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Preparing for the Roll-Out of Electric Vehicles

Exploring how cities can become plug-in ready

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Acknowledgements

I thought about these acknowledgements while standing at the Swedish coast between Lomma and Bjärred. It turned out to be quite a good setting for that: On the right side the decommissioned nuclear power plant Barsebäck, on the left side Malmö, one of my case studies, with the "Turning Torso" in the foreground and the Öresund bridge in the back. Some ships are crossing, a plane is approaching Copenhagen Airport, there is a train on the bridge and, of course, cars. I lean against my road-bike thinking about transportation and electric cars ...

"... they are really clean in Sweden with all the hydro power and nuclear energy. Maybe they should get a discount when crossing the Öresund bridge to make them more attractive. Oh, my thoughts are drifting away. Back to the acknowledgements and whom to thank for all the help and support during the thesis process and during two fantastic years of studying in Lund …

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So, whom did I forget? I hope, nobody." The sun is low and it starts to get cold. I get on my bike again and cycle back to Lund to write down what I have just written.

Abstract

The mass production of plug-in electric vehicles (PEVs) is expected to start in the coming years. Climate change, peak oil and the automotive and economic crisis have put a significant pressure on the current transportation regime. Increasing urbanisation, range and efficiency advantages of PEVs in city traffic and the problem of urban air pollution have moved cities into the focus of PEV dissemination. Three case studies were conducted in this research to analyse the functioning of PEV systems in cities. Different functions like knowledge development, market formation and resource mobilization are analysed and discussed. The main critical issues around PEVs like range, cost, and environmental performance are investigated in a city context, and corresponding recommendations for cities to become plug-in ready are outlined.

Key words: electric vehicles, sustainable transport, Aachen, Denver, Malmö

Executive Summary

There is increasing interest in the electric vehicle (EV). All major automakers have plans to roll-out new battery electric vehicles (BEVs) or plug-in hybrid electric vehicles (PHEVs) within the next five years. The first mass-produced electric cars will enter selected markets at the end of 2010. The EV growth comes at a time when the transportation sector faces major environmental challenges: peak oil, climate change and air pollution. In addition to environmental crises, the economic crisis hit the car industry in 2008, causing decreasing car sales and the exploration of new business fields. Furthermore, the crisis in the automotive industry triggered economic stimulus, of which substantial parts are directed towards the electrification of cars. Although these environmental, economic and political issues have given new momentum for the dissemination of EVs, there is still a lot of uncertainty around the technology.

Current research puts the focus on technological feasibility, economic viability and environmental desirability of EVs and often takes the form of vague predictions, scenarios and ex-ante evaluations. Therefore, science conveys a message of uncertainty to decision-makers in business and politics, and via the media to potential customers. Will the range be sufficient? Are EVs sufficiently safe? Will alternative business models work? Is political support necessary? And are EVs really green? In order to reduce uncertainty, practical experience with EVs is required. Show cases with EVs actually driving on the streets are needed to foster the legitimation of the technology.

At the core of this research are three case studies: Malmö, Sweden; Aachen, Germany; and Denver, Colorado. These cases are used to shed light on the current practice of cities dealing with EVs. While the focus is on cities and their EV activities, it is necessary to understand national and state level policies and the structure of the energy systems first, to put findings from case studies into a context.

Sweden does not have an explicit EV strategy and does not subsidise the purchase of EVs. Some incentives are given through a differential in fuel taxes and in annual car taxes. CO_2 emissions are regulated by an EU standard (130g/km). Electricity production in Sweden is mainly based on nuclear power (40%) and hydro power (45%) and causes the lowest CO_2 emissions in Europe (40 g/kWh). Nearly 100% of all oil that is used for transportation is imported. The German context is very similar. There are two main differences. First, Germany has a dedicated EV strategy with a goal of one million EVs by 2020 and an extensive program for demonstration and pilot projects ("Model Regions for Electric

Background on Electric Vehicles (EVs)

In this study the term EV means vehicles that are used for on-street passenger transport, that can be plugged in and that can drive on electricity only. This includes both purely electric cars and plug-in hybrid electric cars, as well as electric buses and electric scooters.

Batteries for EVs have a low energy density compared to petroleum and make up most of the additional costs of EVs. The energy density of batteries will not suddenly improve in the coming years but the price per kWh battery capacity can be expected to fall significantly. Safety concerns about highly reactive lithium in EV batteries and about the quietness of slowly driving EVs cannot be substantiated. The life-cycle GHG emissions of EVs depend on the electricity mix and can be as high as emissions of highly efficient combustion engine vehicles (CEVs) if electricity production is mainly based on coal. But calculations with cleaner electricity grids show that EVs have an enormous potential for emission reductions. There are not many reasons to assume a risk that oil dependence is simply replaced by a dependence on lithium, since lithium reserves are abundant and high lithium recycling rates can be reached.

Mobility"). Second, electricity production causes higher CO_2 emissions with an average of 575 g/kWh. Electricity from renewable energy sources has a share of about 16%. The context of the case study in Denver differs from the European context. The purchase of EVs in Colorado is subsidised by means of a federal tax credit (up to $7,500) and a state tax credit (up to $6,000). Subsidies and the large build-up of infrastructure are two measures to reach the U.S. target of 1 million EVs by 2015. Apart from that conditions in Colorado are not favourable for EVs: taxes on gasoline and diesel are low, there are no strict emission standards (155 g/km for model years 2012-2016), and electricity production is mainly based on coal (776 g/kWh).

Projects on EVs in the Case Studies

Malmö

- *E-Mobility* (City of Malmö and E.ON Nordic, 3 years, €4 million, 70 PEVs, 60 two-wheelers, 250 charging points)
- *Plug-In City* (City of Malmö, European Development Fund, 3 years, charging infrastructure and feasibility demonstration)

Aachen

- *Smart Wheels* (FEV Motorentechnik, STAWAG and others, 3 years, pilot with focus on ICTs, 12 BEVs, 20 scooters, 1 bus)
- *E-Aix* (STAWAG, RWTH and others, 3 years, €6 million, realization of a comprehensive electric traffic concept)

Denver

- *Project Get Ready* (City of Denver, Rocky Mountain Institute and others, no budget, readiness for EV roll-out)

Despite EV favouring in all three countries, the functioning of the EV systems in Malmö, Aachen and Denver is very limited. The main reason is the deficient market formation. Some signs for an emerging market can be observed in the Denver area where a couple of EV dealerships and conversion shops supply high priced vehicles to early adopters. The EV demand in the three cities is difficult to assess in the absence of supply. But opinion polls show that there is a high interest in EVs and a general acceptance of EV technology and their environmental performance. Beyond the unavailability of electric cars, insufficient mobilization of resources is another major constraint. Both in Malmö and Aachen EV demonstration projects are run for which the project consortia received public funding. Denver was not successful in applying for financial resources so that all expenses for EV activities have to be met from the narrow general budget of the city. But not just financial resources are critical for the progress of an EV system but also human resources. Both in Denver and Aachen various research institutes deal with EV technology or deployment. These institutes help creating a local knowledge base. Furthermore, people who leave these research institutes bring their know-how to innovative companies and therein stimulate the entrepreneurial experimentation with technology, applications and business models.

