose, what needed to be calculated in the technical analysis, what was the best way to go about it given the data available and how consistent and hence valid would it be?

In data gathering, a number of technical assumptions had to be made regarding engineering conventions. For instance, the range of an electric vehicle is a normative measurement, depending on a number of factors such as how the car is driven the temperature, etc. To enable comparisons, the car industry had developed conventions for driving patterns, known as drive cycles. These are a specified set of test conditions, corresponding to local habits, typically incorporating a mix of highway and city driving (high and low speed), a duration of driving etc. In this case, a decision was made to try and use data that corresponded to the North European Drive Cycle (as opposed to other standards). For convenience to the reader, the methodological assumptions made in the analyses are presented in the relevant chapters, so they may be understood in context.

Finally, there were a number of language considerations. Sources for the project were used in a variety of languages, but a large share, especially data, and its associated methodology, was in Danish. This presented challenges, as Danish words and structures are rich in subtle meanings, which are not always obvious to a non-native speaker and easily lost in translation. Every attempt was made to get the best understanding possible, but one cannot be sure.

2.9 The structure of the report

In this chapter, cases of successful implementation of electric cars and the reasons behind them were described; and contrasted with the current organizational and institutional framework for electric cars in Denmark. The research question asks whether theories about institutions, organizations, and feasibility studies could be used to successfully evalutate different implementation models for electric cars on Samsø that integrate with the municipality's existing successful institutional and organizational energy model. A research framework was put forward for answering the question, whereby it is necessary to evaluate different models according to a set of criteria and a methodology.

The report consists of the following chapters:

- Chapter 1 presented a brief overview of Samsø and the potential for electric cars there
- Chapter 2 presented an overview of successful cases of electric car implementation in Norway, as well as the current policy situation for electric cars in Denmark. It then defined a problem, established a research question, and presented a framework for answering it.
- Chapter 3 outlines the theories behind the project and the methods that will be used to investigate it. In particular, starting from the premiss that we are shaped in our discourses by the powers that be to support them, many of our institutions and organizations reflect this. Therefore new thinking is required, and the theory of Choice Awareness is presented in that context, and linked to the theory for feasibility studies. The theory of case study is used to show that an analysis of Samsø is a strong choice. In the methodology section, the feasibility study methodology is presented
- Chapter 4 consists of a number of technical analyses comparing different electric, gasoline and diesel vehicles. It starts by defining the technology behind electric vehicles, then compares vehicles with different drive trains (electric, gasoline and diesel) for fuel consumption and CO2 emissions. From this, it evaluates how much extra wind capacity would be required (if any) for a "Samsø of electric cars" and how much, imported, fossil fuel never makes it to the island as a result.
- Chapter 5 consists of several socio-economic analyses, designed to understand the cost to the society of Samsø of electric cars, compared to the cost of fossil-fueled models. It builds

on Chapter 4, taking the results and calculating cost of ownership as well as cost of externalities such as CO2 emissions.

- Chapter 6 is a study of public regulation. Based on Norwegian policy developments, it looks at what would the impact be if costs were changed. It would like to look at specific impacts on the island, such as the role of income distribution, and the role of owning the energy that goes into electric cars.
- Chapter 7 is the conclusion.
- Chapter 8 is the bibliography

No annexes are attached.

Chapter 3: Theories, methods & the Samsø case

Having presented the background and identified the problem in the previous chapter, this chapter presents the theories that are the basis for the analysis, and the methods that are used in the analysis.

In particular, case study theory is presented in context with renewable energy systems analysis and Samsø, alongside Choice Awareness theory. In the second part of this chapter, "Methods", the feasibility study methodology for the project is presented.

3.1 Overview

Our economic thinking about, including our economic thinking about energy today, is shaped by powerful interests. In the past, power used to be determined by how much land and slaves one had, but the industrial revolution has meant the demand for energy materials has risen exponentially to enable a world of economic power based on manufacture. Suddenly, with coal, we could manufacture iron, and with it long range transport infrastructure: steam ships, trains, even the steam car, as well as the first military submarines. The 19th century, the height of wealth by empire (the result of steam ships rail and coal), saw the argument for "free trade" and mercantilist policies. The later 20th century saw the rise of the argument for the "neoclassical free market" as banking and access to mineral resources was deregulated worldwide by law. With that came oil, followed by nuclear. (Singer 2008)

With our energy systems shaped that way, what of the impact of this on our relationship with the car? According to Robin Cowan and Steffan Hulten, the different technical, economic, and social meanings of electric cars compared to combustion engine cars have led to the two distinct fortunes of both technologies. Furthermore, they argue, the micro-economic analysis of automobile technology choice with standard micro-economic theory shows car owners want to be on the highest indifference curve; that is choosing the technology that gives them the most utility. And car owners define utility to be based on the perceived usefulness of the characteristics of the car and lifestyle it affords. . (Cowan og Hulten 2000)

(Hård og Knie 2000) argue that diesel trucks established themselves because the technology could be adopted by well established organizations, engineering a positive image of diesel, because the new technology allowed old practices to continue, and diesel did not challenge "existing legal and fiscal systems" (Hård og Knie 2000)

Boyce argues that "a long-term perspective also reveals patterns of learned behaviour and conditioned expectations which together set in train so-called "path dependencies" that in turn channel the course of institutional development" (Boyce 2000). In other words, there is path dependency of fossil fuelled car owners now, and current business models for electric car could cause a path dependency for more fossil fuelled electricity.

(Hård og Knie 2000) argue that because cars have a special significance to the humans that own them, in terms of the perceived efficiency of transport, they have a social, psychological as well as technical significance which explains the popularity of the car despite its human and environmental cost (World Health Organization 2011).

The electric car represents a technological change. They further argue that for a technology to be successful, there must be the right "technical, organizational, institutional and cultural ambience" (Hård og Knie 2000). This means barriers to adoption must be removed, and once they are, an economic, social and cultural space for the electric car can be created. In the case of the implementation of the electric car on Samsø, this can mean successful sales and repair services, technological reliability of course, appropriate marketing, a utility framework that supports electric cars, etc.

So in that context, a number of theories are useful towards building a methodology to solve the problem which will be presented in this chapter. In particular, Choice Awareness theory is presented as the basis for the need for alternatives, whereby the bonds between technology and society, and therefore our technology choices depend on their organizational and institutional environment. It is closely linked to theories of consciousness and change presented by Hvelplund, whereby changes in the public regulation can change the organizational and institutional environment to favour a technological change that is good for both business and society. Case Study Theory as seen by Bent Flyvbjerg will be presented and will argue the merits in making an analysis of the implementation of electric cars on Samsø in the context of the Samsø energy system. Finally, feasibility study theory, based on Hvelplund's ideas, is then used as a basis for the methodology for a feasibility study, which follows in the next section.

3.2 Theories

3.2.1 The need for alternatives: Choice Awareness theory

"Choice Awareness" theory was put forward by Henrik Lund of Aalborg University, and based on many of the trains of academic thought in energy planning developed at AAU.

The premiss of Choice Awareness theory is that true choice is necessary for the implementation of radical technological change, such as represented by electric cars, and the energy system in Samsø. According to Lund, technological change is radical because it results in a redistribution of power and wealth.

Hvelplund defines technology as having several dimensions, including technique, organization, profits, etc. Radical technological change can be defined as a change in one or several of the dimensions associated with technology. Therefore Choice Awareness can be understood in terms of power and discourse theories, and the lack of choice preventing technological change. Choice Awareness therefore posits that radical technological change can be achieved by awareness of alternatives, and the implementation of a suitable institutional framework to enable the alternatives in. In this context, Samsø has made real, true, choices, and is therefore ideal for a case study.

Lund's premiss is firstly that shifting from old-guard, centralized, big investment, energy systems with single purpose suppliers and multi purpose consumers to renewable energy systems with multiple suppliers, decentralized production, different institutions represents a radical technological change. Radical technological change is described as one or more changes in the five dimensions of technology, namely “technique, knowledge, organization, products and profit” (reprised from Muller Remmen and Christensen (1984) and Hvelplund). Secondly that discourse and power theories mean existing organizational interests will prevent change, because radical technological change means an economic redistribution. Therefore Choice Awareness theory applies to the how to implement such a radical technological and institutional change.

Under discourse and power theories, existing fossil and nuclear interests try and block technological and institutional change using the argument that there is no alternative choice to their path for society.   Choice Awareness theory proposes that, instead, there is always a choice at the societal level. According to Lund, “it concerns collective decision making in a process that involves many individuals and organizations that represent different interests and discourses, as well as different levels of power to influence the decision making process” (Lund 2010). Choice Awareness means an understanding of the factors blocking change as a precondition for designing alternatives that are true choices.

Choice Awareness deals with instances when collective perception at societal level is of Choice or No Choice. This collective perception can be different at different levels of society (no choice at local level but theoretical choice at national level for instance). Lund argues that “the construction of the collective perception of no choice plays an important role when making major societal decisions on energy planning” (Lund 2010). The concept of No Choice may be for instance about No Choice with regards to technological alternatives (Lund gives the case of no alternative to carbon capture)

3.2.2 Technology paths and public regulation: the theory of technical and socio-economic feasibility

Choice Awareness feasibility is usually assessed in terms of a technical and socio economic feasibility study with a specific methodology. This is best summed up in the work of Hvelplund in Lund et al. (2009)

Hvelplund (in Lund et al. 2009) puts forward a comprehensive methodology based on theories of economics and social anthropology. He argues that classical economics as proposed by Adam Smith assumes a level of knowledge and other conditions only found in a theoretical model (and Adam Smith fully acknowledged this to be a hypothetical model) and that therefore an approach based on classical economics alone is not sufficient. In particular, Hvelplund argues that social economic feasibility studies should pay attention to a number of things. Firstly, he argues, one should heed the technical legacy of the existing energy systems, in particular making sure to think of true alternatives (he stresses the importance of the long time frame in thinking of alternatives).

Secondly, Hvelplund stresses the importance of institutional systems as the scaffold on which technical systems are built. For instance, he stresses the importance of overcapacity, with its consequences of driving energy prices down to close to short-term marginal costs. Furthermore, he points out the importance of the impact on the price of pressure from energy companies on politicians to protect their current state of operations, namely markets and technologies, by excluding competition.

Thirdly, he stresses the importance of evaluating the impact of legislative changes on the system. For instance, tax or subsidies, interest rates, right to sell electricity, etc.

Fourthly and finally, he stresses the importance of analyzing the links between the institutional sensitivity of the system and the political process. This is political sensitivity – who can derail new technologies, who can support them.

A feasibility study, based on the methodology developed by Hvelplund (Hvelplund and Lund 1998) considers technological change in its socioeconomic and institutional context. This means the "best solution from an analysis of economical, environmental, political and social feasibility" (Hvelplund og Lund 1998).

Several relationships pertaining to technology are investigated. First, the relationship between the technological solution and its technological environment (the technical sensisitivity analysis. This means the relationship between an electrified light vehicle transport fleet and the surrounding energy system.

Secondly, the relationship between the socio-economy of the project and its political and institutional environment must be carried out. This is a socio-economic sensitivity analysis

Thirdly, It must analyse the links between the economy of a project and the legislation which is necessary for the feasibility of the project (institutional sensitivity analysis). Fourthly, It must analyse the links between the institutional sensitivity analysis and the political process.

3.2.3 Choosing case study theory as a knowledge making basis

The first question that presents itself in designing a framework for analyzing the problem is that of which framework to select as a knowledge making basis. Flyvbjerg (Flyvbjerg 2006) argues that the case study is a valuable tool, and "makes social science matter".. (Flyvbjerg 2006)

Case studies are not seen as "proper scientific endeavour" in all circles, with the opponents of case studies often taking the view that a hypothetico-deductive approach, whereby a theory is proposed, then verified with a lot of iterations, is more scientifically valid. The conventional views about how scientific knowledge is acquired include that firstly, theoretical knowledge is superior to practical knowledge; secondly, that scientific knowledge acquisition requires conclusions be drawn from multiple cases, not just one, making case study irrelevant; thirdly generating differs from testing hypotheses and theory building; with case studies best suited for the former. Fourthly, that the case study is often presented as biased toward verification and fifthly, is difficult to summarize. (Flyvbjerg 2004) (Flyvbjerg 2006)

There are a number of reasons, however, why here the case study approach is the right one and for making a case study of Samsø. As this project is effectively a case study, one must make the case for the validity of this approach.

A case study brings valuable and new knowledge

There are a number of "theoretical" studies of electric cars, about "theoretical" models of cars, because cars and their associated technologies such as batteries have not really come onto the market yet. But now with cars, batteries, and the question of renewable energy integration (and the long lifetimes of power plants), practical knowledge is needed.

Furthermore, theoretical insight does not help Samsø. Why? The energy system can only exist, after all, in a social science context. Furthermore, human behaviour is not just about rule-governed acts. This case study is important for the learning process and for the knowledge gathered. The choice of Samsø brings together a unique local context and finds new and original research. Social science can only produce context dependent knowledge, not predictive theory, and case studies are ideal for context-dependent knowledge.

Thirdly energy analysis is context dependent. Generalizations about hydro do not work in an island without mountains – creativity is needed.

Fourthly, a case study approach in this project enables a study of the bonds between components in the system, and that knowledge is of value. That knowledge can only be gathered through a case study, not by hypothetico-deductive knowledge. Not using a case study approach would mean a lot would be missed out in knowledge gathering.

The Samsø case as one of Karl Popper's "black swans"

According to (Flyvbjerg 2004), generalization is possible from a single case, and case study may be central to scientific development or alternative to other methods. Non generalization "can cut a path towards scientific innovation". Generalization is overated, and force of example often underestimated. (Flyvbjerg 2004)

Based on Popper's falsification theory, there is no need in this case for large samples of trials. A single case study can bring more knowledge than from a generalization. Like Galileo refuting Aristotle by a single conceptual and practical experiment (Flyvbjerg 2004), a case study for Samsø covers what is different about Samsø.

Case study based research offers a parallel with anthropology (Flyvbjerg 2004). Case studies can be made in multiple and compared. So Samsø can build on previous ones, and set the standard for future ones.

Samsø is a good choice because it is an extreme, critical, paradigmatic case

(Flyvbjerg 2004) argues that there is value in the careful selection of the case to be studied. While adherents to the hypothetico-deductive model generally argue against case study theory as not being a means to test hypotheses, just generate them, he argues that careful selection allows hypothesis testing, as well as hypothesis generation. (Flyvbjerg 2004) adds that for hypothesis testing, the case selected for the study must be special, "extreme", with a certain appeal, as the test should be for falsification. However, he argues, the specialness of the choice must be demonstrated to the scientific community.

Samsø represents a strategic selection for a case study of electric cars in a 100 percent renewable energy system, both from a technical and social perspective, because it is not what could be termed a typical case. It offers a special set of conditions, or circumstances, that make it stronger as a test case. As a "special" case, Samsø, with its unique set of conditions regarding energy production and ownership, enables by the means of study an understanding of the deeper causes of the problem.

Rather than do a theoretical energy systems analysis, better to use Samsø. Indeed, if it works there, it will work elsewhere (unless falsified). Samsø is "most likely" to work for electric cars: therefore the case is best suited for falsification.

Samsø as a paradigmatic case for renewable energy and society: because it is self determined. A paradigmatic case can be a practical prototype, a reference point for a new school of thought. It is necessary to justify the choice of Samsø to the rest of the scientific community as a paradigmatic case: the justification is that its energy system make it paradigmatic.

A case study of Samsø scientifically valid and valuable as standalone

According to Flyvbjerg, case study theory is often critized for not being "scientific" enough to generate new knowledge, instead resulting in verification. But a case study of Samsø would have "its own rigour", thereby generating its own body of knowledge and valuable. (Flyvbjerg 2006)

A single case study can go into a lot of valuable detail, and can close in on the specific situation of Samsø, the point of this particular study rather than a comparison. (Flyvbjerg 2006)

Should any contradictory results occur anywhere, in this case study or another, the total body of knowledge is enriched by contrasting them.

Samsø has quality as a good case narrative

(Flyvbjerg 2004) argues that one of the strengths of the case study approach is that it is an opportunity to create a good case narrative; more specifically, that all the strengths that make a good case study good will make a case study a good narrative. By a good narrative, Flyvbjerg means that the case study "approaches the complexities and contradictions of real life" and he argues that it is important to ask "who will want to learn about a case like this and in this kind of detail?" (Flyvbjerg 2004). So a good narrative is more than just a scientific study.