The knowledge base and entrepreneurial activity are important to start EV projects and to mobilize the human resources to deal with issues like EV maintenance and infrastructure installation. But further incentives are necessary to attract private EV drivers. The city governments of Malmö, Aachen and Denver are all active to create conditions that signal EV-readiness. A common element is the installation of public charging stations. Additionally, Aachen works together with its local public utility STAWAG to introduce electric two-wheelers, which are already available on the market. The electricity at STAWAG charging stations is free and the purchase of electric scooters and bikes is subsidised. In Malmö the initial focus is on the electrification of fleets and the establishment of successful show cases. Furthermore the city looks into concepts to integrate EVs in a more comprehensive sustainable transport system. Due to a lack of financial resources, the City of Denver has a less resource-intensive approach and prepares for the first private EV drivers by simplifying permitting for home charging equipment and identifying locations for public charging points.

The group of actors that are involved in EV projects includes in all three case studies city governments and power utilities. Furthermore, research institutes, specialised companies and mobility providers are members of the project teams. None of the EV projects collaborates with a large company from the automotive sector. This is a major drawback in terms of car availability, know-how and financial resources. Many of the actors are organised in networks, i.e. working groups, industry associations and adviser teams.

The analysis of the three case studies showed that there are still some critical issues around range anxiety, high EV prices and the environmental performance of EVs that are difficult to address in a city context. The uncertainty around these issues is the basis for the first recommendation resulting from this research:

Assure planning security for the stakeholders who are involved.

The combination of range anxiety, the risk of empty public charging stations and the high significance of home charging results in the second recommendation:

Focus more on the vehicles than on the charging infrastructure.

In order to address the environmental performance of EVs in comparison with public transport and other low-impact forms of transportation, a third recommendation should be considered:

Make EVs part of a comprehensive transportation strategy (including car-pooling, public transport integration and alternative business models around EVs).

Integrated transportation systems can also help to deal with high vehicle costs by making the EV use-phase more efficient. In order to trigger entrepreneurial activity and market formation and, as a side effect, create employment opportunities, cities have to become attractive locations for EV businesses. The final recommendation is therefore:

Create favourable conditions for investments in the EV sector.

It will take time until EVs have a significant share of transportation in cities. This means most of the benefits of today's efforts will take effect in the future. The implication should not be to reduce activity but to remain ambitious.

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Abbreviations

BEV	Battery electric vehicle
CAFE	Corporate average fuel economy (standard)
CEV	Combustion engine vehicle
CNG	Compressed natural gas
DOE	U.S. Department of Energy
EC	European Commission
EDF	European Development Fund
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
GHG	Greenhouse gas
HEV	Hybrid electric vehicle
HOV	High occupancy vehicle
ICT	Information and communication technology
Li-Ion	Lithium-Ion (battery)
NEV	Neighbourhood electric vehicle
NiMH	Nickel metal hydride (battery)
NOx	Nitrogen oxides
NRW	North Rhine-Westfalia
OEM	Original equipment manufacturer
PbA	Lead-acid (battery)
PEV	Plug-in electric vehicle (all BEVs, PHEVs and REVs)
PGR	Project Get Ready
PM	Particulate matters
PPP	Public-Private Partnership
PHEV	Plug-in hybrid electric vehicle
REE	Rare earth element
REV	Range extended electric vehicle
RMI	Rocky Mountain Institute
TIS	Technical Innovation System
ZEUS	Zero and Low Emission Vehicles in Urban Society (EC Project)
ZEV	Zero Emission Vehicle

1 Introduction

This research project deals with electric vehicles (EVs), more precisely with EVs in cities. The use of EVs for passenger transport started about 120 years ago. Despite its long history the EV is still perceived as an innovation, as a car with potential. In order to tap this potential the system around electric cars has to be understood and developed. The main purpose of this thesis is to find out what exactly is the potential of EVs and how can it be utilised in practice.

1.1 Background

Three different aspects are important to understand the background of this study: environmental challenges in the transportation sector, the significance of urban areas in the environmental context and the socio-technical development of electric vehicles.

Environmental challenges in the transportation sector are mainly caused by its dependence on fossil fuels. Extensive use of oil causes two major environmental problems. First, the combustion of hydrocarbons results in CO_2 emissions that are the main cause of climate change. Transportation is responsible for about one quarter of global greenhouse gas (GHG) emissions (Kahn Ribeiro & Kobayashi, 2007, p. 328). Second, crude oil is a non-renewable resource. The depletion of fossil fuel stocks is irreversible on a human time-scale and will impact current and future generations. The latest Peak Oil research finds it very likely that Peak Oil will occur before 2030 (Sorrell et al., 2009, p. 171). Furthermore, motorized transport causes several local emissions, like noise, smell, particulate matters (PM), hydrocarbons and nitrogen oxides (NOx) (see U.S. Environmental Protection Agency, 1994). These emissions impact human health and well-being most severely in densely populated areas.

Accordingly, local emissions are the first argument for the significance of urban areas in the context of environmental impacts of transportation. Mega-cities like London, Beijing, Mexico City or Los Angeles suffer severe air pollution. There are two reasons why the number of people affected by air pollution that is caused by transportation will increase. First, urbanization is very likely to proceed. According to the United Nations 2008 was the first year when more than half of the world's population lived in urban areas, 3.3 billion people. This number is expected to increase to almost five billion by 2030 (United Nations Population Fund, 2007, p. 1). In cities people are more exposed to the tailpipe emissions of buses, cars and scooters than in rural areas. Second, in many parts of the world the rate of motorization is still far below industrialized countries but rapidly increasing. In 2009 China became the world's largest market for cars (Yan & Subler, 2010).

In addition to the problem of local air pollution, large cities gain significance in the environmental context as they increasingly see themselves as independent political actors. The C40 Climate Leadership Group, an international association of large cities, drew media attention by making strong claims during the United Nations climate conference held in Copenhagen in 2009. The C40 group set up an own agenda for climate change mitigation and adaptation, including emission reduction commitments and action plans (see C40 Cities, 2009).

The third area that constitutes the background of this research is the socio-technical development of EVs. Advancements in battery technology, growing environmental awareness of consumers and changes in the geopolitical landscape have changed the status of EVs from being the perpetual promising alternative to a viable option for sustainable transport systems (Sonnenschein, 2010). Leading the way in EV technology and deployment creates market opportunities for both cities and countries that support this technology.

1.2 Problem Definition

While the basic EV technology dates back to the end of the 19th century, the actual start of large scale vehicle electrification is happening right now. Since 1997 Toyota has sold 2.68 million of its hybrid electric vehicle (HEV) Toyota Prius and plans to increase its yearly hybrid sales to one million (Kim, 2010). All major car manufacturers plan to produce HEVs, Plug-in hybrid electric vehicles (PHEV) or even pure battery electric vehicles (BEV) in the near future (Plug In America, 2010). Nissan is the first company that mass produces fully functional BEVs. Sales of the Nissan LEAF start on selected markets in late 2010 and more than 18,600 pre-orders have already been made (Loveday, 2010). The current developments in the area of EVs are very dynamic. Since both technological aspects and the political environment are undergoing drastic changes and there is no experience with a significant share of the vehicle fleet driving on electricity, big gaps exist in the research around EVs.

Before discussing the specific problem definition of this thesis, an overview of potential research areas is given. These are mainly organized around three aspects of EVs: technological feasibility, economic viability and environmental desirability. From a technological perspective battery performance and adequate charging infrastructure are the focus areas. But also the impact of plug-in EVs on the electricity grid becomes more and more important. How does the charging of thousands and millions of EVs affect the necessary peak capacity? Can the vehicle-to-grid (V2G) technology help to integrate higher shares of renewable energy into the grid?