The case of Samsø is a good narrative case in terms of what it has achieved with renewable energy. It is a good narrative in terms of the technological change it has put in place in its energy system, and a good narrative in terms of how it has achieved it.

3.3 Methods

3.3.1 A feasibility study

Choice Awareness, in context with theories about the bindings between technologies and the institutions and organizations of society, is a useful theoretical basis for investigating the implementation of electric cars on Samsø, and thereby reinforces Flyvbjerg's arguments in favour of the scientific basis of a case study. The theory can be interpreted in terms of choice at the individual level, and choice at the societal level. Most importantly, choice at the community level may differ from choice at the national level. Samsø has made choices at the individual and societal level with regards to energy production and ownership which are different from the rest of Denmark and the world, and it is important to find out if electric cars would be feasible in that environment

A methodology for a feasibility study is designed to analyze several things. By analyzing the economy of a technology as a function of an energy system, or the role of any overcapacity in the system, or the environmental effects of new energy investments, or the sensitivity to the institutional and political environment, it can understand the interdependence between the technology and its surrounding energy system (the technical sensitivity of the system). It must also take seek to understand the time and risks dimensions of the technology being analysed.

Therefore, the feasibility study must propose first technical alternatives and analyse their feasibility in the said system. In the case of this project, this means looking at the technical feasibility of electric cars, by means, say, of a basic energy analysis.

With this in mind the feasibility study will start by ascertaining whether current renewable energy production could meet the energy needs of an electrified light vehicle fleet of the inhabitants of the island, as was intended with the offshore wind farm, built to offset transport emissions. It will also look at the total amount of fossil fuel displaced from the island by such a change.

This feasibility study will then try to understand the impact on society, by calculating costs to various actors of electric cars on the island, then try and present public regulations measures that would facilitate implementation, perhaps by the design of a particular implementation model.

3.3.2 What, for whom and how?

A feasibility study should start by outlining what should be studied exactly, for whom and, of course how; before proceeding to establishing criteria as to what to analyse and how. (Hvelplund and Lund 1998)

What should be studied?

At a time when electric cars are entering the market, and business models and alliances are emerging to define electrified transport; it becomes important to investigate the feasibility of implementing electric cars in the system. In particular, as these emerging business models reflect the current power relations in the industry, it is necessary to investigate alternatives to the current offerings.

The island of Samsø in Denmark is a small community, geographically well defined (since it is an island), with a claim to having a 100% renewable energy supply, which is mostly owned by the island and whose profits accrue to the island. Therefore it offers a good opportunity to analyse the short term feasibility of electric vehicles with an energy system in which citizens have a stake and are therefore have interests in the feasibility. This represents the potential for a kind of direct and relevant knowledge about feasibility that incorporates an institutional approach to a market one, rather than purely a market one where institutions are not part of the picture.

For whom should this study be done?

The study is of relevance to the people of Samsø at the basic level, but in a way directed to the institutions representing them who can implement a set of choices for them. At the second level, this study is relevant to Danish society as a whole.

For instance, such a study is interesting to municipalities seeking to integrate electric cars in their cities, as it provides knowledge of alternatives. Why this is important is explained in the next section.

At the third level, the study is valuable at an international level. It constitutes a valid investigation into the practicalities of implementing electric cars and contributes to the international body of knowledge on the subject.

Why should it be studied?

There are a number of reasons why this feasibility study should be done. The implementation of electric vehicles represents a radical technological change, which will imply changes in organizations and institutions, governed by the changes in the dimensions of technology: technique, knowledge, organization and products as well as profits. (Lund 2010) (Hvelplund 2005)

Such a technological change involves an economic redistribution, and who gains and who loses will be determined by the broad institutional context of the change. Gains and losses may not be spread evenly across all levels of society, and established technologies may be favoured by the existing institutional set up. Established institutions and organizations, as exemplified by the financial system and money flows, may also determine who gains and who loses as they hold financial power. It is important not only to identify the gains and losses, but also think about how the institutional context may need to be redefined with new institutions around the market. (Lund 2010) (Hvelplund 2005) (Hvelplund and Lund 1998)

At a time when policy in Denmark is moving towards the electrification of the light vehicle sector, and larger commercial interests are becoming involved (whether it be fossil fuel industry or the defence industry), alternative paths must be found. This is particularly important for Samsø, as it has taken its own path to energy independence. Researching alternatives to the current electric car offering is important, in order to avoid a "lock-in", a one solution fits all in electric cars. This is because electric cars are part of an energy system, and often bound to a particular system by money flows. So in the case of Samsø, a model befitting the 100% renewable energy system must be found.

Samsø is currently reviewing and appraising its progress towards 100 percent sustainability, and as part of that it is looking into electric cars, which failed the first time round. As technology as advanced since that time, and as Samsø has a designed amount of wind power to offset transport, it must see from a technical point of view if that amount is still suitable, in light of any conditions that may have changed. From a society point of view, if must find out how electric cars compare to fossil fuel, if they are cheaper or more expensive. And the municipality, as a facilitator for renewable energy, must find out if they are worthwhile to facilitate, in terms of chargers, etc.

Which time horizon and time priority should the study have?

The study is concerned with the short-term feasibility of electric cars on the island. This means that it is concerned with energy systems (including cars) are they are now, and financial conditions as they are now. Therefore in the technical analysis in the next chapter, only current or shortly to come to market models will be analysed.

The reasons for this are as follows. Samsø has already made the technological changes necessary to its energy production system to make it 100% renewable. Furthermore, it has designed the institutional and organizational environment on the island to support those technological changes. Electric cars, on the other hand, are coming onto the market at once – their design is unlikely to change much in the intervening few years, and their lifetime is no way near as long as, say, a coal power plant (8 or 13 years as opposed to 50 years). Therefore, a study is made with a short-term energy system perspective in mind.

3.3.3 Criteria for analysis

Organizational goals

These include achieving fossil fuel independence in the car sector, by means of the implementation of electric cars, finding the best value for money electric car, value for money for the user and for society. It includes fitting in the electric car along the same democratic processes that the rest of the energy system was redeveloped into a 100 percent renewable system with.

Organizational resources

Samsø, and this study, are unusual in that area. Samsø has a wealth of experience, an organizational resource, in implementing 100 percent renewable energy systems, since that is exactly what it has done. And this study does not focus on local employment effects. However, the value of the experience with building co-operatives, planning energy systems and getting them implemented is the organizational resource at the basis of this study.

Financial resources

In Denmark, municipalities are not directly allowed to make money from selling wind power. However, they are allowed to own and produce renewable energy, and re-invest the revenues into other renewable energy projects. The Municipality of Samsø is in such a situation.

On the other hand there is uncertainty about the financial costs and risks of electric cars. Different costs for chargers, proprietary chargers, leasing schemes, etc. which all present risks for owners of electric cars.

Natural and socioeconomic environment

Introducing electric cars would bring about changes in CO_2, electricity consumption, etc.

3.3.4 Consequences for the analysis

The combination of the theory underpinning the need for case studies, what must be analysed, for whom and why, and the organizational goals and resources, financial resources and the natural and socioeconomic environment indicate that Samsø is a good case for analysis.

The combination of an existing renewable energy system, the mass production of electric cars, and the special institutional setting of Samsø mean much can be learned from a case study. In particular, a body of knowledge can be gathered about our technological choices as societies and what compels them along certain paths. Indeed, what scale should energy institutions have? This study is relevant for local planning, and local economic development, and local choices.

From the organizational goals and the natural and socioeconomic environment, it can be deduced that an analysis of the technical feasibility is necessary. In particular, how much electricity would be needed per type of car for a typical driving pattern over a year, and how much nameplate capacity this represents. This needs to be compared with the gasoline equivalent in fuel saved. The total amount of CO_2 not emited must also be calculated. Due to the uncertainties over driving patterns and range, a sensitivity analysis should be performed on the above with a lower yearly number of kilometers traveled and with a battery with a lower range of car (due to ageing of battery, etc).

From the organizational goals and organizational resources, it can be deduced that an analysis of the socio- economic feasibility of implementing electric cars is necessary

From the organizational goals and the financial resources, it can be deduced that an analysis of public regulation might be worthwhile.

3.4 The next chapter

The next chapter starts the feasibility study by presenting a set of technical analyses that will serve to understand the interrelations between different models of electric cars and the Samsø energy system. By this it aims to establish the technical feasibility of electric cars in the Samsø energy system.

Chapter 4
The technical feasibility

The previous chapter identified the need to assess the technical feasibility of electric cars on Samsø, by means of the design of a feasible technical alternative to the existing situation of combustion engine cars. This corresponds for a need to assess the relationship between the technology that represents electric cars and the surrounding energy system. This relationship will set the scene for the socio-economic evaluation in later chapters.

4.1 Overview

This chapter starts by explaining what is an electric car, including cars but also the systems they are part of. The differences between cars in terms of power trains, including energy sources, battery types and size, etc are presented and their implication for energy use by that car, in terms of range, etc.

The physics underpinning electric cars is then used to establish a methodology for evaluating the implications of different electric car models for energy system planning. It will present the energy needed by electric cars, and calculate the wind nameplate capacity that might be needed. It will also contrast the electricity consumption with the CO2 emissions and quantity of fossil fuel foregone as a result. As the project refers to Samsø, which may have a lower average mileage than the rest of Denmark, a sensitivity analysis is performed on the results with reference to lower mileage and lower battery efficiency.

The outcome of the chapter will be an identification of a number of suitable electric cars for the island.

4.2 What is an electric vehicle?

4.2.1 The drive train

A vehicle is defined in terms of its power train, also known as a drive train. A power train is defined in a wider sense, as "including all of its components used to transform stored (chemical, solar, nuclear, kinetic, potential, etc.) energy into kinetic energy for propulsion purposes." (Wikipedia u.d.). There are as many kinds of drive trains for cars as there are ways of storing energy for cars, from steam to fuel cells.

In electric cars, power trains can consist of either solely batteries in an all electric vehicle; or a heat engine – battery combination in a hybrid vehicle, with the heat engine in series or in parallel to the battery. These different designs reflect different optimizations of energy transformation considerations.

The characteristics of the different power trains of electric vehicles are summed up in Figure 6.

	HEV	PHEV	NEV	BEV
Drive train	Series heat engine – battery hybrid	Parallel heat engine – battery hybrid	All electric hybrid: mains – battery (catenary), high energy battery – high power battery	All electric hybrid
Fuel types	Gasoline, Diesel	Gasoline, Diesel, Biofuels, Hydrogen	Electric only	Electric only
Electric motor and battery pack	Yes	Yes	Yes	Yes
Typical battery pack size	1-2 kWh	10-20 kWh	2-10 kWh	15+ kWh
Top speed	160 km/hour	160 km/hour	25-35 mph	160 km/hour
Range	480 km+ gas, 3.2 km electric	960 km gas, 65 km electric	50 km electric	Typically 160 km (THINK City).
V2G possible	No	Yes	Optional	Yes
On board battery charger	No	Yes	Optional	Yes
Air conditioner and heater	Yes	Yes	Optional	Yes

Figure 6: Electrical Vehicle types based on models on the market (Source: Compiled from (Beck 2009) and revised by author)

Hybrid electrical vehicles, combining a heat engine with a battery in series, result in a Non-Plug-In Hybrid Electric Vehicle (HEV). While capable of being powered electrically, HEVs do not charge off the grid, instead being charged by their combustion engine (the battery and engine run in series).

Hybrid electrical vehicles combining a heat engine with a battery in parallel are known as Plug-In Hybrid Electric Vehicles (PHEV). These also are characterized by dual power sources (electric and combustion), but can charge their battery off the grid, and can run on their heat engine independently.

All Electric Vehicles (EV, which are sometimes refered to as Battery Electric Vehicles, or BEV) are all-electric vehicles, fed from the Grid, sometimes able to feed back to the Grid (V2G). They include a sub-category, namely Neighbourhood Electric Vehicles (NEV), typically smaller, slower, shorter-ranged, with 3 or 4 wheels. Examples include golf carts, fork lifts, etc. (Beck 2009). This study will only consider BEV and diesel and petrol-fuelled heat engine vehicles.

4.2.2 The Battery Electric Vehicle (BEV) and Electric Vehicle Supply Equipment (EVSE)

The previous section showed how the design of the drive drain has implications on range and performance. Likewise, different design considerations apply to Battery Electric Vehicles (BEV) and are examined in this section.

A Battery Electric Vehicle (BEV) has specific characteristics. BEVs, since they are entirely powered by battery, need the largest amount of energy (kWh) per volume of battery with the smallest weight possible, compared to a hybrid which, being constantly recharged by the ICE, needs maximum power (kW) for minimum size. The total cumulated driving distance is a function of battery size and energy density.

Because BEVs require large battery sizes (for most kWh) and batteries are the most expensive component of BEVs; with 75%-85% for the electrochemical cells, 15-25% for the battery system assembly. Cost and energy density are a trade-off, which is not linear: bigger batteries offer diminishing extra range. Role of Wh/kg: Most important thing with batteries is weight. Range is not linearly proportional to battery energy, because of the weight of the battery, which consumes energy. For a given weight (kg), range (km) will differ according to battery energy (Wh/kg)

An important feature of batteries in EVs is cycling. A full EV uses deep discharge cycling,, that is the maximum energy stored in the battery in one charge. An EV is typically fully charged overnight, and discharged the following day, every day, so the number of cycles of the battery can be counted at a rate of one cycle/day (using up to 80% of the energy stored in the battery) in days. Li-ion batteries have a life of 3,000 cycles at 80% discharge, representing 360,000 km for a 120 km range.

Batteries can be defined in terms of their technical parameters, namely specific energy, number of cycles, and energy efficiency. According to (Van den Bossche, Matheys and Van Mierlo 2010), who collected data from manufacturers (shown in Figure 7), these parameters “determine the required quantities of batteries for each technology as well as the frequency in which the batteries are replaced during the vehicle’s lifetime.” Therefore it seems natural these parameters will be factored into the time dependent analyses.

	Specific energy (Wh/kg)	Number of cycles	Energy efficiency (%)	Heating losses (%)
Lead	40	500	82.5	
NiMH	70	1,350	70.0	
NiCad	60	1,350	72.5	
Li-ion	125	1,000	90.0	
NaNiCl	125	1,000	92.5	7.2

Figure 7: Technical characteristics of traction batteries (source: reproduced from (Van den Bossche, Matheys and Van Mierlo 2010))

Electric vehicles have an on-board charger, which is part of the EVSE. The charger has an impact on performance, for it determines the flow of current to the battery.

There are several technological possibilities as to charging that can affect electricity demand. In the simplest case scenario of Dump Charge, a car may charge a certain amount of time, continuously, in a one-way processIn a more technologically heavy scenario, a car may charge only when there is a power surplus in the system, using communications software to determine that, as well as a Smart Grid. This is known as Smart Charge. It is, however, like Dump Charge, still only a one way process. Finally, the third scenario is one where charging one way in times of surplus as well as discharging to the Grid in times of need both occur. This is known as V2G. (Source: (Lund 2010)?) The important point is that all three charging schemes have very different technological implications, in terms of technology needed, and in terms of the energy system.

Advanced charging implies communications technology associated with electric cars. The EVSE consists of all the additional equipment not directly related to the motion of the car but part of delivering power to (and from, in the case of V2G), it. This includes “the conductors, including the ungrounded, grounded, and equipment grounding conductors, the electric vehicle connectors, attachment plugs, and all other fittings, devices, power outlets or apparatuses installed specifically for the purpose of delivering energy from the premises wiring to the electric vehicle.” (The 1996 National Electric Code (NEC) for the US)

In practice, this means several things. Firstly, additional, new (in contrast to say a combustion engine car) hardware is involved, both outside the car (such as a wall mounted charging station, connector cable, connector plug) and inside (such as a charger to the battery. Secondly, software is also involved, at the basic level enabling a two way flow of information between the car charger and the charging station to deliver electrical power safely. (reference: still NEC? UDel? (Green Autoblog 2010))

At the more advanced level though, additional hardware may be used for V2G, such as the Vehicle Smart Link (VSL) hardware, which is responsible for providing Grid location, an internet portal, the power connection, and the interconnect permit in V2G. At the software level, the technology becomes more far-reaching, with large scale software development with a large commercial value part of the package (for instance IBM are involved in Bornholm, SAP in other places – Renault? In which case is Better Place just a demo project?) or large servers for V2G (the aggregator). (references: UDel?