When it comes to economic viability the potential economies of scale are one major research area. The price per kWh battery capacity has to drop significantly to make EVs more competitive. While upfront costs are considerably higher than for combustion engine vehicles (CEV) the fuel for EVs, electricity, is cheaper than diesel or gasoline. Therefore, the business model for marketing EVs is an important aspect. Car leasing, battery leasing and pay-as-you-drive solutions are some of the ways to spread higher car (battery) costs over a longer time period. But most likely a good business model alone will not be enough to make EVs attractive enough to compete on the free market. Political support instruments can help the initial dissemination of EVs until economies of scale kick in. Therefore, its is important to research multiple policies and their interconnections in different areas.

Research about environmental desirability is closely related to the debate about political interventions. One very contentious issue is the life-cycle impact of EVs as compared to efficient diesel cars or cars running on various biofuels. Much seems to depend on the development of the electricity mix and the integration of high shares of renewable energy. Another open question in the environmental context is whether EVs will break the dependence on crude oil by creating a new dependence on other materials such as lithium.

All research areas outlined above are relevant and need to be further developed for the EV to be successful, or to prove it a failure. But current research on technological feasibility, economic viability and environmental desirability often takes the form of vague predictions, scenarios and ex-ante evaluations. Therefore, science conveys a message of uncertainty to decision-makers in business and politics, and via the media to potential customers. Will the range be sufficient? Are EVs sufficiently safe? Will alternative business models work? Is political support necessary? And are EVs really green?

But in some places the first EV fleets are on the streets, infrastructure is installed and business models are running. Example cases are necessary to reduce uncertainties and show best practice. Currently, EV programs are few and mainly concentrate on cities where distances are short and comprehensive charging infrastructure is easier to install.

The reciprocal nature of the relationship between uncertainty and EV dissemination causes a vicious circle. Because of the uncertainty there are few EVs on the streets. And contrariwise there is much uncertainty because the practical experience with EVs is insufficient. There are two possible ways out that can be researched. The traditional approach is to reduce uncertainty by advancing technology, developing policy instruments and researching environmental impacts. An alternative way is to investigate how to further practical experience. The author of this thesis is convinced that research that focuses on the practical experience in EV programs is less advanced. Therefore, the problem that is addressed in this thesis is:

There are too few EVs on the streets that can serve as practical show cases to reduce the uncertainties around the EV as a viable option.

1.3 Research Objective and Questions

In order to address the problem that is outlined above the main objective of this research is to help improve existing EV projects and facilitate the start of new programs for introducing EVs. The intended outcome of this thesis is an improved understanding of the whole system around EVs in urban areas. This understanding helps to identify points of intervention and to formulate recommendations. The research objective is based on the assumption that the dissemination of EVs is beneficial from an environmental perspective. Despite all the uncertainty around EVs, scientific support for this assumption can be found (see section 3.4).

In order to facilitate EV dissemination the first step is to understand ongoing programs and existing systems around EVs in cities. Therefore, the first research question of this thesis is:

(1) What are the main elements of an EV system in cities?

The elements of an EV system are not just physical ones, like EVs and charging infrastructure, but also actors and networks that are involved, the relevant institutions and the measures that are already taken to support EVs. Furthermore, the context of EV systems in cities is important in order to better understand the functioning of the respective system.

Once understood, EV systems can be analysed in order to identify the most important factors for the dissemination of EVs. Accordingly the second main research question reads:

> *(2) What factors induce or constrain the dissemination of EVs in a city context?*

Again this research question has several aspects to it. In addition to identifying different factors as drivers or constraints, it is important to investigate at what level (local, regional, national, international) factors can be located that take effect at the city level. Furthermore, the interactions between different factors may be important for the functioning of the system.

Based on a thorough understanding of the relevant factors and their origin, leverage points can be identified and strategies can be developed. If this can be achieved there will be an answer to the third question that guides this research:

> *(3) What are the supportive interventions at the city level that can help the dissemination of EVs?*

The discussion of this question is based on the elements, drivers, constraints and interconnections that are identified in the earlier questions.

1.4 Scope

The subject of this study is the EV system in cities which is a very broad term. In order to make it researchable it has to be narrowed down. In anticipation of the analytical framework that is presented below, the categories for scoping are the spatial domain, product vs knowledge field, and breadth vs depth (Bergek et al., 2008, p. 411).

The geographical focus is on cities. There are no strict boundaries for this scope. For the case studies the surrounding (metropolitan) areas are also considered. Furthermore, the respective state level, national and international context are explained and taken into consideration in the analysis.

The focus is on the product "EV" and not on related knowledge fields like battery technology. The use of the term EV needs further explanation as it can mean different things. In this study EV means vehicles that are used for on-street passenger transport, that can be plugged in and that can drive on electricity only. This includes both purely electric cars and plug-in hybrid electric cars, as well as electric buses and electric scooters. The term EV is used interchangeably with the term plug-in electric vehicle (PEV). Neighbourhood electric vehicles (NEVs) and golf carts, electric forklifts and other vehicles that are not used for passenger transport are not within the scope of this thesis.

One purpose of this study is it to get an understanding of what belongs to an EV *system*. Hence, few things are excluded from being elements of this system. Actors, networks, institutions, complementary products, infrastructure, financing, norms are all within the boundaries of what is understood as a system in this study.

2 Research Methodology

The objective of this thesis is not to develop a completely new and innovative approach for cities that want to include EVs in their sustainable transport strategy. It will investigate how existing frameworks and practices can be further developed. This approach is reflected in the methodology. At the core of the research are three case studies that are used to shed light on the current practice of cities dealing with EVs. To put these case studies into context some background information about EV development is necessary. The analysis of the case studies is carried out with the help of a tested analytical framework for technical innovation systems (TIS). The different methods used in the three main research parts and the limitations of this study are described below.

2.1 Background

Data for technical, environmental, economic and political aspects of EVs can mainly be found in literature, such as academic articles, reports, websites, blogs, books, news-papers etc. The relevant literature can be found in different ways. For this thesis three channels have been used. First, the conventional search in library catalogues and databases has been carried out. Second, the most relevant online sources have been identified through the subscription to RSS feeds of blogs (e.g. “autobloggreen”, “cars 21” and “treehugger – cars and transportation”), the screening of relevant websites with the help of search engines and search tags, and surfing from link to link (e.g. from a blog to the website of a governmental organization to a report of a research institute to their website and so on). Third, literature recommendations and advice of interviewed experts have been followed.

Even if several channels have been used to collect data it is impossible to present background information that is free of any bias. By reviewing technology (friendly) blogs, talking to decision-makers that push for EVs and living and studying in an environment of people with green minds, the selection of information bears the risk of idealization. To come to a triangulated review of available literature two strategies have been followed. First, literature from different paradigms has been included (e.g. research commissioned by power utilities and research of fuel cell advocates) and people in different positions and from different geographical areas have been interviewed (e.g. an EV producer and a Greenpeace representative). Second, the presentation of background information tries to make critical positions as strong as possible by applying the principle of charity, i.e. to understand a position as if not having an own opinion on the topic (Archie, 2006).