4.3 Assumptions and conventions for technical analysis

This study differs from previous studies in that it seeks to compare actual cars, rather than modeled versions. A word therefore needs to be said about data. As pointed out in Chapter 3, existing research and therefore available data and results is not numerous, and datasets exist independently of each other and are not really compatible. In practice, this means conventions have to be agreed upon in this paper for making calculations.

4.3.1 Choice of vehicle models

In this analysis a number of models of electric vehicles are analysed and compared in terms of electricity consumption, CO2 emissions, fossil fuel displaced (both gasoline and diesel). As a result, a number of assumptions had to be made when choosing the models. The electrical models correspond to those currently or shortly available on the Danish market. This constitutes a broad range of vehicles, all with very different technical characteristics and therefore performance, from the smallest to the family sedan, and the sports car.

For an analysis of CO2 displaced, and fossil fuel displaced, equivalent models were selected, for both gasoline and diesel. The methodology for the choice was looks, styling, and other factors that a typical prospective buyer would use. (N. Pearre 2011) A more energy systems specific approach might have been torque, but the limited time frame and the purpose of the study did not give time for detailed analysis of the physics of the vehicles.

The vehicle types, including electric vehicles, and their gasoline and diesel equivalents, are listed in Figure 8. Full characteristics of vehicles are given as an appendix.

Electric cars and van	Gasoline cars and van	Diesel cars and van
Kewett Buddy	Toyota iQ 1.0 l	Toyota iQ 1.4 l
Citroen C1 E	Citroen C1 1.0 l	Toyota iQ 1.4 l
Renault Fluence Z.E.	Renault Fluence 1.6 l	Renault Fluence 1.5 l
Nissan Leaf	Nissan Tilda 1.6l	Nissan Tilda 1.5 l
Mitsubishi MIEv	Mitsubishi colt 1.1l	Mitsubishi Colt 1.5 l
Think City	Smart ForTwo	Toyota iQ 1.4 l
Fiat 500 E	Fiat 500	Fiat 500 1.2 l
Tesla Roadster	BMW Z4 2.5 l	Audi TT 2.0 l roadster
AFUTURE EV Pro1	Lexus IS 2.5 l	Lexus IS 2.2 l
Fiat Fiorino E (17kWh)	Fiat Fiorino 1.4l	Fiat Fiorino 1.3 l

Figure 8: Vehicle models compared in the study (the Fiat Fiorino E is a light goods vehicle, known as a van)

A word must be said about the choice of models. Firstly, a variety of sizes and battery capacities was included in the study, the idea being that not everyone buys a two seater, small car. Secondly, it was decided to focus on "known brand" electric cars, classified as cars (M1 in the European classification), that are on the market or coming onto the market shortly. This means that the Hummer neighbourhood vehicle and one EV listed on the Dansk Elbil Komite website as available on the Danish market were left out. (Dansk Elbil Komite 2009) (Dansk Elbil Komite n.d.). And in some cases, several models were available, such as the Renault Fluence (available in 1.6 l and 2.0 l for gasoline, and several diesel models too). The smallest consumption model was used.

Secondly, some car models are the same as other models, with just the brand being different. This is because of having been developed jointly by a consortium as a single vehicle to be branded differently by the members of the consortium. One example is the Mitsubishi-Peugeot-Citroen partnership. According to Chambers, the Citroen C-Zero, the Mitsubishi i-MiEV and the Peugeot iOn are really the same car, except for interior and exterior styling and somewhat substantial price difference. (Chambers 2010). Even the battery, a 16 kWh Li-ion is the same for all three models. (Citroen n.d.) (Peugeot n.d.)

With regard to vans, some calculations were made using data for one light van model available in Denmark (the Fiat Fiorino model). An electric truck also used to be available in Denmark from Modec (a British company), but there is uncertainty over its availability as the company went into receivership in April 2011.

4.3.2 Yearly mileage driven and range of BEVs

The total amount of electricity needed is calculated using the figure for average Danish car mileage per year (18,000 km/year), along with battery capacity and efficiency. The Danish figure for car mileage was used because no figures could be obtained for Samsø, and technically allows for valid comparison to be made with the rest of Denmark. (Energistyrelsen (DEA) 2010)

Perhaps here something needs to be said about the mileage figure and range. The question often arises as to whether the technical characteristics of electric cars meet the needs of drivers compared to combustion engine vehicles. Indeed, as (Pearre, et al. 2011) point out, storing electricity is more bulky and expensive than gasoline and refueling is slower than gasoline, making range and refuel questions primordial for Battery Electric Vehicles. (Pearre, et al. 2011)

Taking the two successful Norwegian models, they have have a range of 160 km for a THINK City (THINK u.d.) and 80-120 km (depending on the battery type) for the Buddy respectively (Pure

Mobility 2010) on one charge. The question is how does a Think City or a Kewett Buddy fare with the Danish yearly mileage?

Assuming the car is used for commuting to the mainland, a 18,000 km/year mileage, assuming the car is driven 5 days a week for 50 weeks a year, corresponds to ((18,000/50)/5) 72 km/day. Assuming the car is driven 365 days a year, that is (18,000/365) just under 50 km a day. In both cases, a Think City or a Kewett Buddy can handle the mileage, provided, in the case of the Buddy, the driver (Renault u.d.) pays attention to the type of battery in the car, some top up charging if needed in the case of long commuting. In effect, the driver must make sure he/she selects the right electric car for his/her needs, or adjusts driving patterns accordingly.

How does this compare in general? Even in the US, a country of big cars and long distances, there is research to suggest electric cars may cover most driver needs there. (Pearre, et al. 2011), in his survey of driving patterns in the US for gasoline cars, that in one day “9% of the vehicles never exceeded 100 miles (about 160 km), and 21% never exceeded 150 miles”. Pearre concludes that a third of drivers “could substitute a limited-range vehicle, like electric vehicles now on the market, for their current gasoline vehicle without any adaptation in their driving at all”. Pearre further finds that the same 100 mile (160 km) range EV would meet the needs of a further 17% of the remaining drivers if they are willing use alternative transport two days a year, increased to 32% if using alternative transport 6 times a year, a total of 62%. (Pearre, et al. 2011)

For the calculations, the range and fuel efficiency figures used were those given by manufacturers. Care was taken to use figures based on the NEDC driving cycle (a study of driving patterns and test procedure for fuel efficiency based on European driving patterns for cities and highway driving), and expressed in km/litre, as is the convention in Denmark. While the Danish yearly mileage and NEDC driving cycle may differ from those of Samsø, their use here enables comparison of like for like.

4.3.3 Car models, range and price

The electric car market offering in Denmark includes a number of vehicle models available for purchase, now and coming onto the market later this year. At the time of writing, nine (9) cars (personbiler), and two (2) goods vehicles (vare og lastbiler) were listed as models available in the country, with one truck undertermined (Modec went into administration in April 2011). Of the car models, two have lead acid batteries, which have a short range but are cheaper, and the others have Li-ion batteries, with a higher energy density but also a higher price.

The previous section explained how BEVs are characterized by their batteries. Battery chemistry, size and cycling determine energy density and lifetime of a battery, as well as range and price of the vehicle.

The cars (personbiler) currently available, or soon to be available, are compared in Figure 9 below according to business-economic price and range (rebates are not included, but taxes are). The figure should be taken with some caution, as some vehicles are available with different battery options (which are not presented here) and range not a precise variable. However, the picture that emergest is that all electric vehicles are not created equal, and there are differences in prices and ranges.

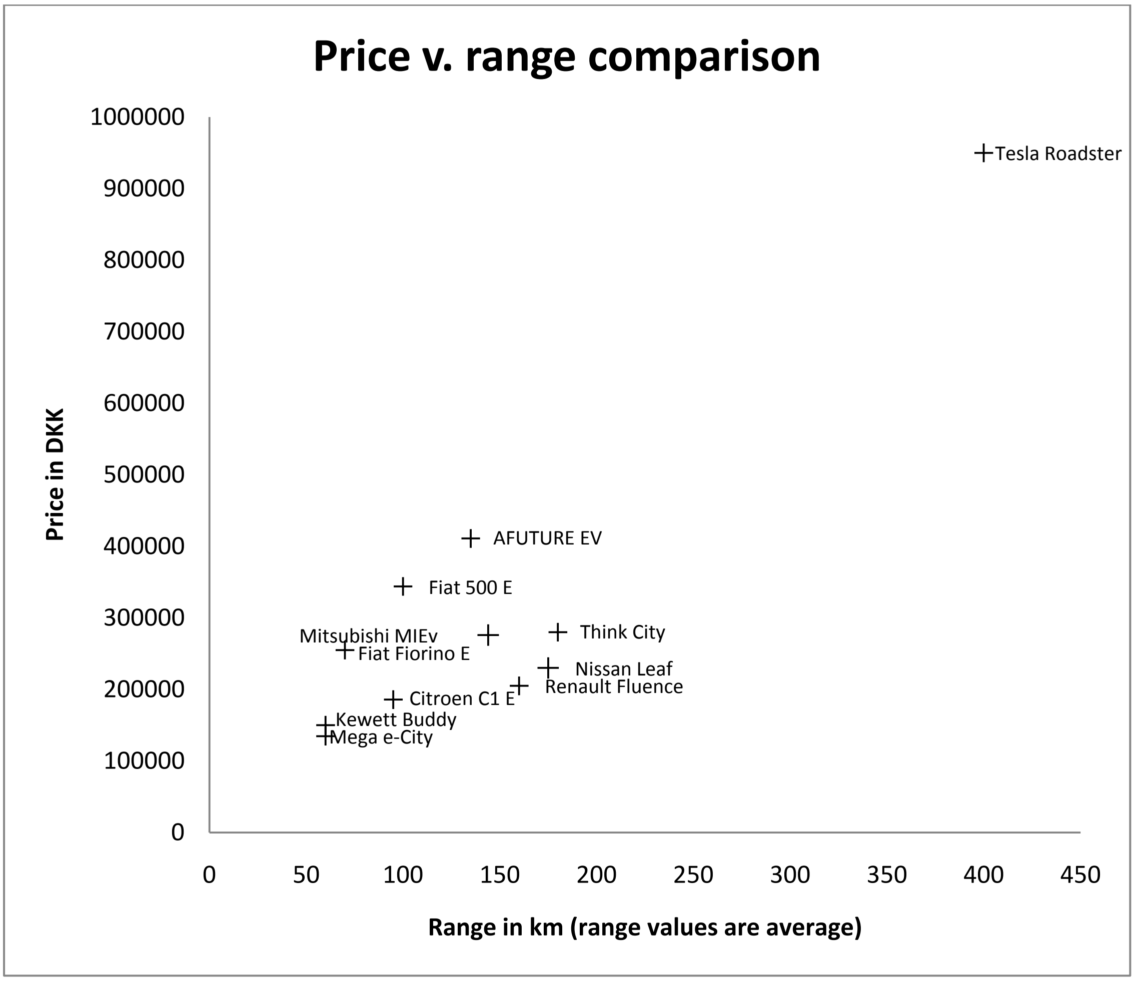

Figure 9: How much range for the money? Purchase price v. range comparison of electric vehicles on the Danish market or soon to be on the Danish market (Renault Fluence not including cost of monthly battery lease). Source: (Dansk Elbil Komite 2009), (Renault 2011) for Renault Fluence, (Dansk Elbil Komite n.d.) for Mitsubishi i-MiEV, (Nissan u.d.) for Nissan Leaf, (Wikipedia u.d.) for Nissan Leaf

The two models with lead acid batteries (the Buddy and the e-City) have the shortest range but this does seem proportionally reflected in the price. Line of best fit?

The Fiat Fiorino E, a small goods van, is within the cluster of EVs in terms of price to range ratio. It is in the top left quadrant of the cluster, meaning it is more expensive and with a slightly lower range for price than other cars, but it is still cheaper than some cars: the i-MiEV is slightly more expensive, and with more range, and the Think City doubly so. However the Fiat 500 E, for a similar range is significantly more expensive. The A Future EV, also with slightly more range, is however significantly more expensive as a sedan.

For the remainder of the study, the Mini Hummer (a neighbourhood vehicle) and the Tesla Roadster will be discounted. Their characteristics are not in keeping with most electric cars, and therefore unlikely to make them universally adopted. Some calculations will be made for the light goods vehicles for illustrative purposes.

Electric cars as a whole have an impact on the energy system they are part of. To evaluate the impact on Samsø, having some ideas of the differences between models available, it is necessary to evaluate the electricity consumption of each model, and evaluate the impact it would have on the island as a whole. This is investigated in the next section.

4.4 Evaluating the electricity consumption of electric cars in the Samsø energy system

This section looks at the technical feasibility of implementing electric cars on Samsø by evaluating the electricity consumption with only electric cars would have, for each and every model in the study. The fossil fuel displaced and CO_2 emissions avoided will be calculated in the next sections.

In terms of impact on the energy system, battery electric vehicles have two big advantages from an energy planning perspective. Electric vehicles have the advantage of being much more efficient than combustion-engined ones; approximately three times more so in fact. This means that given electricity generated from a comparable fossil fuel, a 100% electrified light vehicle transport sector can reduce emissions by two thirds over combustion engine vehicles. Should the electricity be generated from 100% renewable sources, then all CO_2 emissions from light vehicles can be taken out of the system. (Lund 2010)

Though this will not be considered here, as a part of an electric energy system, they have the advantage of being capable of storing and if permitting, releasing electrical energy to the Grid, they are ideally suited for regulation of a renewable energy generated electric energy system. A number of studies show that as a result they enable the large scale integration of renewable energy, including wind over 40%, by dealing with critical excess electricity production that occurs by storing it, and if enabled, releasing it to the grid in times of need. (Lund og Kempton 2008) (other citations!) (more precise details about results of studies?)

In order to make the calculations, a number of questions have to be answered and assumptions made.

4.4.1 Methodology

To evaluate the electricity consumption of electric cars in the Samsø energy system, one must make assumptions about efficiencies of cars, that is the ratio between the energy going into the car (in the battery) and the energy going out of the car and transferred to the wheels. One must also make assumptions about the energy system efficiency: how much wind is turning the wind turbines (energy into the system) and how much electricity is produced (energy out of the system).

When making the analysis, a choice had to be made as to the data to be used for the analysis. While the scientifically most accurate choice would be to calculate efficiencies using exact weights of vehicles, with driver and in accordance with drive cycle testing procedure (that is an energy consumption incurred driving in carefully controlled conditions), range calculated using this efficiency, with the battery specific weight and energy density, much of the data necessary for this is not available.

Therefore, the data used is that which the consumer has access to. Range as given by manufacturers is used, and assumed to reflect the vehicle efficiency. When a variable range is given (for example between, say 70 and 130 km for a vehicle), an average is used. And the uncertainty of the range based data is dealt with by making a sensitivity analysis

4.4.2 Results

Now that it is known whether electric cars can meet range needs, it is necessary to determine the additional electricity consumption electric vehicles would imply.

There is no data as to the types of cars driven by the islanders in terms of size and gas consumption and mileage, so the electricity consumption was calculated for each model. The utility of such a scenario is not to assume that everyone on Samsø will drive a Tesla Roadster, but rather to understand the role of the size of the battery, and car efficiency, in the overall system, and if additional energy production is required, because if shortages occur, then one driver having a large battery will have implications for other drivers competing for electricity.

The methodology used is that used by (Lund 2010) (Lund og Kempton 2008) and shown in Figure 10 for all the cars available in Denmark according to (Dansk Elbil Komite 2009). In addition, the calculation is performed for vans all 475 vans in the municipality using a Fiat Fiorino E as an example, and shown added to the car calculations for interest.