2.2 Case Studies

As mentioned above the main objective of this research is to understand EV systems in cities and develop recommendations. To understand and eventually improve current practices it is necessary to investigate several city programs for EVs including their respective context. Therefore, three case studies have been carried out. These studies are instrumental to finding ways to facilitate and improve EV city programs. The aim is not to merely *understand* the respective cases (Stake, 1995, p. 3).

The selection of the three cases that have been researched did not follow strict criteria. First and foremost, Denver, Malmö and Aachen are all cases for which the author could easily establish contacts to key actors within the EV program. A second and less pragmatic reason for this selection is the variety that these places represent. They differ substantially with respect to their location, number of inhabitants, economic and political situation, and their progress of the EV program. Variety is helpful in the context of this research since the starting point is an existing framework that shall be tested and further developed. Exposure to a wide variety of different factors that can be identified in the different cases helps to discover gaps in the existing framework and makes it more robust. The sample of cases that is at the bottom of this research is not representative. It does not include the most salient cases like London, San Francisco or Shanghai, and excludes cities without any EV efforts. This is not problematic as the aim of this research is not to produce generalization but to achieve the “modification of generalization” that is already available (Stake, 1995, p. 8).

To be able to make statements about EV systems in cities the first step is to get access to the cases. Once a key stakeholder has been identified and contacted a snowball effect can start. New contacts appear and further literature becomes available. The author of this thesis had the advantage to spend seven weeks in the Denver area at the Rocky Mountain Institute which works with cities throughout the country to improve their EV-readiness. The direct contact with stakeholders as well as the attendance of meetings and workshops gave valuable insights into the case. Being a student in Lund, the author could as well meet stakeholders of the Malmö case study in person and get an impression of the research area.

All interviews were either conducted via telephone or in person. Because of the variations between cases and the different roles stakeholders play in the respective cases it was not possible to use the exact same set of questions for all interviews. The talks to different actors were semi-structured in order to both cover the central issues of this research and find out the specific function, experience and knowledge of the individual interviewee. Some aspects were addressed in all interviews to enable comparisons between the views of different stakeholders and between different cities.

2.3 Analysis

Data from the case studies is not merely used for understanding the cases but to improve current EV systems in cities. Before the actual data analysis can be carried out it is necessary to define what the **goal** of a well-functioning or successful city system is. While this goal – if it can be identified – gives the direction in which everything shall develop it is also important to develop and present a **framework** that forms the basis of the subsequent analysis. The actual **analysis** of the three cases has two purposes: first, to assess the functioning of the respective EV system; and second, to identify drivers, constraints and interconnections. In the **discussion and conclusion** the results of the analysis are put into the context of some critical EV issues, and recommendations are developed.

For the formulation of the goal of an EV city system experts were interviewed and asked for their views. Since just few EV city programs exist and cases vary substantially it was not possible to reach a consensus about the goals. Therefore, the analysis had to be carried out without a goal that would help to define the progress of different EV city systems.

The theory that frames the analysis of the three case studies is a composition of an established analytical framework for technical innovation systems (TIS) (Bergek et al., 2008) and reports on EV city programs (International Energy Agency, 2002; Olsson, 2000; Schewel & Wilson, 2009). All have been identified in a literature review. The specific content has been used to adapt the TIS framework to EV systems in cities. Vice versa the framework helped to identify gaps in existing lists of indicators and measures that support the EV dissemination in cities. By applying the framework to the case studies leverage points were identified that form the basis for further discussion.

The data of the three cases does not fit neatly into the framework. The sets of data are not homogeneous, not comprehensive and in some cases even inconsistent. Therefore, interpretation was unavoidable. Since much of the data is the result of direct interaction with interviewees and given that the views of different actors were often influenced by their personal agenda, it was impossible to get rid of the subjective element of case study data (Stake, 1995, p. 42). To make the interpretation that is presented in this thesis as strong as possible the author put an emphasis on a clear structure of argumentation, on double-checking interpretations with interviewees, on making underlying assumptions explicit and considering conflicting views whenever possible.

2.4 Limitations

During the research several factors appeared that limited the gathering of information and the analysis of the collected data. The factors that limited data collection can be put into two categories: first, limitations that have to do with the subject area itself; second, limitations arising from the process of information gathering. The subject area “EV systems in cities” is not well established and researched. Therefore, few reports, scientific articles and project evaluations exist. Furthermore, it was a big challenge that in most cases there were few physical elements that could be evaluated. Most cities are still in the phase of planning and testing. The role-out of large quantities of EVs starts in selected markets in late 2010. Therefore, data gathering for this research had to focus on somewhat more soft elements of EV systems, like project plans, networks, institutions and the knowledge base. Another challenge related to the subject area is its dynamic development. Much of the literature that was used for this thesis has been published in the time period that the research was carried out. The half-life of information in this field is very short.

Additionally, some frequent challenges that are related to the *process* of data gathering were experienced. The availability of interviewees, the time and location during the research, and different languages in different case studies made the collection of qualitative data a difficult undertaking. “It is always the same problem with Europe during summer. They are on holiday for two months” (Anonymous). The language challenge was not just about different mother tongues (English, Swedish, German), but also about the jargon of people working in the field. This is partially reflected in the list of abbreviations of this thesis. EV, PEV, CEV, ICEV, HEV, PHEV, BEV, NEV, ZEV, FC, CNG – what are the differences? And who stands behind DOE, EPA, CCIA, NREL and PGR?

The *analysis* of data was limited for mainly two reasons: the breadth of the scope and, in some areas, the sparse information base. Three case studies combined with various different elements of EV systems and several potential indicators for each element made it impossible to analyse every aspect (in-depth). While the broad scope combined with a selection of the essential aspects was part of the research design, more time and a more narrow focus could have allowed to follow up on interesting aspects that are just touched upon in the analysis. Furthermore, substantial parts of the analysis are based on interpretations of interviews and observations that are not completely validated, e.g. by talking to more stakeholders within the same case studies.

3 Electric Vehicles and Sustainable Transportation

Before presenting the analytical framework and the case study research, this section gives a brief overview of basic EV and charging technology and discusses some contentious issues. The purpose of this section is to introduce the terminology for the case studies and to clarify some issues that are subject to popular misunderstandings. This chapter shall also explain the role of EVs in a more sustainable transportation system, without presenting it as a panacea.

3.1 EV Technology

The variation of different EVs ranges from simple hybrid EVs without a plug-in option to pure battery EVs. In addition to the plug-in option, EVs differ with respect to design of the drive-train and the degree of hybridization. An overview and explanation of the current technological diversity of EVs is given in the table below (see also Union of Concerned Scientists, 2007).

Table 1: Technology overview of different EV types (adapted from Friedman, 2003)

Type	Regenerative brakes	Drive only with electric motor	Plug-in battery charging	Gas engine	Examples
Combustion engine vehicle (CEV)	✘	✘	✘	✔	*Hummer, VW Beetle*
Mild hybrid electric vehicle (HEV)	✔	✘	✘	✔	*Honda Civic Hybrid*
Full hybrid electric vehicle (HEV)	✔	✔	✘	✔	*Toyota Prius*
Plug-in hybrid electric vehicle (PHEV)	✔	✔	✔	✔	*BYD F3DM*
Range extended electric vehicle (REV)	✔	✔	✔	✘/✔[1]	*Chevy Volt*
Battery electric vehicle (BEV)	✔	✔	✔	✘	*Nissan LEAF*

Regenerative brakes can recover part of the kinetic energy of a moving vehicle. The motor is used as an electricity generator in the braking process. The electricity is stored in a battery. Depending on the type of power-train, energy from braking operations is "recycled" in different ways.

The three main types of hybrid gas-electric **power-trains** are: series, parallel and series-parallel. In a series hybrid only the electric motor provides the power to make the wheels turn. Electricity is provided by batteries and by a generator that is driven by a highly efficient gas engine. The batteries are either charged by the engine/generator, by regenerative braking or by plugging the car in. The main advantage of the series hybrid configuration is that the engine for driving the generator is very efficient as it can operate at

[1] The gas engine in an REV is used to generate the electricity for the electric motor. It does not drive the wheels directly.

a constant load, independently of the start-stop-operations of the car. In a parallel hybrid both the engine and the electric motor provide the power to drive the wheels. They are connected to a transmission. The advantage of this configuration is that energy from the engine does not have to be converted into electric energy before driving the wheels and, thus, avoids conversion losses. On the other hand, a parallel hybrid is not as efficient as a series hybrid in city traffic with many start-stop-operations. A series-parallel drive-train combines the other two set-ups. Both the gas engine and the electric motor can drive the wheels individually. This is currently the most efficient but also most costly option since two motors, a generator, a big battery pack, and advanced computing equipment are necessary (Friedman, 2003, p. 12).

3.2 Charging Technology

Charging a PEV is, at first glance, a very simple process. You plug in the vehicle and it will be charged. But some tricky aspects appear when the fit of plug and outlet, the speed of charging, and the place of charging are considered. The smallest challenge is to match the vehicle plug and the outlet. Both international standardization efforts and the equipment of vehicles with different adapters counteract potential compatibility problems (see Wikipedia contributors, 2010a).

The time it takes to charge an EV battery depends on the voltage and amp of the charger, also called EV supply equipment (EVSE), and the battery type that is charged. There are three main types of outlets: the 100-120V outlet (Voltage of domestic power in North and Central America and Japan), the 220-240V outlet (Voltage of domestic power in Europe, Asia, Africa and Australia) and outlets with more than 400V (mainly in industrial applications). In addition to the voltage differences battery charging differs with respect to the amps. The classification of EV charging into Level I (120V and <20A), Level II (220V and about 30A) and Level III (does not exist for AC, yet; with DC >400V and up to 100A) is not exactly defined, but nevertheless commonly used (Mattila, Interview; Ingram, 2010).[2] The differences between the Levels are large. While Level I charging might take a whole night and more (for BEVs like the Tesla Roadster), Level III charging can take less than one hour (see Motavalli, 2010; Ipakchi & Albuyeh, 2009, p. 56).

Charging an EV is not just about the flow of electricity but also about the flow of information. For utilities it is important to know who charges the vehicle when with how much electricity of which provider. Consumers might want to know the degree of discharge, remaining range, distance to the next charging point etc. (see J. Gartner, 2010b). To enable easy charging in public places and at charging stations of different providers a roaming system – similar to mobile phone networks – needs to be established. Also in this area standardization efforts are under way (Mattila, Interview).

3.3 EVs and the Electricity Grid

As far as the electricity grid is concerned EVs are both a challenge and an opportunity. The main issues around EVs and the grid are capacity requirements, off-peak charging and smart grids. The additional capacity requirements when adding a certain number of EVs to the grid depend on the scale of focus. While even millions of EVs are not a big challenge for the existing national or state electricity production capacity (see for example Lemoine

[2] All references labelled with "Interview" are personal communications. The dates of the interviews can be found in table 11. Citations of interviews are just referenced if the reference does not follow from the text.

et al., 2008, p. 6), problems might arise with local distribution grids if several EVs start charging batteries in the same street at about the same time (Stark, Interview; Mollstedt, Interview).

For power utilities it is best if EVs are mainly charged at times of low demand, e.g. at night. That is the time when utilities have spare capacity and could increase both electricity sales and the efficiency of their plants without making additional investments. Off-peak charging has the advantage for the consumer that electricity is cheaper. With an increasing share of renewable energies in the grid, temporary excess production gets a more frequent phenomenon. When there is "too much" wind and sun EV batteries can be used as buffers. But it will take years and years until the volume of vehicle batteries in the grid is large enough to enable a significant buffering effect (Simpson, Interview).

In order to steer the charging process of EV batteries and adapt it to grid requirements, communication between battery and grid is necessary. Plug-in EVs are part of many theoretical discussions about "smart-grids" (see for example Ipakchi & Albuyeh, 2009, pp. 55-60). While the inclusion of battery charging in demand management and load shaping systems will soon be feasible, the application of EVs for energy storage and vehicle-to-grid (V2G) systems cannot be expected in the short term (Simpson, Interview).

3.4 Contentious Issues

In the following sections some popular statements that frequently appear in debates around EVs will be presented and discussed. The issues that are outlined below have been identified in interviews with different transportation experts. The analysis of the statements is based on a literature review. Both technical aspects (energy density and price of batteries, safety issues) and environmental aspects (CO_2 emissions, resource dependence) have been considered.

Even in the long run the price of EV batteries and their energy density will prevent a wide dissemination of EVs.

The battery is definitely the most contentious issue around EVs. The statement above implies three questions. Will the price of batteries go down? Will the energy density of batteries increase? And will a high battery price and low energy density prevent a wide dissemination of EVs? Experts agree that with mass production of EV batteries scale effects will kick in and the **battery price** will go down. But how big this price drop will be is one of the most contended issues. The investment banker of Goldman Sachs are rather optimistic. They predict a drop of battery costs of 40-50% already in the next four to five years (Goldman Sachs, 2010, p. 26). In their battery investment research Goldman Sachs also comes up with a cost breakdown of an EV battery system which shows a very diverse distribution of cost factors – lithium accounting for only five percent of the total cost (see figure 1). The U.S. Department of Energy (DOE) comes to a similar conclusion. In the time from 2009 to 2013 DOE expects battery costs to drop by half, by 2015 some batteries even by 70% (U.S. Department of Energy, 2010a, p. 6). While also Deutsche Bank has published similar figures (Deutsche Bank, 2010), some estimates are less optimistic.

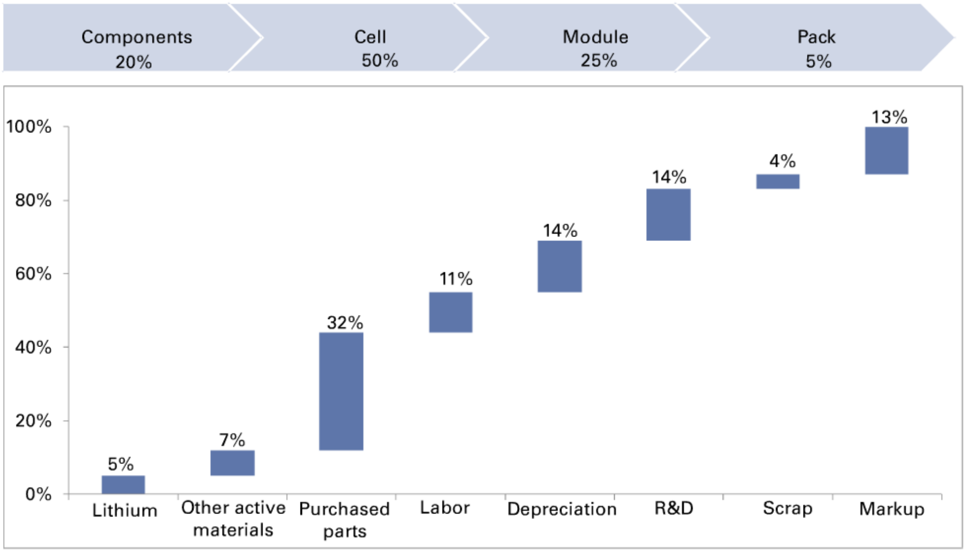

Figure 1: Cost breakdown of EV battery pack (Goldman Sachs, 2010, p. 25)