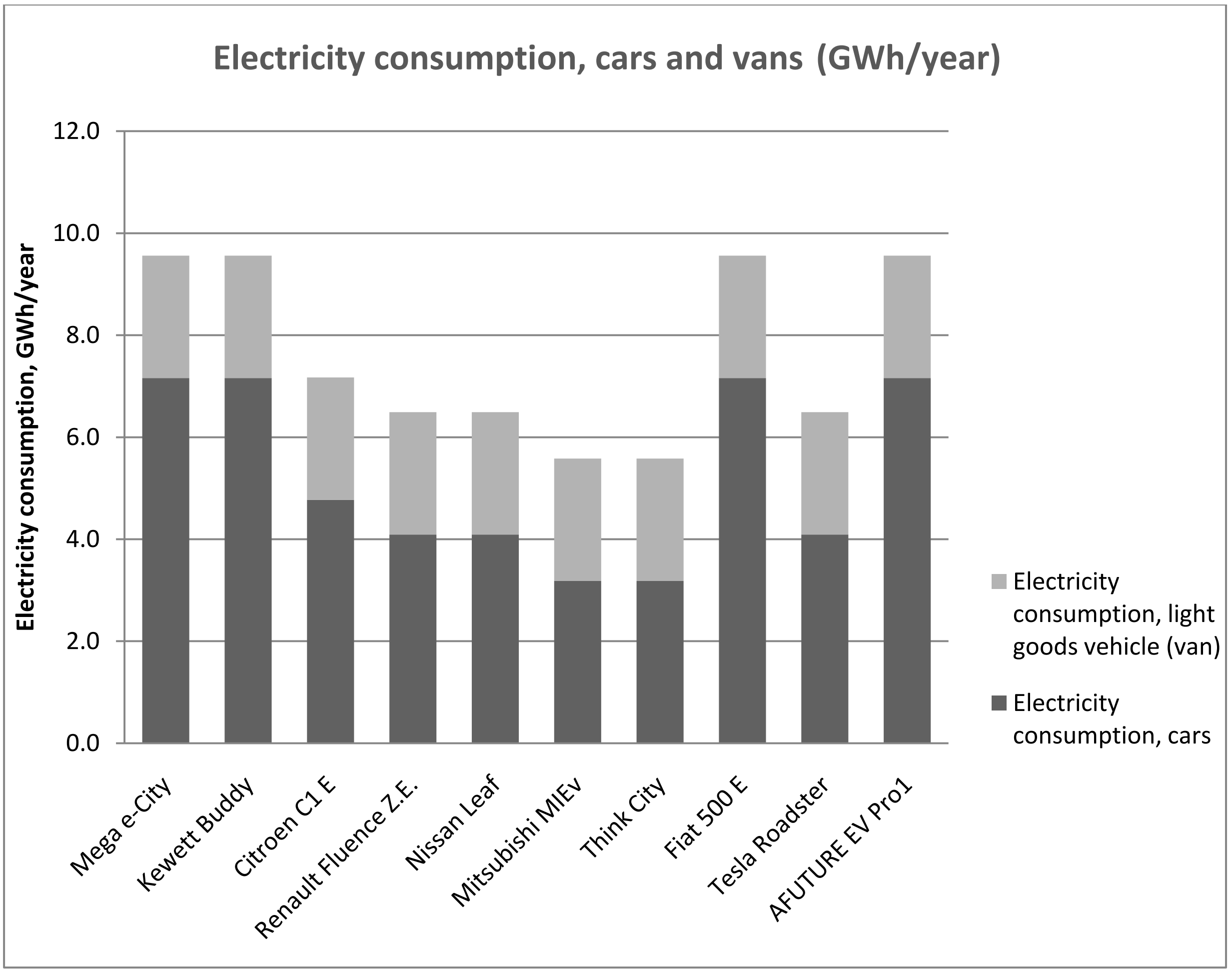

Figure 10: Total electricity consumption of cars and vans on Samsø (GWh/year)

The results of the calculations are interesting. Figure 10 shows that total electricity consumption for electric cars alone would be between 3.5 GWh/ year in the best case scenario, and 8.0 GWh/year in the worst case scenario. In addition, electrifying vans would mean an extra 2.4 GWh/year.

Interestingly, efficiency does not seem directly correlated to price, with the Citroen C1 E, the Think City and the Tesla having the highest efficiencies, and translating into the lowest demand onto the energy system. On the other hand, the Mega e-City, the Kewett Buddy, the Fiat 500 E, the AFuture EV Pro1 and the Fiat Fiorino E van all have the lowest efficiencies, with only 4 km/kWh and the highest demands on the energy system. As the true demand would be somewhere in between the two extremes, taking the Citroen C1 E as average, with an efficiency of 6km/kWh, the total demand for electric cars would be around 5.3 GWh/year, and 7.7 GWh/year if vans are included.

4.5 How much wind capacity would be needed?

While the total amount of electricity needed for the electrification of cars is known, the next question is whether the existing electricity production infrastructure in the municipality can provide it, or whether additional capacity is needed.

When the Samsø energy system was redesigned for renewable energy, no technology was deemed suitable enough for making transport renewable, so the offshore wind farm was built specifically to offset fossil fuel transport. The offshore wind farm consists of 10 turbines amounting to a capacity of 23 MW (5 of which are owned by the municipality, 3 by commercial operators, and 2 by small shareholders). The wind farm produces 80.5 GWh/year, half of which owned by the municipality. The total amount of transport energy at 2005 figures is estimated at 60 GWh (Energiakademi 2007). This means that while the municipality can cover the electrification of cars, it cannot cover the whole transport sector, but electrification actually helps it take ownership of transport.

To calculate the wind turbine capacity needed, that is the "nameplate" rating for a wind turbine, a methodology wasused whereby the capacity factor for the Samsø offshore wind farm was calculated, and then used with the demand for electricity needed per car model to determine the name plate rating. The capacity factor is a ratio between the energy output of a wind farm over a year to the capacity multiplied by the number of hours in a year. This corresponds to the ratio of the actual output of the wind farm over a year and its potential output if it had operated at full capacity 24/7 for a year (Wikipedia). So the actual output is 39.3 percent of the total potential. From the capacity factor, it was easy to determine what nameplate capacity turbine would be needed for the car specific electricity demand, and calculate it. This is shown in Figure 11.

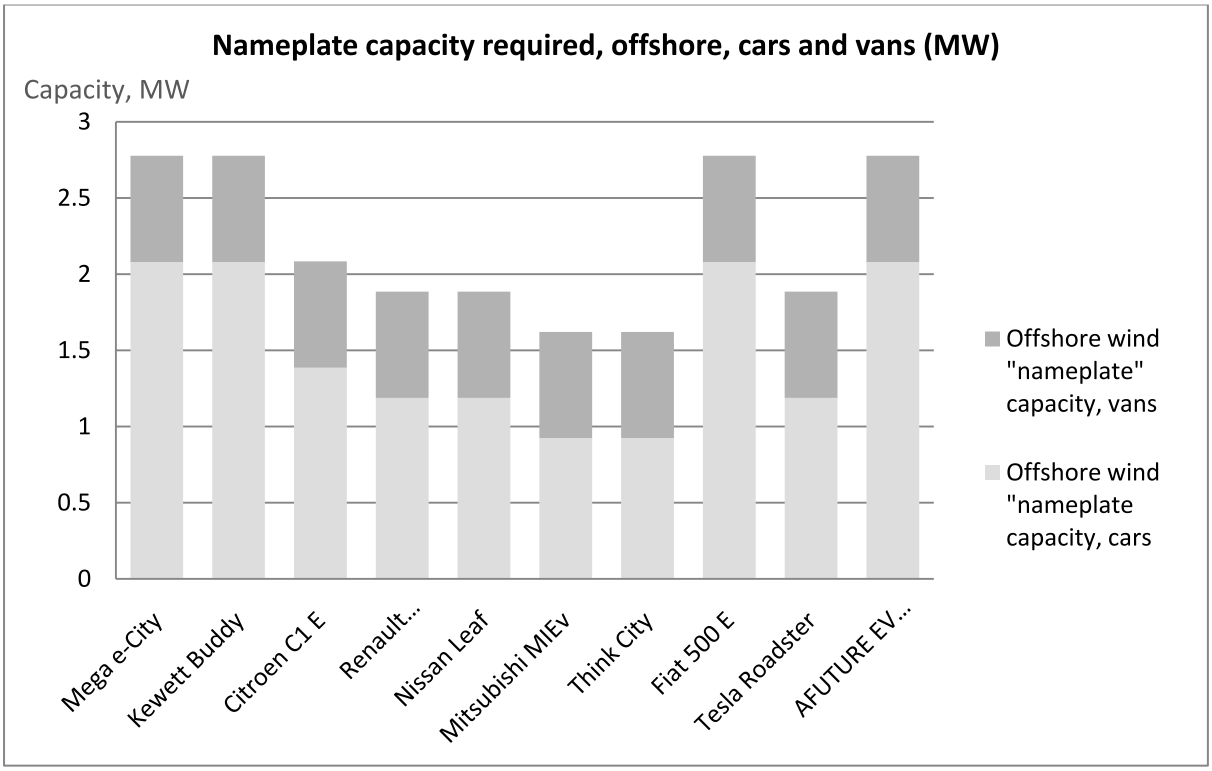

Figure 11: nameplate capacity required for each electric vehicle, with vans (Fiat Fiorino) added.

Figure 11 shows a number of interesting things. Firstly, the nameplate capacity required to power electric cars on the island varies greatly from model to model. The most efficient models are the Think City and Mitsubishi i-Miev, requiring less than a megawatt, followed by the Renault Fluence Z.E., the Nissan Leaf, and the Tesla Roadster. The family sedan (AFuture EV), and the Mega e-City and Kewett Buddy fared worst. Ten 2.3 MW turbines were installed offshore, and if vans are added to the demand, the total demand could be taken care of with just one turbine in the case of six vehicles: the Citroen C1 E, the Renault Fluence Z.E., the Nissan Leaf, the Mitsubishi i-MiEV, the Think City and the Tesla Roadster. It is interesting to note that while the calculations are based on energy consumption per type, they are interchangeable, so any system with a mix of those cars would be fairly predictable in demand.

From this can be deduced a number of things. The size of the car (determining efficiency), and the battery chemistry are an important factors in designing energy systems for BEV.

Another implication is for the offshore wind farm at Samsø. It was designed to offset total transport emissions for the island, and covers electric car demand for energy. However, more efficient cars mean a surplus of electricity, which can be traded on the open market.

The implications of the link between efficiency and the energy system will be examined further in the chapter public regulation, with particular reference to pricing and profit flows.

4.6 How much fuel is displaced on Samsø by electric cars?

The counter effect of using electric cars instead of fossil fueled ones and demanding more electricity for them is that the equivalent amount of fossil fuel is not burnt. This section evaluates how much.

Fossil fuel displacement per model of electric car is calculated using the corresponding fossil fuel model. The fossil equivalent fuels were petrol (gasoline) and diesel. In some cases, a diesel equivalent model was not found (like for the very small, micro cars) and the Mitsubishi i-MiEV. For models with no direct fossil fuel model (such as the Kewett Buddy and the Think City for example), the choice of alternative was made based on variables such as weight, wheelbase, length, acceleration, general styling, etc. Brand was not part of the choice (for instance no Ford alternative was found for the Think, despite Think being owned by Ford Motors). (N. Pearre 2011)

In 2005, the consumption of energy for transportation was 210 TJ, or 58.4 GWh, of which 65 TJ, or 18 GWh was for petrol and diesel cars (Energiakademi 2007). Using 2005 figures shows a saving of about two thirds of energy used, consistent with the efficiency gains from the different drive trains. Calculating from the number of cars today, using the same efficiency for combustion-engined cars that (Lund og Kempton 2008) use of 14 km per litre, the total amount of energy used is 21.5 GWh/year ((18,000 km/year / 14 km/litre) * 1591; converted to GWh/year). While neither of the calculations is very accurate, there is enough consistency between both to show the reduction in energy use from electrification.

Under the assumptions for mileage and efficiency made above, the electrification of cars displaces 2.3 million litres of fossil fuel (gasoline and diesel) in the municipality per year. This represents a significant amount of CO_2 savings, as well as a significant amount of money that is not spent on fuel but has the potential to stay on the island.

The methodology for calculation is as follows. The annual kilometers driven by the EV are multiplied by the km/litre fuel consumption of the equivalent gas car for a year. That gives litres of gasoline not burned per year. This is then multiplied by the total number of cars for the total amount of fuel displaced on the island by car type (N. Pearre 2011). While calculations for the Tesla EV were performed, it was deemed of little realism to envisage a scenario where all islanders drive a Tesla. However, it nevertheless included because it is a well known car.

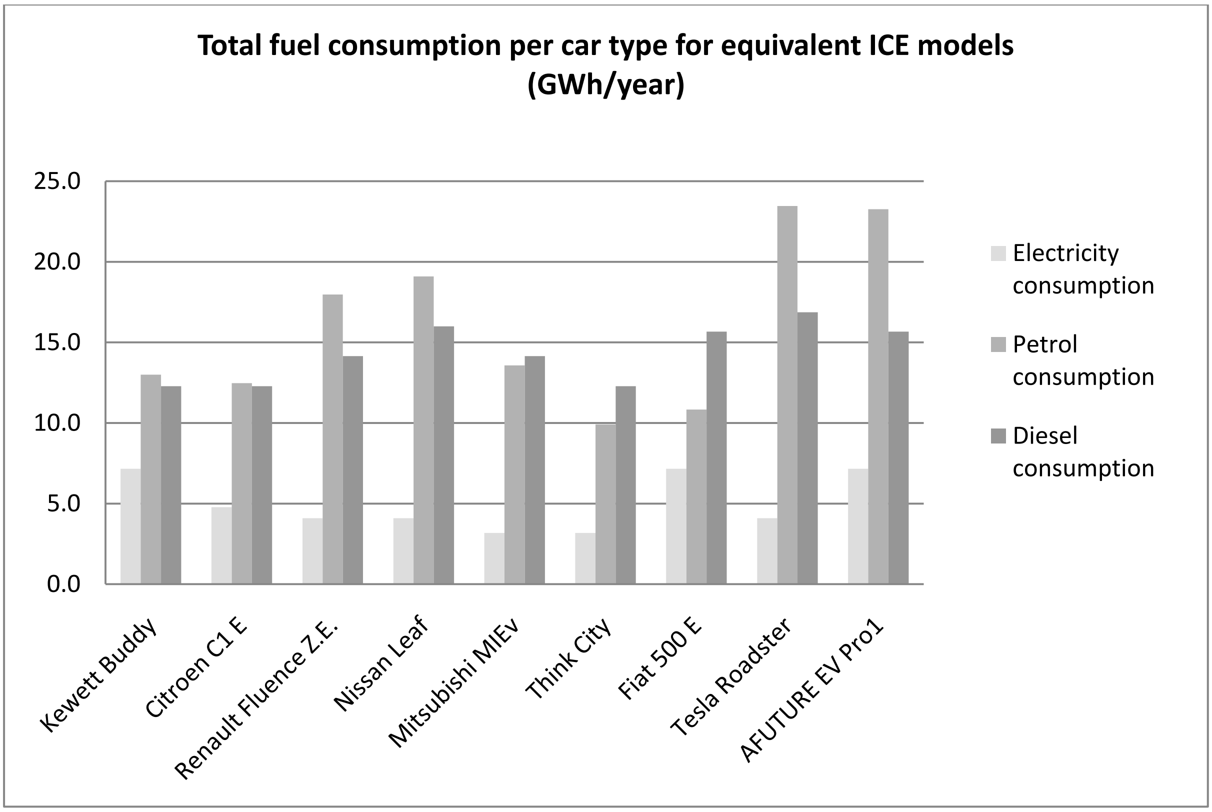

Figure 12: Equivalent gasoline and diesel displaced by electric cars, er model, (GWh/year) (Source: own made)

While using a model of similar size, styling, or even the same model but in gasoline or diesel version is not a very scientific way of making a choice of alternatives (from an energy perspective, perhaps torque would have been better); it fits a consumer approach to choice of alternatives.

The graph shows, that in all cases, the fuel displaced, in both diesel and gasoline versions, is significant, and especially high for gasoline. The Think City, Nissan Leaf and Mitsubishi i-MiEV offer the most fuel economy amongst "family" cars.

4.7 How much CO2 emissions are displaced by models?

Having seen the effective fuel displacement, it is interesting to see it in terms of CO2 displaced.

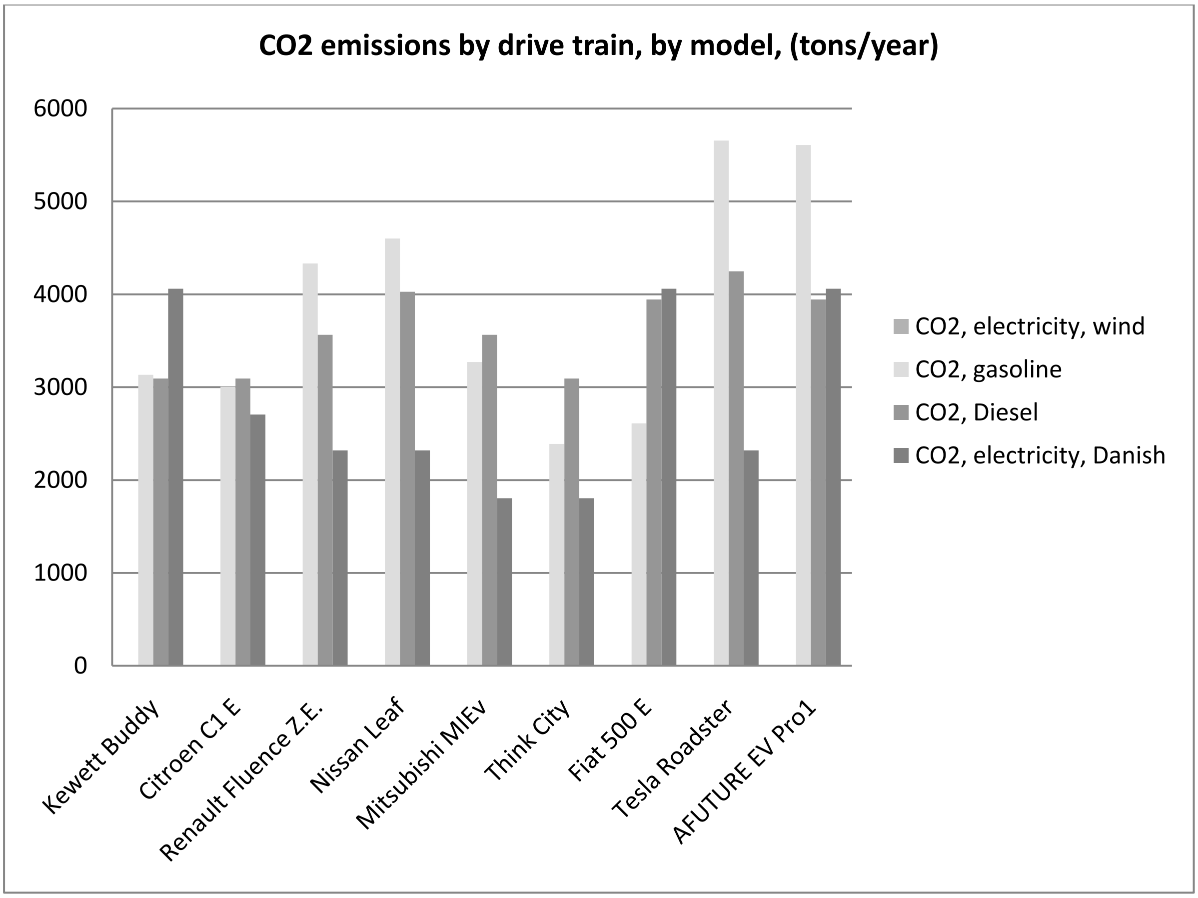

Figure 13: CO_2 emissions for equivalent gasoline and diesel cars, per car type, in tons/year, for the whole of Samsø

Figure 13 shows the displaced CO_2 emissions by fuel type, including electric. In this case, the energy system was assumed 100% renewable for the electricity supply, such as it is in Samsø – so there was no CO_2 release from switching to electric cars.

It can be argued it would have been interesting to compare, with say the Danish electricity supply, to see whether switching to electric by itself reduces emissions, even if the electricity supply is not 100% renewable. I believe this is done in a number of studies on electric cars in Denmark, including (Mathiesen 2009) and (Mathiesen, Lund og Nørgaard 2008).

4.8 The impact of lower range and mileage

Different models of electric cars have been compared using a standard Danish yearly mileage figure and "perfect" batteries. However, batteries do loose efficiency over time, and Samsø residents may not all drive as many kilometers as mainland Danes. Small trips around the island may be the norm. As no data was available, both are taken into account. Both loss of efficiency and lower mileage would have an impact on the demand on the electricity system, and on the other variables. This is analysed here, for an electricity demand that has doubled (from batteries needing charging twice as often) and a mileage that is half that on the mainland (9,000 km/year).

The results from halving the mileage to 9,000 km/ year include that electricity consumption does not go down exactly by half (for instance the MiEV). A good guess is that this is a function of battery chemistry. Also vans do not halve their consumption. With regard to emissions, there is a drop in emissions from all drive trains and from a Danish energy system mix, but this regarding the Samsø one it is already zero emission. The ratios of drop in fuel use differ also to do with efficiency.

The results from halving the range are that electricity demand goes up, but not the demand for the fossil fuels. The name plate capacity required goes up. But CO_2 emissions, if the system is wind, do not change. However if an electricity mix with fossil fuel is used, then emissions do go up.

A sensitivity analysis of both a lower range and lower mileage together were not performed, because the change in only one parameter should be measured at a time with respect to the system.

4.9 Partial conclusions and the next chapter

4.9.1 Partial conclusions

This technical analysis has had both expected results and new knowledge. In keeping with existing Danish energy planning research, the analysis finds that electrifying the light vehicle sector does significantly reduce the amount of fossil fuels needed on the island, and significantly reduces the total energy demand (and CO_2 emissions) for transport. This is a significant result from an energy system perpective, as cars represent a large share of the energy demand in Samsø and Denmark. The aim of the renewable energy integration in Samsø was first to displace emissions, and secondly to integrate renewable energy technology.

In 2005, the consumption of energy for transportation was 210 TJ, or 58.4 GWh, of which 65 TJ, or 18 GWh was for petrol and diesel cars (Energiakademi 2007). Using 2005 figures shows a saving of about two thirds of energy used, consistent with the efficiency gains from the different drive trains. Calculating from the number of cars today, using the same efficiency for combustion-engined cars that (Lund og Kempton 2008) use of 14 km per litre, the total amount of energy used is 21.5 GWh/year ((18,000 km/year / 14 km/litre) * 1591; converted to GWh/year). While neither of the calculations is very accurate, there is enough consistency between both to show the reduction in energy use from electrification.

Under the assumptions for mileage and efficiency made above, the electrification of cars displaces 2.3 million litres of fossil fuel (gasoline and diesel) in the municipality per year. This represents a significant amount of CO_2 savings, as well as a significant amount of money that is not spent on fuel but has the potential to stay on the island.

The second finding is that while electric cars mean less wind electricity is exported, and therefore less of the emissions from the Danish electricity system are displaced, the net displacement effect of the technology change is positive, with emissions from displaced fuels higher than emissions from corresponding amount of electricity from the Danish energy mix.

Thirdly, once extreme cars such as the Tesla are taken out of the equation, the analysis has shown that vehicle efficiency is an important factor on the expected load of the energy system. Clearly the average efficiency of the vehicles in the system will have an impact. Not all electric vehicles are equal in an energy system.

The implication is that the battery type matters to name plate capacity, given a size. Lead acid consumes a lot more, even though it is cheaper to buy that car. This means that what failed in

Samsø 1.0 (batteries not lasting) might work in Samsø 2.0 (better quality batteries, less need for electricity). In addition, in the electric car world, the size of the car matters to the energy system, given a battery type. The family sedans consume more than twice what a smaller car uses.

Fourthly, while Samsø has already made offshore wind installations to offset transport emissions, and potentially one day power electric vehicles, the nameplate capacity is affected by the efficiency of the vehicles. Using inefficient vehicles could lead to the need for additional capacity, but more efficient ones could lead to an electricity surplus which can be sold at a profit.

Fifthly, electric cars do succeed in displacing fossil fuel, and CO2 from the island. What is not taken into account is the fossil fuel (and CO2) displaced from not having to import fossil fuel to the island. Furthermore, the choice that Samsø has made to have a 100% renewable electricity production bring the additional benefit that CO2 emissions are zero, compared to using electricity from, say, the Danish energy system which includes a substantial amount of coal and gas.

4.9.2 The next chapter

The technical findings have interesting implications for the next analysis. Therefore the next chapter consists of a socio-economic analysis of the short term feasibility of implementing electric cars on Samsø. Taking the technical results obtained in this chapter, it sets to find out from a socioeconomic perspective whether electric cars would cost Samsø more to implement than keeping ICE cars.

Some of the variables compared will include the cost of investment and fuel, as well as the cost of CO2 emissions. These costs are born by car owners, the municipality, etc.

Chapter 5
Socio-economic feasibility

The focus of this chapter is on determining the socio-economic feasibility of implementing electric cars on Samsø. The socio-economic feasibility is determined by asking if the implementation of electric cars on Samsø is a good idea for society, that is whether it more advantageous in terms of costs to the island to implement electric cars over fossil fuelled ones.

5.1 Overview

The purpose of socio-economic analysis is to determine the cost to society of a technological change. In the previous chapter, a technical analysis determined that, under the conditions, electric cars are feasible for the island in terms of the total amount of energy consumed, and the CO2 emissions foregone and represent an important step towards a fossil fuel free Samsø. However, the analysis also found that the energy efficiency of the car was an important factor in the feasibility of the system, and that there is wide variance in impacts. It seems proper to ask what the socio-economic implications of these findings are for Samsø.

According to (Hvelplund and Lund 1998), this can be done in a number of ways, such as by evaluating the impact of potential future changes in an energy system, analyzing the impact of legislation and political process on economy, evaluating change over a time period long enough to be independent of existing technical systems, or evaluating what keeps existing systems going a long time.

A comparison of socio-economic costs by energy mixes – wind versus the Danish mix in the case of electric, which is a financial flow, a displacement of welfare or cost to society. What does it mean socio-economically to use wind at home rather than the Danish fossil mix? This chapter builds on the results of the technical analysis, analyzing the cost to society of different models of cars, both electric and fossil-fuelled, in order to determine the one with the lowest cost to society in terms of costs of hardware, maintenance, interest, fuel and CO2. Since an electric car uses electrical energy that can be produced in a variety of ways, the impact on economy of producing it sustainably on Samsø is also analysed. While a number of socio-economic analyses are possible, the choice is to try and understand the contribution, and the impact that electric cars, as consumers of electrical energy, can have in a society that not only produces all its electricity by renewable energy, but has made the decision to own the means to do so.

This enables us to ask if, for example, the cost of CO2 in fossil fuel makes the cost of ICE cars outweigh the cost of additional infrastructure for electric cars. It also allows us to understand any differences in the costs between electric cars, and evaluate if some are better than others in terms of fixed costs and variable costs.

Making a comparison of the costs of producing electricity by offshore wind, as opposed to the Danish electricity supply mix enables us to understand the socio-economic cost to Samsø of producing electricity for electric cars, and whether doing it by wind is the right decision.

Also a comparison of social cost displacement between fossil fuels: How much is the social cost of using a little wind a t home (link with technical analysis) and how does it compare with the

This chapter evaluates the impact of electric cars on the economy of the energy system, compared to alternatives such as fossil fueled ones.

Thirdly there is a sensitivity analysis of those socio-economic costs under a lower electric vehicle range and different mileage. This answers the question as to what happens when the electric cars require more electricity for the same mileage (a loss of range, due to ageing of the batteries) and whether it is worth it for Samsø, which may have a special, lower, mileage since it is a small island.

5.2 Assumptions

These technical analysis results are used to analyze the socio-economic costs of the different models of cars by drive train (electric and combustion).

Using a similar approach to (Mathiesen 2009), the total costs to the island are analysed in terms of the socio-economic costs of the vehicles.   Because socio-economic costs refer to the costs to society, taxes and subsidies, a form of public regulation, are not included. Costs of CO2 for instance, are included.

In this study, the socio-economic cost of vehicles is defined to include the costs of fuel, the cost of CO2, the costs of fixed operations and maintenance (Fixed O&M), investment costs for different vehicles as well as the cost of variable operation and maintenance as defined by the socio-economic analysis assumptions by the DEA. The assumptions provide a set of tools for making comparisons based on common, defined fuel costs and technologies , pricing externalities that would not otherwise be priced and being regularly updated.

Therefore fuel and CO2 costs are used that are adjusted to 2010 prices, and have been adjusted for externalities.

Regarding the pricing of the vehicles by drive train, it is based on energy output. The total vehicle cost is split into fixed operation and maintenance costs, variable OMM, and vehicle investment costs. Fuel is additional.

Since vehicle costs are a function of energy output, these costs were used to price gasoline and diesel vehicles (based on range). For electric vehicles, the costs were recalculated for each model using the EEA methodology, of a 5% interest rate and a 13 lifecycle for the car. This enabled a comparison of the individual car models as a function of their energy output and tax free sales price.

5.3 The socio-economic cost of the drive train

Error! Reference source not found. shows the socio economic cost per drive train and vehicle, with gasoline vehicles to the left, diesel vehicles in the middle, and electric vehicles to the right.

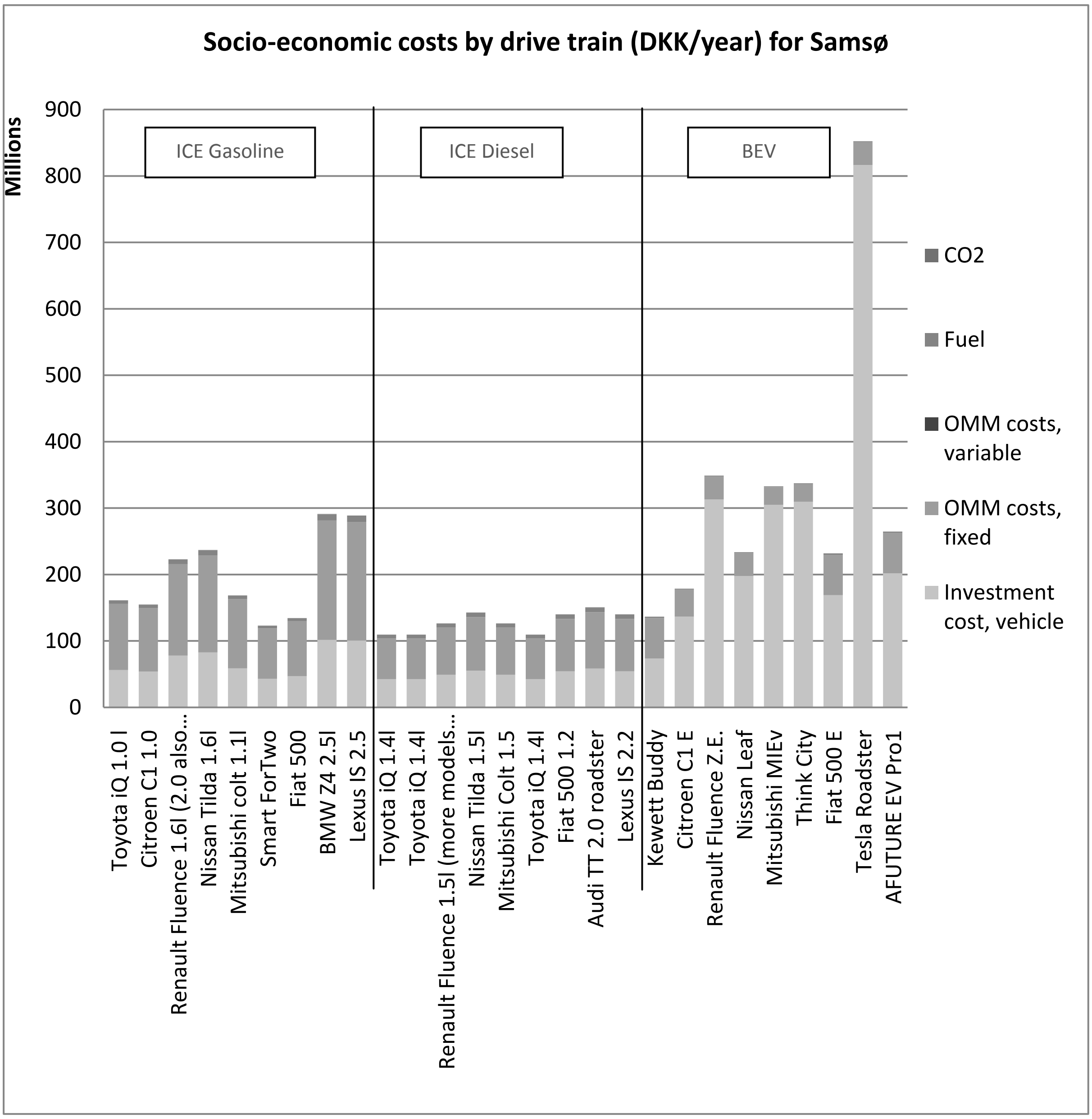

Figure 14: socio economic costs of gasoline, diesel and electric drive trains by model (Source: compiled from (Energistyrelsen (DEA) 2010))

Of the 36 models compared, five of the BEVs have the lowest socio-economic costs. They are Li-ion and modestly priced, efficient vehicles. These are the Citroen C1 E, the Renault Fluence ZE, the Nissan Leaf, the Mitsubishi MiEV and the Think City. The Fiat 500E, Tesla Roadster, and AFUTURE EV Pro 1 failed for having higher vehicle purchase costs (in the cast of the Tesla, due to the cost of the extra large battery) combined with large OMM costs. The Kewett Buddy also failed on the OMM costs and had higher fuel costs than the other electric cars (due to its lead-acid battery)

Both the petrol and the diesel cars have the highest fuel costs, compared to the BEVs. This fits with Mathiesen's findings about Denmark (Mathiesen 2009), and therefore his finding that ICE vehicles would be vulnerable to increases in fuel costs holds. Likewise, non-automobile investment costs and automobile operations and maintenance are the highest costs on ICEs.