Boston Consulting Group (BCG) expects prices to drop by at most 60% till 2020, which is slower and later than in the other forecasts (Boston Consulting Group, 2010, p. 7). The main reason for this is that about 25% of current battery costs are relatively independent from production volumes, according to BCG. John Petersen, lawyer in the alternative energy sector, argues in the same line commenting on the optimistic Goldman Sachs report mentioned above (Petersen, 2010). While several good arguments are exchanged in the comment section of Petersen's blog, consensus about the development of EV battery packs seems to be far. At least several national governments are betting on a growing battery market and support domestic manufacturers, e.g. South Korea with $12.5 billion over 10 years (Yonhap News, 2010) and the U.S. so far with $2.4 billion under the Recovery Act (U.S. Department of Energy, 2010a).

The **energy density** of batteries is magnitudes lower than that of carbon fuels. This restricts the range of EVs and increases the weight of the vehicles. Therefore, increasing the energy density is a central research focus. For decades lead-acid (PbA) or nickel metal hydride (NiMH) batteries with their energy densities of about 35 Wh/kg and 65 Wh/kg were the batteries of choice (Chan, 2002, p. 267). The state of the art lithium-ion (Li-Ion) batteries that are used in today's EVs reach an energy density of up to 130 Wh/kg (Tesla Motors, 2010). The energy density of petroleum is 12,400 Wh/kg (Chan, 2002, p. 268). Assuming that an electric motor has an efficiency of about 90% and a combustion engine an efficiency of less than 20%, the propulsion energy in one kg Li-Ion battery would be “just” twenty times less than in one kg petroleum. Radically new battery types have the potential to further increase the energy density. One candidate is the lithium-air battery. But this technology is still very immature and it is not likely that it will be introduced to the market within the next 20 years (Rahim, 2010). As long as the energy density of batteries is significantly lower than the energy density of petroleum debates about the range of EVs will remain.

It is far from clear what will happen in the coming decade if there is no new breakthrough in battery technology and the costs of batteries do not drop as much as hoped for. Many important influence factors, such as the oil price, carbon pricing or the development of charging infrastructure, are difficult to foresee. Furthermore, it will be interesting to follow the development of range anxiety. Currently range is identified as the most constraining factor in opinion polls, while statistics show that the vast majority of all trips is shorter than the range of the first EVs that hit the market (Mattila, Interview).

EVs are not as safe as CEVs since the batteries are easily explosive and the vehicles are so quiet that pedestrians and cyclists cannot hear them

The view that Li-Ion batteries tend to overheat or explode is based on the chemical properties of lithium. With just one electron on the outer shell lithium is a highly reactive element, especially if it comes in contact with water (Wikipedia contributors, 2010b). The **high reactivity** is a desired quality for high battery performance. But at the same time it is a challenge for constructing safe batteries. Standards for the safety of EVs exist, e.g. the standard ISO 6469 which includes the "On-board rechargeable energy storage system", "Vehicle operational safety means and protection against failures" and "Protection of persons against electric hazards" (ISO, 2010). Standards, technical approval by authorities and the deterrent effect of bad publicity after accidents are strong drivers for safe EV batteries. A similar argument applies to protection from electric shocks caused by electric components of EVs. Whether vehicles with batteries are more or less dangerous than vehicles fuelled with petrol will become certain when a substantial number of EVs have been driving on the roads for some years.

A second potential health hazard is the **low noise** of electric motors. A report of the U.S. National Highway Traffic Safety Administration supports this view by presenting empirical evidence for the higher accident rate of HEVs with pedestrians and bicyclists (NHTSA, 2009, p. 19). On the other hand, EVs reduce noise pollution that also has negative health impacts. Furthermore, the "problem" of too quiet EVs appears only at low speeds. At higher speed tire and aerodynamic noise give notice of approaching EVs. Several automakers address the problem of the quietness of EVs at low speeds by adding automatic sound generators (e.g. Nissan, 2010a).

The third safety aspect of EVs is the **additional weight** of the batteries. These are usually positioned under the floor pan which lowers the centre of gravity of EVs and therewith improves their roadholding (see Commuter Cars, n.d.). Because of the higher total weight of EVs they have a longer breaking distance. On the other hand, additional weight brings a safety benefit in accidents since the heavier a car is, the smaller is the change in momentum if it is hit by another vehicle (National Research Council, 2002, p. 71).

If EVs are driven in a region with a high share of coal in the electricity mix their CO_2 emissions are higher than those of efficient CEVs

Along with battery development the GHG emissions related to EVs are among the most contentious issues. While research in this area is not conclusive, there is wide agreement on the fact that EVs can contribute to the reduction of GHG emissions from transportation if the share of renewable energies (or nuclear power) in the electricity mix is high. The impact of motorized vehicles in terms of GHG emissions depends on three factors: the distance driven, the fuel economy, and the life-cycle emissions per unit energy (see table 2).[3]

[3] The author is aware that emissions from vehicle production are part of the life-cycle emissions. They have not been considered as the use phase of both EVs and CEVs has the biggest impact. Differences between the emissions from EV production and CEV production are marginal. "A Li-ion battery in an [B]EV does not lead to an overcompensation of the potential benefits of the higher efficiency of [B]EV compared to an [I]CEV." (Notter et al., 2010, p. F).

Starting from the back, there is no evidence, yet, about whether the **distance driven** in an EV and the distance driven in a comparable CEV differ. Therefore, it is assumed that the distance driven is the same in both cases. An argument in favour of less distance driven in an EV is the restricted range due to the limited energy density of batteries. On the other hand, once an EV is purchased the fuel, electricity, is cheaper than petroleum, which might be an incentive to drive more. With the assumption that the distance driven is the same it is sufficient to look at the emission intensity (gCO_2 /km) of the whole life-cycle, well-to-wheel, to compare the GHG impact of EVs and CEVs (Notter et al., 2010, p. F).

Table 2: GHG emission factors for EVs and CEVs

GHG emissions	=	*life-cycle emissions per unit energy*	*	*fuel economy*	*	*distance driven*
g CO_2 (EV)	=	*g CO_2/ kWh*	*	*kWh/ km*	*	*km*
g CO_2 (CEV)	=	*g CO_2/ l*	*	*l/ km*	*	*km*

There are several studies on life-cycle **emissions per litre petroleum**. Life-cycle emissions can be split into two phases. While emissions of the second phase, the actual combustion in the engine, can be determined by applying simple chemical conversion factors, the emissions from the first phase, from well-to-pump, are more difficult to determine. They depend on extraction methods, refining, and means and distance of transportation. Well-to-pump emissions make up for around 20% of well-to-wheel emissions (Gerdes & Skone, 2009, p. 2). The actual combustion of one litre of gasoline emits 2.3 $kgCO_2$ /l. The combustion of diesel, which has a higher carbon content than gasoline, results in 2.7 $kgCO_2$ /l (U.S. EPA, 2005). That means total life-cycle emissions of CO_2 are around 2.9 kg/l for gasoline and 3.3 kg/l for diesel.