The BEVs have the highest vehicle investment costs, that is purchase costs, by several orders of magnitude, even if they were all averaged out to make a single typical vehicle, and bearing in mind that ICE vehicle investment costs were based on a standardized model from the DEA. However the much lower other investment costs and OMM mean that comparing like for like, the Renault Fluence ZE is almost half the cost of the gasoline version

Socio-economic costs vary greatly overall between models, the highest measured difference being between a gasoline BMW Z4 (a convertible) and a Think City or a Mitsubishi MiEV, with the BMW costing almost three times more.

5.4 The socio-economic value of the Samsø electricity system to BEVs

This section looks at the socio-economic costs of producing electricity. Electric cars may have lower socio-economic cost, but what is the socio-economic cost of different forms of electricity production?

The cost of coal is only marginally higher socio-economically as part of the whole chain.

5.5 CO2 costs and energy system social costs

Figure 15 is a close up comparison of the socio-economic costs of CO2 for the different car drive trains and a Danish electricity supply versus a Samsø electricity supply. The amounts are more modest, up to approximately 625,000 DKK/year for a petrol roadster or a large family car. But all electric cars tanking up on Samsø wind power have a nil CO2 cost, meaning that for all cars, going electric and tanking up on Samsø has the lowest CO2 cost. While the amount of money is small in comparison with the other costs, it can serve as the basis for the design of public regulation in the next chapter.

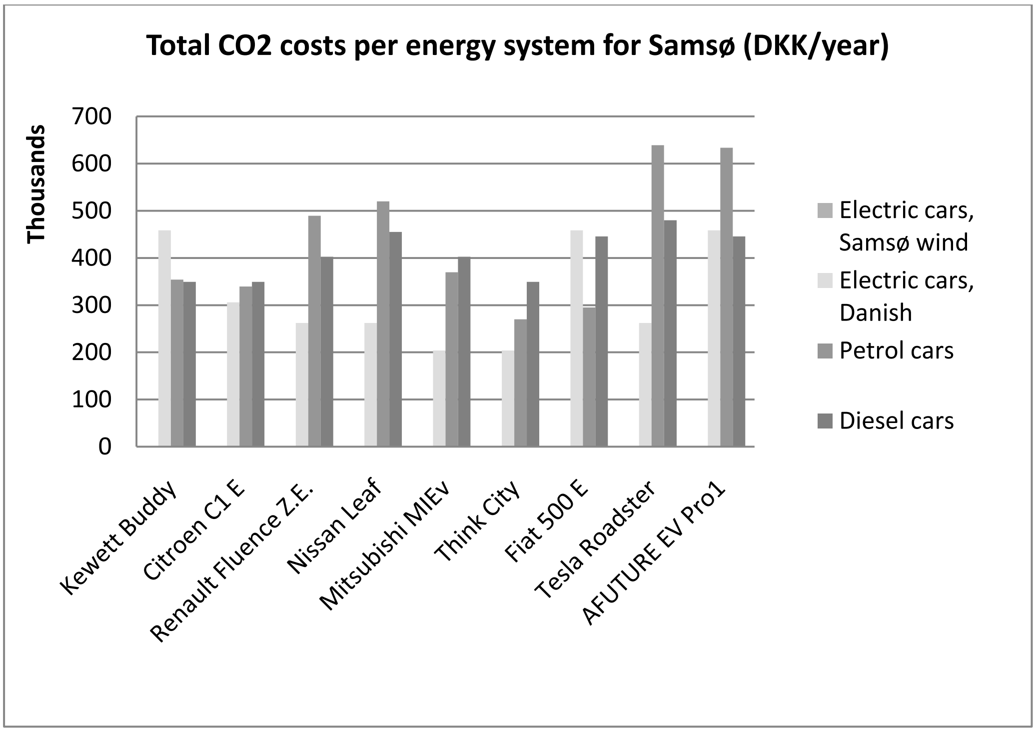

Figure 15: CO2 costs per energy system for Samsø (DKK/year) – petrol, diesel and electric cars compared

Figure 16 is a close-up comparison of socio-economic fuel costs for the cars understudy, the electric models and their petrol and diesel alternatives. It shows that the social cost of fuel is much higher for ICE cars than for electric cars, by several multiples. The Nissan Leaf, for instance, has an electric fuel cost of just over a million DKK, and its equivalents have costs of approximately 6.5 million DKK for diesel and 4.25 million DKK for petrol. In the Samsø case, the wind is home produced, so the electric cars represent a fuel money flow that stays in the economy, compared to a fossil fuel money flows several times bigger flowing out. This will serve as a basis for the design of public regulation in the next chapter.

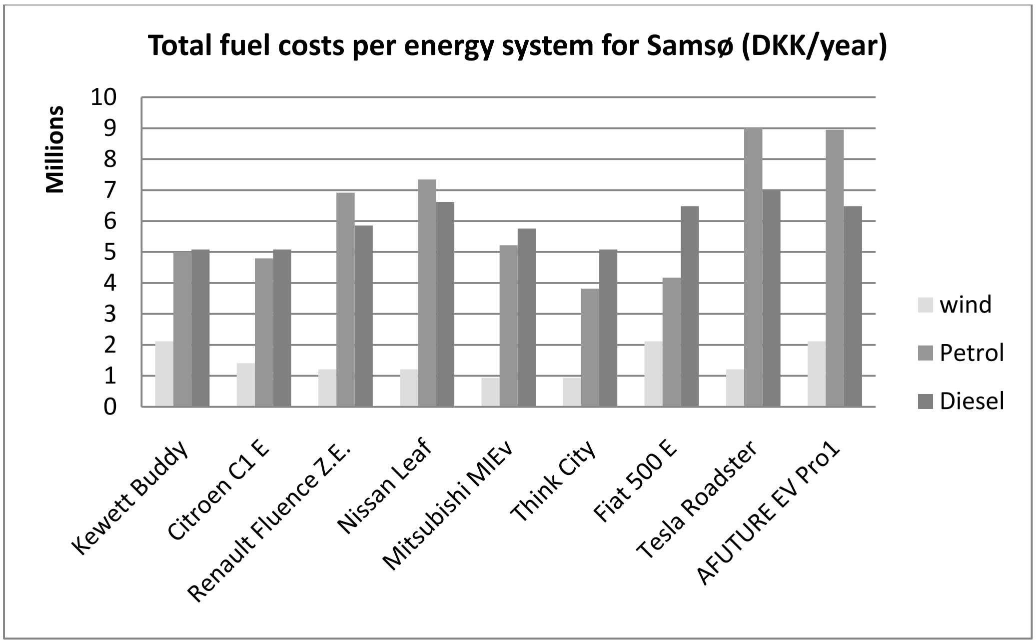

Figure 16: Socio-economic fuel costs for cars on Samsø: petrol, diesel and wind compared (electric car model names used)

5.6 What happens with a lower range and mileage?

Over time, batteries become less efficient and the Samsø actual car mileage may be much less than the national average. Since the socio-economic costs are calculated as a function of the efficiency of the car, adjusting for a lower range and mileage can help deal with uncertainty.

The lower mileage means the fixed O&M costs go down significantly, making ICE cars much much cheaper than electric ones.

The lower range appears to reduce costs equally for electric cars.

5.7 Preliminary conclusions and next chapter

This chapter made a number of socio-economic analyses, to determine the cost to Samsø society of implementing electric cars. In particular, it was necessary to determine if BEVs were cheaper to society than ICE models overall, and in terms of component costs (both pertaining directly to the vehicle and to the energy system, such as the fuel), and relative to each other.

Therefore, the socio-economic costs of electric cars were compared to those of vehicles with fossil fuel drive trains; by model. The result was that the efficiency of the cars may affect the socio-economic costs, with the most efficient family size BEV cars having the lowest costs of all the drive trains. The Tesla was an exception, because of its high vehicle cost, due to an expensive battery (the battery being expensive because of its size). In terms of the scale of the difference, the Renault Fluence Gasoline was found to have about twice the costs of the Renault Fluence Electric.

An analysis was conducted of the socio-economic costs of the electricity supply for cars. A comparison of the wind-based, Samsø electricity supply with a standard Danish one revealed that while the cost of fuel is a small component in the total, producing it locally by wind brings a sizeable local socio-economic benefit.

The next chapter will make use of these results to try and find public regulations, in the form of models for successful implementation. In particular, it will compare different models for ownership of electric cars and the impact on cost of different public regulations.

Chapter 6
Public regulation

This chapter looks at changing the public regulation governing the ownership and operation of electric cars, and in particular to look at how it would fare in the Samsø energy system. Public regulation is analysed in context with two things: the cars, and the energy system. The assertion made by this chapter is that the special nature of the public regulation of the Samsø energy system has benefits that can be extended to incorporating electric cars, and that electric cars have benefits because their cost structure is different from ICE vehicles.

6.1 Overview

So far, the project has looked at the feasibility of electric cars on Samsø from both a technical and a socio-economic perspective, determining the impact electric cars have in the energy system; and what their cost impact on society might be, as well as the value of the energy produced on Samsø for them. It showed that several models have the highest efficiency and the lowest socio-economic costs.

Technical findings
Electric cars displace fossil fuels away from the island, and integrate wind locally.
Socio-economic findings
Costs of cars high Socio-economic benefit integrated locally from using local energy production, socio-economic cost displaced away from the island, both in terms of fuel and CO2. Socio-economic cost of the car a function of efficiency: more efficient car have lower costs.

Figure 17: Overview of technical and socio-economic conclusions of analyses so far

What does this mean for practical implementation? In society, organizations and institutions are bound to each other in a complex economic structure, and how they are bound is defined by the social and institutional context they are in. This means that public regulation has an important role to play in the implementation of radical technological change by making old bindings weaker and favouring new ones that may be technologically and socio-economically a better choice. (Hvelplund and Lund 1998)

This approach is illustrated in Figure 19 which shows two situations. Situation I describes a society where a set of public regulation governing the market (Business Economy I) may be in direct contradiction with what a socio-economic study shows to be best for society (Socio-Economy I). The situation is then assessed by democratic political processes (Parliament, ministries, etc) and a new public regulation defined (Market Economy + Public Regulation II), which will bring about the desired conditions (Situation II) for what is best for society to be also the best for business (Business Economy II). (Hvelplund and Lund 1998)

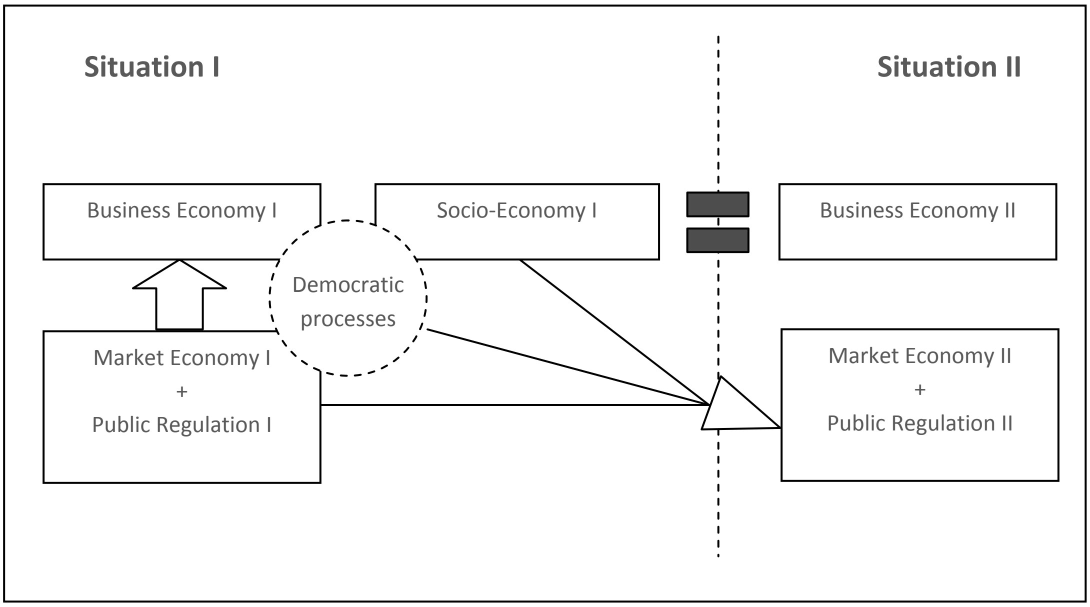

Figure 18: The relationship between business economy, socio-economy and public regulation (Source: (Hvelplund and Lund 1998))

Public regulation can mean a number of measures. As (Hvelplund and Lund 1998) put it, while in economic theory public regulation is usually taken to refer to fiscal instruments such as taxes and subsidies, public regulation is not just about administrative means, but also about "the social and institutional context in which public regulation functions". (Hvelplund and Lund 1998).

This project has analyzed what is the best choice from a technical and from a socio-economic point of view. Now an analysis of public regulation must be made, where what is best for society is also made best for business.

6.2 Making the "best for society" the "best for business"

In order to propose and compare different public regulations, it is necessary first to understand the different organizations involved and their bindings. (Hvelplund and Lund 1998) cite the case where a society may have an existing public regulation that economically favour fossil and nuclear fuels. Socio-economic analysis shows these have a higher cost to society than sustainable alternatives, but that sustainable alternatives have a higher business cost. In this example, organizational and institutional analysis often reveals "asymmetries of financial and political power between the old fossil fuel-based technologies, and the new energy conservation technologies". (Hvelplund and Lund 1998)

As things stand, car owners on Samsø face three possibilities if deciding on an electric car: to purchase outright, or to lease, from companies such as Better Place, ChoosEV or ClearDrive. The "best for society" has to be the "best for Samsø society", and making the "best for Samsø society" the "best for Samsø business". The analysis can be one where the institutional and organizational structure for the implementation of electric cars is optimalized for Samsø.

From the previous analysis, the options that Samso should go for are: energy efficient electric cars, using 100% wind. These options will now be evaluated to see if the existing public regulation facilitates them, or if new public regulation is needed. This means integrating the renewable energy on the island into electric cars, and integrating electric cars in a way that people want to buy them.

This section will consist of a business-economic comparison of car implementation models in terms of costs to individuals and how to maximize their utility. These are Better Place, ChoosEV, private ownership of the car and direct purchase of the electricity in the Samsø context, and a co-operative -owned model incorporating the ownership of electricity. This should enable an understanding of whether, with their generous existing public regulation, electric cars may need some more to boost models that are part of local systems.

6.3 Comparing existing options

Having compared models of electric cars with each other, several models are selected for comparison by implementation model. The idea is to compare cars that the technical analysis has found to be most efficient, and that the socio-economic analysis has found to be lowest cost to society, under several implementation models, such as the Better Place model, the ChoosEV model, the private ownership model, and the co-operative sharing model.

The analysis will include the Renault Fluence, because it is the model offered by Better Place, the Mitsubishi i-MiEV available from ChoosEV, and some of the other cars, such as the Think, the C0 and the Nissan Leaf. Furthermore, the Renault Fluence ZE, the Mitsubishi MiEV, the Nissan Leaf, the Think City and the Citroen C0 are the five most efficient models technically and socioeconomically overall. This should enable comparison of the Better Place, ChoosEV models with the private and co-operative models.

The mileage will be labeled so that like can be compared with like.

6.3.1 Better Place

The Better Place pricing model is as follows. The Fluence Z.E. "Prime Time" will cost from 205,000 DKK including VAT. Five mileage packages will be available from Better Place, shown below including VAT. (Business Wire 2011) (Better Place Denmark 2011)

Km/year	10,000	15,000	20,000	30,000	Unlimited
Car cost (DKK)	205000	205000	205000	205000	205000
Establishing fee	9995	9995	9995	9995	9995
Abonnement/month	1495	1695	1895	2495	2995
Minimum/year,	27935	30335	32735	39935	45935

Figure 19: the Better Place model

Services included in the subscription: access to Better Place charge spots and battery switch stations, unlimited electricity consumption, "personalized energy management and navigation services via in-car and network software, an inventory of batteries with a guaranteed service level agreement, 24-hour access to customer service and support, and a private charge spot". (Business Wire 2011) (Better Place Denmark 2011)

6.3.2 ChoosEV

ChoosEV offer both electric cars and vans for lease, including two models of cars (the Mitsubishi i-Miev and Peugeot Ion) and a light goods vehicle (a van in every day English, the Peugeot Partner). The van leasing programme runs over 60 months (5 years and 75,000 km) and charges a monthly fee. The car leasing programme, for a distance of 45,000 km, over three years, totaling 36 months, is as follows:

	Private	Business	Public sector
Car cost (DKK)	50000	0	0
Car cost/month, Miev	5395	5595	5195
Car cost/month, Ion	5495	5595	5295
Abonnement/month	599	599	599
Charger/month	399		
Car swap/month, from	159		
Installation charge	4900	175/month	175/month
Total, 36 months, Miev	50000+(5395*36)+(599*36)+4900		

Figure 20: The ChoosEV model

The model functions as follows. It involves a monthly repayment of the capital of the car over three years. Private customers pay an additional extra 50,000 DKK one off payment at the start. And monthly rental for electricity is 599 DKK per month for 36 months. Options include a stand alone charger, car swap and insurance.

6.3.3 The private ownership model

This is a scenario where the owner buys the car the traditional way, and covers the electricity costs, any needed charger and maintenance costs himself or herself and directly with providers. Five cars are included in the comparison: the Renault Fluence ZE, the Mitsubishi MiEV, and the Think City, the Nissan Leaf and the Citroen C0. The mileage is that of the Danish average, namely 18,000 km, used in the technical analysis. Interest rate, if used, is on par with a commercial interest rate of 3 percent. A loan period is seven years, and the lifetime of the cars 13 years.

Regarding a charger, a cost is assumed to be 5000 DKK, as per the DEA

The costs are shown below:

Name	Citroen C1	Renault Fluence ZE	Nissan Leaf	Mitsubishi MIEv	Think City
Cost of purchase, total	185750	364250	230000	275995	280000
Cost of purchase, (DKK/year)	14288	28019	17692	21230	21538
Operation and maintenance					
Other (charger), total	5000	5000	5000	5000	5000
Other (charger), DKK/year	500	500	500	500	500
Other (interest)					
Electricity, 18000 km, (295 DKK/MWh)	885	759	759	590	590
Electricity, 18000 km, (301 DKK/MWh)	903	774	774	602	602
Electricity, 18000 km, (451 DKK/MWh)	1353	1160	1160	902	902
Electricity, 18000 km, (518 DKK/MWh)	1554	1332	1332	1036	1036

Figure 21: the private ownership model

6.3.4 Resulting cost comparison

The leasing companies subsidize the cost of the vehicle, but charge high monthly prices. They favour the business market who have high milage. While the cost of a car in private ownership is more expensive in real terms, it is cheaper in the long run. Therefore, a new approach might be co-opertiv e ownership

6.4 The co-ownership model and institutional bindings

The third scenario is one where the Samsø institutional and organizational structure is incorporated as much as possible and additional public regulation is introduced. In the socio-economic analysis, the benefit of displacing CO2 emissions and saving a lot of money on fuel was identified. This section uses a co-operative model to try and evaluate public regulation such as CO2 tax breaks for renewable energy co-operatives. The cost of chargers is also evaluated, namely should it be paid for by the customer, the co-operative, or the municipality?

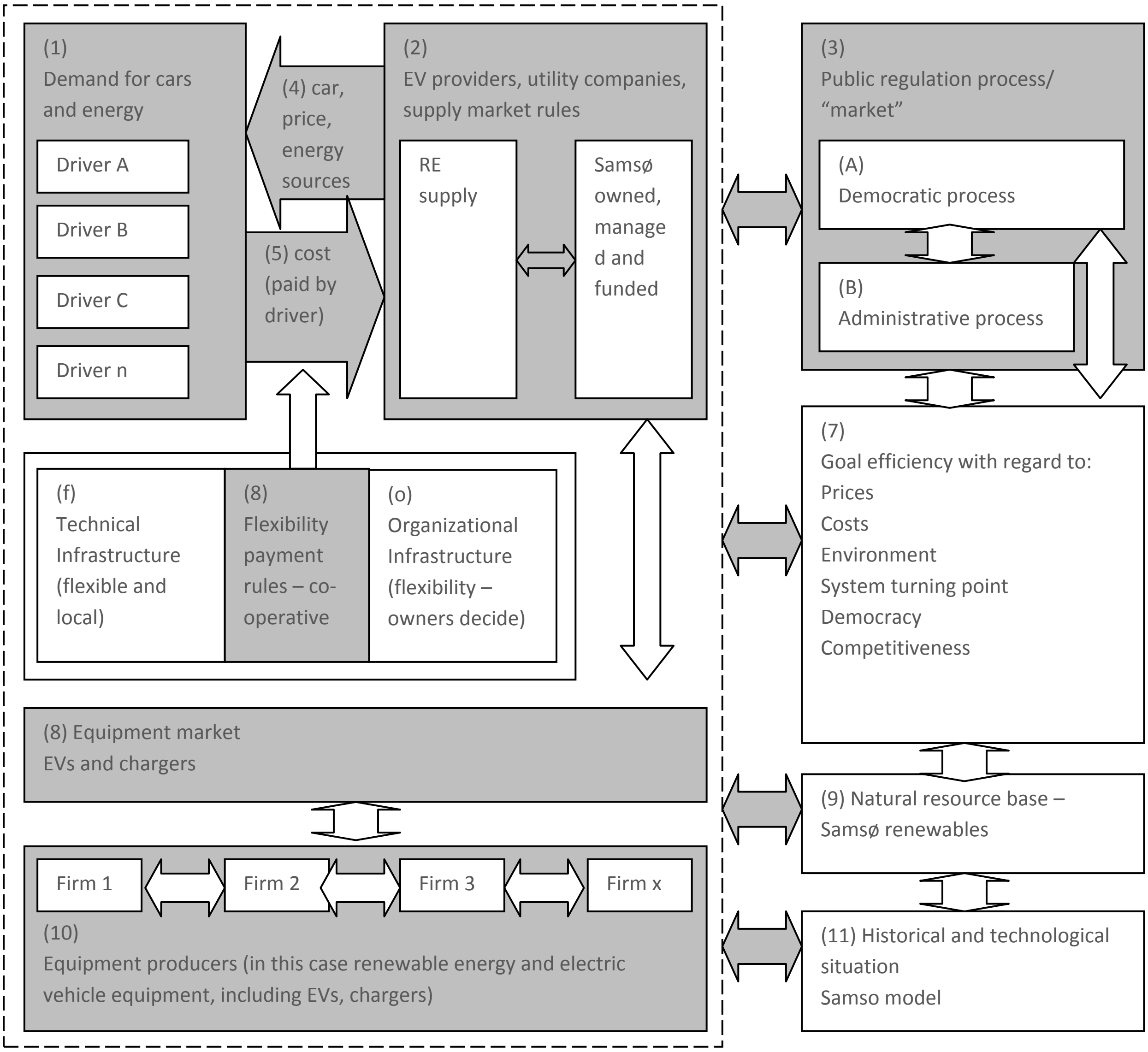

Figure 22: Macrostructure for Samsø. Based on (Hvelplund 2001)

Figure 22 represents a macro structure for EVs on Samsø. It represents the different areas of the system, including equipment such as the car and for the energy system, the money flows, the energy flows, the institutions involved in the energy system, etc. It is just as relevant for non Samsø EVs.

On the right side, outside the dashed line, is the public regulation process, the goals to be achieved by the radical technological change, and the historical and technological situation, as well as the natural resource base. In this case it is a feasible implementation model for EVs.

In the top left quarter of the figure, boxes (1) and (2) represent the market for EVs and energy that consumers face. Having an energy co-operative means they can have the energy at the best cost, and receive any profit. They may also be able to use public chargers from the municipality.

The equipment market is represented by box (8). Equipment includes energy equipment, chargers, and EVs. They come from outside Samsø, but are purchased to build the energy system.

Technical and organizational infrastructure and the payment rules determined by flexibility, as they impact the market between consumer and supplier, are represented by boxes (6), (f) and (o). This can represent the changing price of the renewable energy supply. Since Samsø residents own their energy supply, this is flexible for them.

6.5 On the potential for car sharing

Another option for reducing car cost would be carsharing. The co-operative owns the chargers, and a starter number of cars which islanders can rent out. As research shows that car-sharing is effective in making households give up a second car (because it is cheaper to rent from a car share than to put a lot of money in sunk costs in a second car), the starter number of cars is taken to aim for the number of second cars. There are 1415 families with a vehicle on the island, 1213 of which have just one vehicle, 185 have two, and 17 have three (Danmarks Statistik 2011). Just those 17 families would represent 34 vehicles and with the 185 second cars would represent a total of 219 cars.

Optionally it has a purchase agreement for electricity from the Samsø Energy Company, known as a bilateral agreement. It is assumed that the price for that is on average lower than the utility company's.

6.6 Other public regulation options

A report by EnergiNorge, the Norwegian Electricity Industry Association with about 270 members, convened by the Ministry of Transport and Communications and chaired by EnergiNorge, in collaboration with other Norwegian actors (business, civil, public, etc), proposes the following financial measures for electric cars in Norway (EnergiNorge 2009):

- State grant of NOK 100 million for building charging points not in residential houses (EnergiNorge 2009)
- New fee system to make electric cars attractive in 2011 budget (EnergiNorge 2009)
- NOK 30000/ per car for any purchase of N1 and M1 electric or rechargeable hybrid cars and delivery vans until 50000 such vehicles in Norway (EnergiNorge 2009)
- Alternatively, support for battery with energy density over 70Wt/kg of NOK 1.8 per Wt (EnergiNorge 2009)
- VAT accounting on leasing electric cars to be the same as for delivery vans (Class 2), for both companies and municipalities (check what is meant by compensation). (EnergiNorge 2009)
- Reduction of taxable basis for electric company cars: 75% off (currently 50%) (EnergiNorge 2009)
- VAT rate of 0% for battery replacement and other maintenance of rechargeable cars connected with batteries. (EnergiNorge 2009)

- Rechargeable cars to be written off after one year, making them attractive for companies. (less tax?) (EnergiNorge 2009)

6.7 Partial conclusions:

The co-operative model seems to show promise with public regulation. However, more work must be done.

Conclusion

Starting from the successful implementation of renewable energy supply in Samsø, and taking inspiration from Norway, in light of a number of car models coming to market, this project asked if electric cars could be feasible in a 100% renewable energy system like Samsø's.

A number of different car models on or coming to market in Denmark were evaluated and compared for their performance in the energy system. The findings were that they not only displaced fossil fuels on the island, but integrated renewable energy further on the island, in keeping with the idea of the original Samsø project. However, this project was able to rank the cars according to their performance and determine that battery chemistry and car efficiency were of direct consequence to the energy capacity needed and the quantity of emissions foregone. Mileage driven and battery wear and tear also were a big issue in planning.

The technical findings were evaluated with a socio-economic methodology to see what the cost to society of implementation might be. Cost of equipment and maintenance were found to be the highest. However, CO2 and fossil fuel displacement were a positive balance.

From this, it was determined that private ownership and leasing are expensive. Private ownership means high purchase costs at the start, leasing means high monthly subscriptions which cost more in the long run. A third solution was put forward, that of an co-operative, where the members benefit from ownership of the energy system, keep costs down because producing locally, and produce just what they want, while at the same time enjoying the benefits listed about.

What lessons can be drawn? That planning for cars is necessary, and that public regulation could be put to good and fair use if it focused on helping democratic businesses such as co-operatives. Energy planning is not just a matter for large scale national companies. Municipalities, by Danish law, have energy planning responsibilities. They must be able to come up with alternatives to bigger players.

Therefore, perhaps a model like the on of the Norwegian Transnova for instance fills just such a role there. Secondly small measures could make a big difference, as the more integrated a co-operative energy business, the more solid.

Bibliography

Angioni, Giovanni. *Estonia – Mitsubishi Deal: a Good Use of Unused Carbon Dioxide Credits.* March 4th, 2011. http://www.estonianfreepress.com/2011/03/estonia-mitsubishi-deal-a-good-use-of-unused-carbon-dioxide-credits/ (accessed March 9th, 2011).

Autoblog, Green. *Will Israeli military be a Better Place?* February 14, 2009. http://green.autoblog.com/2009/02/14/will-israeli-military-be-a-better-place/ (accessed June 5, 2011).

Beck, Leonard J. *V2G - 101.* Newark, DE, 2009.

Better Place. "Better Place Denmark Names Johnny Hansen as CEO." *Better Place.* March 1st, 2011. http://www.betterplace.com/the-company-pressroom-pressreleases-detail/index/id/better-place-denmark-names-johnny-hansen-as-ceo (accessed March 21st, 2011).

Better Place Denmark. *Better Place Abonnementer.* 2011. http://danmark.betterplace.com/elbil-til-dig/better-place-abonnementer/ (accessed June 5, 2011).

Better Place. *Meet our team: Moshe Kaplinsky.* http://www.betterplace.com/the-company-leadership-detail/index/id/moshe-kaplinsky (accessed June 5, 2011).

Bjørn, Claus. *Co-operation in Denmark - Past and Present.* Danske Andelsselskaber, 1988.

Bornholm Municipality. *Case: Elbiler på vindkraft.* http://www.brk.dk/bornholm/site.aspx?p=815 (accessed April 09, 2011).

Borochkov, Rivka. *Today's Defence - Israel under the dashboard.* may 8, 2011. http://todaysdefense.com/?p=1406 (accessed June 5, 2011).

Boyce. *Co-operative structures in global business: A new approach to Networks, Technology transfer Agreements, Strategic Alliances and Agency Relationships.* Routledge, 2000.

Business Wire. "Better Place and Renault Launch Fluence Z.E., the First "Unlimited Mileage" Electric Car Together with Innovative eMobility Packages, in Europe's First Better Place Center." *www.businesswire.com.* March 2011. http://www.businesswire.com/news/home/20110303005669/en/Place-Renault-Launch-Fluence-Z.E.-%E2%80%9CUnlimited-Mileage%E2%80%9D (accessed March 2011).

—. "Better Place and Renault Launch Fluence Z.E., the First “Unlimited Mileage” Electric Car Together with Innovative eMobility Packages, in Europe’s First Better Place Center." *Business Wire (A Berkshire Hathaway company).* March 03, 2011. http://www.businesswire.com/news/home/20110303005669/en/Place-Renault-Launch-Fluence-Z.E.-%E2%80%9CUnlimited-Mileage%E2%80%9D (accessed March 21st, 2011).