CO_2 **emissions from electricity production** depend on the energy sources that are used. The electricity mix varies significantly from region to region. For the three countries where the case studies of this thesis are placed the CO_2 emissions are:[4] Germany 575 g/kWh in 2009 (German Federal Environment Agency, 2010), Sweden 40 g/kWh in 2003 (Econologie, 2008), Colorado 776 g/kWh in 2008 (U.S. Energy Information Administration, 2010b). The CO_2 emissions from coal fired power plants alone are about 1,000 g/kWh electricity (Herminghaus, 2009). But the energy source is not the only determinant of the emissions that are associated to EV charging. The time of charging changes the emissions of the consumed electricity as at different times different combinations of power plants produce electricity (Lohbeck, Interview). It is likely that most of the charging will happen at night when power utilities have spare capacities. While some experts talk about charging EVs at night from surplus production that is otherwise dumped, other reports consider the emissions from the marginal power plant, the plant that is used to serve additional demand, which is usually coal (Horst et al., 2009, pp. 32-34).

[4] As life-cycle emissions are analyzed transmission and distribution losses have to be considered (Voelcker, 2009, p.44). As it is not clear to the author in which of the following numbers this has already been considered and in which it has not, the emission values will be used as they are.

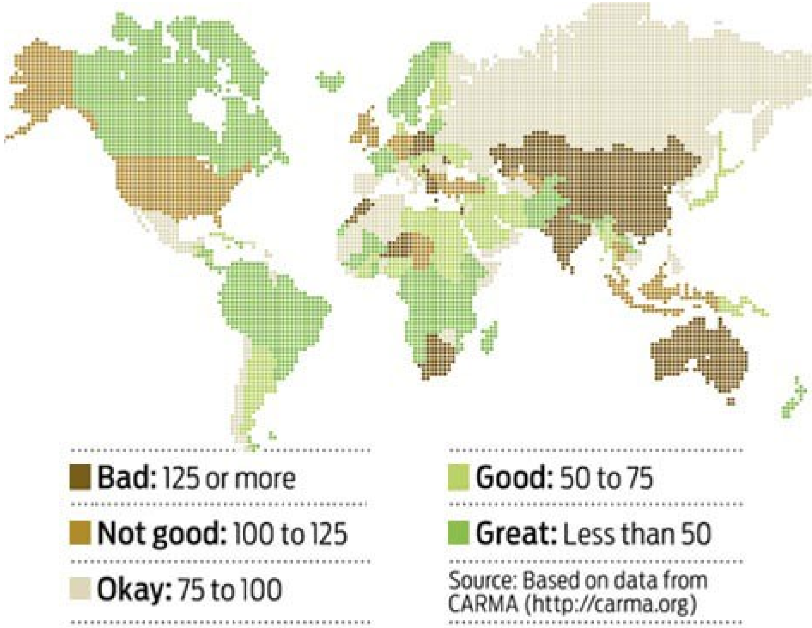

Figure 2: CO2 emissions of electric driving (g/km) (Voelcker, 2009)

The second determining factor of the emission intensity of driving EVs and CEVs is the **fuel economy** of the vehicles. A lot of data are available for CEVs: average fuel economy of fleets, of new cars, of driving in the city, of driving on the highway, of combined-cycle driving etc. According to the website "fueleconomy.gov" the most efficient compact car in the U.S. in 2010 is the Volkswagen Golf with an official EPA rating (combined cycle) of 6.9 l/100km (diesel). In Europe some cars are available that consume less than 5 l/100km (diesel) (European drive cycle). Considering that the average fuel economy of current CEV fleets in the U.S., Germany and Sweden is far worse than that, it is safe to assume a fuel economy of 5 l/100km (diesel) and 6 l/100km (gasoline) without discriminating CEVs in this comparison. For EVs very little data are available. This is one of the most critical constraints in comparing emissions of CEVs and EVs. Assuming a charging efficiency of around 85%, the plug-to-wheel energy efficiency of a Tesla Roadster is reported to be around 200 Wh/km (Wikipedia contributors, 2010c). Mini states the energy efficiency of the electric Mini with 140 Wh/km (see specs in Mini USA, n.d.). The U.S. DOE test of the Mini-E shows a plug-to-wheel energy consumption of about 165 Wh/km (U.S. Department of Energy, 2009). Nissan claims a battery-to-wheel energy efficiency of 150 Wh/km for its LEAF (Nissan, 2010b). That is the same efficiency that EV expert John Voelcker assumes in his IEEE article "How Green Is My Plug-In?" (Voelcker, 2009, p. 44). Greenpeace expert Wolfgang Lohbeck calculates with less efficient 200-300 Wh/km (Lohbeck, 2010). For this study a plug-to-wheel energy efficiency of about 175 Wh/km shall be assumed for a compact five seater series-production EV.

Table 3 presents the results of the calculations. What it shows is that the claim: (B)EVs are not cleaner than (very efficient) CEVs if the electricity comes from a grid that is (almost exclusively) based on coal, is true. But the table also shows that EVs have a big potential for substantial reductions of GHG emissions if the electricity is produced in a clean way (see also Elgowainy et al., 2009).

Table 3: CO_2 emissions per kilometre of a BEV and a CEV

BEV	*g CO_2/km*		*g CO_2/ kWh*		*kWh/ km*
Coal	*175*	=	*1000*	*	*0.175*
Colorado Grid	*136*	=	*776*	*	*0.175*
German Grid	*101*	=	*575*	*	*0.175*
Swedish Grid	*7*	=	*40*	*	*0.175*
CEV	*g CO_2/km*		*g CO_2/ l*		*l/ km*
Efficient Diesel	*165*	=	*3300*	*	*0.05*
Efficient Gas	*174*	=	*2900*	*	*0.06*

When EVs are mass-produced the dependence of oil will be replaced by a dependence on Lithium and Rare Earth Metals

With respect to the availability of lithium three aspects have to be considered: Is there sufficient lithium for the electrification of a large share of the car fleet? Is there a risk of running into a dependence on imports from few (politically unstable) countries? And is it likely that a high price for lithium will prohibit an early uptake of EVs ?

For the U.S. DOE the Argonne National Laboratory researched the **availability of lithium** until 2050. Calculating with the currently known reserve base and assuming a rapid growth in battery demand, the researchers conclude that lithium demand can be easily met until 2050, the last year of their scenario. They foresee a growth in demand for virgin lithium material until about 2035 when increasing recycling rates and an increasing feedstock for recycling kick in. Li-Ion batteries are not considered to be the "silver bullet that permanently solves all of the world's energy storage problems, but they can certainly make a large contribution for at least several decades". Additional exploration and better batteries can extend the supply with lithium even further (Gaines & Nelson, 2009).

While lithium reserves are not a risk factor for EV production in the coming decades, the **dependence on lithium exporting countries** is a risk that is still debated. Known reserves are concentrated in a few countries, namely Bolivia, Chile, China and Brazil, that have more than 90% of the world reserve base. The current production is led by Chile, Australia, China, Argentina and the U.S. (Gaines & Nelson, 2009). The development of production capacity and its geographical distribution, the development of demand and the building up of recycling infrastructure are critical factors for the risk of unwanted effects from lithium dependence. Once recycling capacity and a lithium feedstock for recycling are available the risk of negative impacts from lithium dependence is considered to be very low (Electrification Coalition, 2009, pp. 80, 84; see figure 3).