Chambers, Nick. *Same Electric Car + Different Brands = $18,000 Price Difference?* March 16, 2010. http://gas2.org/2010/03/16/same-electric-car-different-brands-18000-price-difference/ (accessed June 04, 2011).

Citroen. *Zero Carbon Horizon - 100% electrisk C Zero Beskrivelse.* http://www.electric.citroen.com/#/dk/mit-liv-med-c-zero/mavie_car/100-elektrisk (accessed June 4, 2011).

Coate, Jim. *"Electric Tractors", published in "The Natural Farmer".* 2003. http://www.eeevee.com/tractors/TNF_article.html (accessed March 4, 2011).

Cowan, Robin, and Staffan Hulten. "The Electric Vehicle: A Problem of Entrenchment or of Technological Impossibility?" In *Electric Vehicles. Socio-economic prospects and technological challenges.*, by Robin Cowan and Staffan Hulten, 1-20. Aldershot: Ashgate, 2000.

Dahlbom, Caroline. *Transnova - for bærekraftig mobilitet. Elbil som transportløsning i boligområder.* February 3, 2011. http://www.transnova.no/project/elbil-som-transportl%C3%B8sning-i-boligomrader (accessed June 04, 2011).

Danish Association of Engineers. "IDA 2050 Climate Plan." 2010. http://ida.dk/sites/climate/Documents/Klima%20Hovedrapport%20UK%20-%20WEB.pdf (accessed March 2011).

Danish Energy Industries Federation. Partnership for intelligent energy systems. *Intelligent Energy Systems. A White Paper with Danish Perspectives.* White Paper, Copenhagen: Ea Energy Analyses, 2010.

Danmarks Statistik. *Transport.* March 15th, 2011. http://www.statistikbanken.dk/BIL11 (accessed March 15th, 2011).

Dansk Elbil Komite. *Elbil Salg.* 2009. http://www.danskelbilkomite.dk/Elbil_salg.htm (accessed April 1, 2011).

—. *Prøvekørsel av Mitsubishi i-MiEV (Per Praem).* http://www.danskelbilkomite.dk/imievtest4.htm (accessed May 7th, 2011).

DB. *Electric Cars and the magic date of 2015.* February 23, 2011. http://dieoffdebunked.blogspot.com/2011/02/electric-cars-and-magic-date-of-2015.html (accessed May 12th, 2011).

DONG Energy. *About us: Our Vision.* 2011. http://www.dongenergy.com/EN/About%20us/dong%20energy%20in%20brief/Pages/our%20vision.aspx (accessed May 25, 2011).

eCars - Now! *eCars - Now!* http://ecars-now.wikidot.com/ (accessed April 9th, 2011).

EcoCities. *Environmental zones and green technology equals cleaner air and less polluting cars.* http://energibyer.dk/en-US/InspirationalCases/Transport/Sider/TrafficSolutions.aspx (accessed April 09th, 2011).

Energiakademi, PlanEnergi and Samsø. *Samsø. A renewable energy island. 10 years of development and evaluation.* PlanEnergi and Samsø Energiakademi, 2007.

EnergiNorge. "Action Plan for Electrification of Road Transport." *Energi Norge.* July 8th, 2009. http://www.energinorge.no/publications-in-english/action-plan-for-electrification-of-road-transport-article7309-444.html (accessed April 09, 2011).

Energistyrelsen (DEA). "Socio-economic assumptions." *Danish Energy Agency.* 2010. http://www.ens.dk/en-US/Info/FactsAndFigures/scenarios/assumptions/Sider/Forside.aspx (accessed June 2, 2011).

Energistyrelsen. "Forsøgsordningen for elbiler - I perioden 2008-2012 giver Energistyrelsen tilskud på i alt 35. mio. kr. til forsøg med elbiler." *energistyrelsen.dk.* July 13, 2009. http://www.ens.dk/Documents/Faktaark/elbiler%20130709.pdf (accessed March 14th, 2011).

European Commission. *Models and generic interfaces for easy and safe Battery insertion and removal in electric vehicles (EASYBAT).* January 18, 2011. http://cordis.europa.eu/fetch?CALLER=FP7_PROJ_EN&ACTION=D&DOC=6&CAT=PROJ&QUERY=012db0fa4c34:5429:5754f83e&RCN=97743 (accessed March 9th, 2011).

Flyvbjerg, Bent. "Five Misunderstandings About Case Study Research." *Qualitative Enquiry* 12, no. 2 (April 2006): 219-245.

—. *Five Misunderstandings about Case-Study Research.* Aalborg: Aalborg University, 2004.

General Motors. "GM US Deliveries for April 2011." *media.gm.com.* 2011. http://media.gm.com/content/Pages/news/us/en/2011/May/0503_gmsales/_jcr_content/rightpar/sectioncontainer/par/download/file.res/Deliveries%20April%202011.pdf (accessed May 12th, 2011).

Globes. "October 2011 Israeli debut for electric Renault." *Globes.* http://www.globes.co.il/serveen/globes/docview.asp?did=1000606775&fid=1725 (accessed March 2011).

Green Autoblog. *What is EVSE? It's Electric Vehicle Supply Equipment, and here's what it's all about.* November 1st, 2010. http://green.autoblog.com/2010/11/01/what-is-evse-its-electric-vehicle-supply-equipment-and-heres/ (accessed April 20th, 2011).

Grønn Bil. "Ladbare biler og ladestasjoner i Norge." *Grønn Bil.* 2009. http://www.gronnbil.no/elbilkartet (accessed March 24th, 2011).

GSAS Alliance for Justice in the Middle East (AJME), a student group at Harvard University. *War Criminals at Harvard - Moshe Kaplinsky.* http://harvardwarcriminals.blogspot.com/2007/05/moshe-kaplinsky.html (accessed June 5, 2011).

Hannisdahl, Ole Henrik, interview by Pascale Blyth. *Project Manager, Grønn Bil* (May 6th, 2011).

Hård, Mikael, and Andreas Knie. "Getting out of the vicious traffic circle." In *Electric Vehicles: Socio-economic propects and technological challenges*, by Robin Cowan and Steffan Hultén, 21-28. Aldershot: Ashgate, 2000.

Hayes, Scott. *SA Car Fan.* March 11, 2011. http://sacarfan.co.za/2011/03/first-drive-renault-fluence/ (accessed May 12, 2011).

Hvelplund, Frede. *Erkendelse og forandring. Teorier om adækvat erkendelse og teknologisk forandring med energieksempler fra 1974-2001.* Aalborg University, 2005.

—. *Renewable Energy Governance Systems.* Aalborg: Aalborg Universitet, 2001.

Hvelplund, Frede, and Henrik Lund. *Feasibility Studies and Public Regulation in a Market Economy.* Aalborg: Aalborg University, 1998.

Iceland News. "Interview: Iceland and the electric car. Sturla Sighvatsson of Northern Lights Energy explains the 2012 initative. (PART 1)." *Iceland News.* December 13th, 2009. http://www.icelandnewsonline.net/2009/12/13/interivew-northern-lights-md-talks-to-iceland-news-about-icelands-future-with-the-electric-car-1/ (accessed April 09, 2011).

—. "Interview: Iceland and the electric car. Sturla Sighvatsson of Northern Lights Energy explains the 2012 initative. (PART 2)." *Iceland News.* January 9th, 2009. http://www.icelandnewsonline.net/2010/01/09/interview-iceland-and-the-electric-car-sturla-sighvatsson-of-northern-lights-energy-explains-the-2012-initative-2/ (accessed April 9th, 2011).

Loewenstein, Anthony. *Australian green company linked to Israel's occupation in palestine.* 2010. http://antonyloewenstein.com/2010/06/16/australian-green-company-linked-to-israels-occupation-in-palestine/ (accessed June 5, 2011).

Loveday, Eric. *UK electric truck maker Modec to cease operations.* April 30th, 2011. http://green.autoblog.com/2011/04/30/uk-electric-truck-maker-modec-to-cease-operations/ (accessed May 11th, 2011).

Lund, Henrik. *Renewable Energy Systems: The Choice and Modelling of 100% Renewable Solutions.* Burlington, San Diego, London: Elsevier, 2010.

Lund, Henrik. "The Kyoto Mechanisms and Technological Innovation." *Energy* (Elsevier) 31, no. 13 (2006): 2325.

Lund, Henrik, and Willett Kempton. "Integration of renewable energy into the transport and electricity sectors through V2G." *Energy Policy* Volume 36, no. Issue 9 (2008).

Maegaard, Preben. "Lecture, Aalborg University." March 11, 2011.

Mathiesen, Brian Vad. *Analysis of Power Balancing with Fuel Cells and Hydrogen Production in Denmark.* Project Report, Aalborg: Aalborg University, 2009.

Mathiesen, Brian Vad, Henrik Lund, and Per Nørgaard. "Integrating transport and renewable energy systems." *Utilities Policy* (Elsevier Science) 16 (2008): 107-116.

Miljøverndepartementet. *St.meld. nr. 34 (2006-2007), Norsk Klimapolitikk, Tilråding fra Miljøverndepartementet av 22. juni 2007, godkjent i statsråd samme dag. (Regjeringen Stoltenberg II).* June 22, 2007. http://www.regjeringen.no/nn/dep/md/dok/regpubl/stmeld/2006-2007/Stmeld-nr-34-2006-2007-.html?id=473411 (accessed May 25, 2011).

Møller, Peter Jørgensen. May 16th, 2011.

Mueller, Jens. "Making ends meet - local socio-technological transformations in the South." Paper for FAU Conference, Workshop 5, CBS, Copenhagen, Department of Planning and Development, Aalborg University, Copenhagen, 2007.

Nissan. *Nissan LEAF autonomy and charging.* http://media.nissan.ru/GB/en/inside-nissan/innovation-and-technology/autonomy.html (accessed May 8th, 2011).

NRGi. *Private communication.* February 2011.

Orecchini, Fabio, and Adriano Santiangeli. "Automakers' Powertrain Options for Hybrid and Electric Vehicles." In *Electric and Hybrid Vehicles. Power Sources, Models, Sustainability, Infrastructure and the Market*, by Gianfranco Pistoia, 579-636. Oxford: Elsevier, 2010.

Pearre, Nathaniel. April 28, 2011.

Pearre, Nathaniel S., Willett Kempton, Randall L. Guensler, and Vetri V. Elango. "Electric vehicles: How much range is required for a day's driving?" *Transportation Research* Part C (2011).

Peugeot. *Peugeot iOn.* http://www.peugeot.co.uk/vehicles/peugeot-car-range/peugeot-ion/ (accessed June 4, 2011).

Pure Mobility. "Buddy Teknisk Info." *Pure Mobility (puremobility.com).* 2010. http://www.puremobility.com/no/buddy/teknisk-info (accessed March 24th, 2011).

Rand, David Anthony James, R Woods, and Ronald M. Dell. *Batteries for electric vehicles.* Taunton: Research Studies Press Ltd, 1998.

Renault. *Renault Fluence.* http://www.renault.com/en/vehicules/renault/pages/fluence.aspx (accessed May 14th, 2011).

—. *Renault Fluence Z.E.* 2011. http://www.renault.com/en/vehicules/renault/pages/fluence-ze.aspx (accessed May 7th, 2011).

Samsø - the green island. Transportation. When idealism meets reality. http://samsoe.wordpress.com/topic-4/ (accessed March 2nd, 2011).

Savov, Vlad. *Nissan Leaf launches in Europe, takes us for a drive.* October 26th, 2010. http://www.engadget.com/2010/10/26/nissan-leaf-launches-in-europe-takes-us-for-a-drive/ (accessed May 8th, 2011).

Scheer, Hermann. *Energiautonomi - En ny politik for vedvarende energi.* Antje Kunstman GmbH (Muenchen), Hovedland (Danish publisher, 2006), 2005.

Schwartz, Nelson D. *In Denmark, Ambitious Plan for Electric Cars.* December 1, 2009. http://www.nytimes.com/2009/12/02/business/energy-environment/02electric.html (accessed May 25, 2011).

Singer, Clifford E. *Energy and International War. From Babylon to Baghdad and Beyond.* Vols. World Scientific Series on Energy and Resource Economics - Vol. 6. Singapore: World Scientific Publishing Co. Pte Ltd., 2008.

Skogstadt, Knut. *Norge blir en bitteliten mygg i forhold.* May 09, 2010. http://www.tv2underholdning.no/broom/norge-blir-en-bitteliten-mygg-i-forhold-3224098.html (accessed May 15, 2011).

The Copenhagen Post. *Renault threatens electric car withdrawal.* January 22nd, 2010. http://www.cphpost.dk/business/119-business/48036-renault-threatens-electric-car-withdrawal.html (accessed April 9th, 2011).

THINK Norway. *Charging, THINK City.* http://www.think.no/nor/THINK-City/Lading (accessed March 15th, 2011).

—. *Kampanjetilbud.* http://www.think.no/nor/Velkommen-til-THINK-dager/Kampanjetilbud (accessed March 30th, 2011).

THINK. "THINK City Tekniske data." *THINK.* http://www.think.no/nor/THINK-City/Spesifikasjoner/Tekniske-data (accessed March 24th, 2011).

Transnova. "Forslag til mandat for Transnova- prosjektet." *Transnova.* 09 2010. http://www.transnova.no/wp-content/uploads/2010/09/Transnovas-mandat.pdf (accessed May 12th, 2011).

Ungerleider, Neal. *Better Place and Renault Delivering 115,000 Electric Cars in 2011.* December 14th, 2010. http://www.fastcompany.com/1709616/better-place-teams-up-with-renault (accessed May 24, 2011).

US Department of Energy. *Consumer Energy Tax Incentives.* http://www.energy.gov/taxbreaks.htm (accessed May 25, 2011).

—. *State Incentives and Laws.* http://www.afdc.energy.gov/afdc/laws/state (accessed May 25, 2011).

Vad Mathiesen, Brian. "Notat vedr. samfundsøkonomiske effekter af indførsel af elbiler." *Mandad Morgen.* Aalborg: Departement of Planning and Development, April 03, 2008.

Van den Bossche, Peter, Julien Matheys, and Joeri Van Mierlo. "Battery Environmental Analysis." In *Electric and Hybrid Vehicles. Power Sources, Models, Sustainability, Infrastructure and the Market*, by Gianfranco Pistoia, 347-374. Amsterdam, Oxford: Elsevier, 2010.

Warner, Geraldine. *"Electric-tractor maker gears up" on Good Fruit Grower.* December 2010. http://www.goodfruit.com/Good-Fruit-Grower/December-2010/Electric-tractor-maker-gears-up/ (accessed March 4, 2011).

Wikipedia. *Capacity factor.* 2011. http://en.wikipedia.org/wiki/Capacity_factor (accessed May 27, 2011).

—. *Chevrolet Volt.* http://en.wikipedia.org/wiki/Chevrolet_Volt (accessed May 12th, 2011).

—. *Drive-train.* http://en.wikipedia.org/wiki/Drive-train (accessed March 15th, 2011).

—. *Electric car use by country.* http://en.wikipedia.org/wiki/Electric_car_use_by_country#cite_note-finnexpo-8 (accessed April 9th, 2011).

—. *Nissan Leaf.* http://en.wikipedia.org/wiki/Nissan_Leaf (accessed May 8th, 2011).

Willis, Scott. *Better Place, DONG Energy close funding for Denmark electric car network.* January 27, 2009. http://www.copenhagenclimatecouncil.com/get-informed/news/better-place-dong-energy-close-funding-for-denmark-electric-car-network.html (accessed May 25, 2011).

World Health Organization. *Violence and Injuries Prevention, Road Traffic.* 2011. http://www.who.int/violence_injury_prevention/road_traffic/en/ (accessed June 4, 2011).

www.skat.dk. *SKAT: Motor og nummerplader.* 2011. http://www.skat.dk/skat.aspx?oId=166038 (accessed May 25, 2011).

Abbreviations

DEA	Danish Energy Authority ("Energistyrelsen" in Danish)
NEDC	New European Driving Cycle
NiMH	Nickel Metal Hydride (a battery chemistry)
NiCd	Nickel Cadmium (a battery chemistry)
Li-ion	Lithium Ion(a battery chemistry)
NaNiCl	Salt (a battery chemistry for molten salt batteries)