The third aspect of a potential scarcity is the development of the **lithium price**. For the next five to ten years, when the mass roll-out of EVs is expected to start, the price for Li-Ion batteries is expected to drop (see above). This development depends very little on the development of the price of lithium since lithium makes up only about 5% of the price of the whole battery pack (Goldman Sachs, 2010, p. 25). The consultancy Roland Berger even expects large over-capacities for the EV battery market around 2015 (Roland Berger, 2010).

While the risk of lithium scarcity and dependence is well-researched and seems to be manageable, the supply with **Rare Earth Elements** (REE) is much more uncertain (see U.S. Geological Survey, 2002). One of the 17 elements that are summarized as REEs, neodymium, is an important material for magnetic electric motors as they are used in EVs. Lanthanum is frequently used in NiMH batteries. Jack Lifton, expert for strategic metals, identified the HEV Toyota Prius as "the biggest user of rare earths of any object in the world" (Gorman, 2009). While REEs are not as rare as it might sound, the current production is extremely centralized. More than 97% of the 2009 world supply came from China. After China had drastically reduced the 2010 export quota for REEs, several activities for REE mining in other regions of the world intensified (Taylor, 2010; for a discussion from the perspective of the U.S. see Chameides, 2010). Whether REE scarcity can become a problem for EV production is impossible to foresee. There is a dependence at the moment, but it is not clear how this dependence will be reduced through new production capacity and recycling, and if the dependence will result in scarcity.

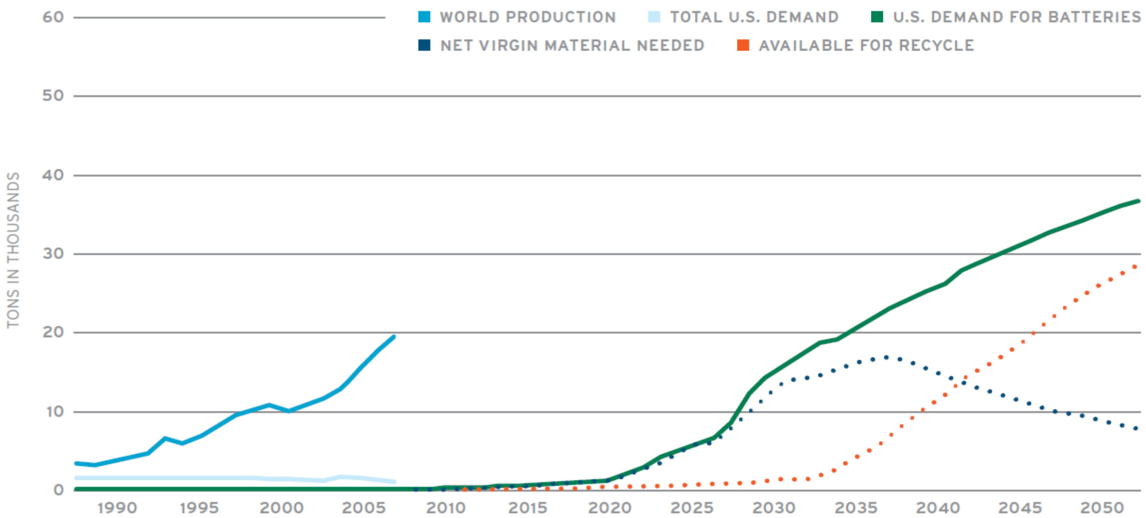

Figure 3: Historical and projected lithium demand (Electrification Coalition, 2009)

4 Analytical Framework

The presentation of EV technology and the discussion of contentious issues have shown that EVs are a viable alternative for personal transportation. But few EVs are on the streets so far. A gradual shift towards electric mobility is likely to happen. But it will take time. In academia and politics this shift is often called a socio-technical transition. In this section transition theory will be outlined. Based on that, a framework for the analysis of TIS will be introduced and critically discussed. The framework identifies seven generic functions of innovation systems. While the TIS framework is very general there are some reports on EV city programs that present specific aspects for the functioning of such innovative programs. By categorizing the specific aspects according to the seven functions of the TIS framework, a structure for analysing the cases of this research can be obtained.

4.1 Transition Theory

For the last 90 years the dominant propulsion technology in motorized road transport has been the internal combustion engine. In the beginning of the 20th century CEVs shared the market with EVs and steam cars. Embedded in a favouring socio-economic environment, the CEV won the race. EVs merely survived as niche applications, e.g. as golf carts, neighbourhood electric vehicles (NEVs) or delivery vans (Sonnenschein, 2010). The century-long development of a CEV-based motorized transport system has created a lock-in situation. Suppliers, manufacturers, consumers, politicians, media and further stakeholders have established networks, institutions and an infrastructure around the CEV that are very stable. This stable configuration is called a *regime* in the language of Transition Theory.

The traditional Dutch school of Transition Theory (Berkhout, 2008; Geels, 2002; Kemp et al., 1998; Nill & Kemp, 2009; Rotmans et al., 2001) differentiates between three layers that help to structure and understand the process of a socio-technical transition. Established regimes form the intermediate layer. “The different levels are not ontological descriptions of reality, but analytical and heuristic concepts to understand the complex dynamics of sociotechnical change.” (Geels, 2002, p. 1259). Hardly influenceable but highly influential

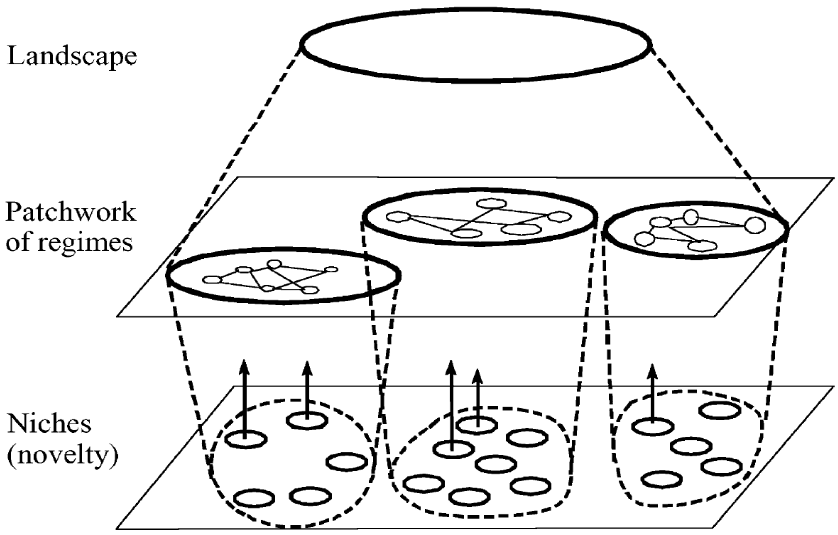

Figure 4: Technology in a multi-level perspective (Geels, 2002, p. 1261)

is the macro level, also called *landscape*. This category is used to comprise factors that can be regarded as “deep structural trends, […] such as oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, environmental problems” (Geels, 2002, p.1260). Landscape factors influence regime formation and regime adaptation.Additionally, regimes can be influenced from the micro level. Socio-technical *niches* that are far less institutionalized than regimes allow for radical innovations. In addition to pressure from the landscape, strategic niche management (Kemp et al., 1998) could be a way for the EV to enter the existing car regime or compete with it.

The multi-layer model is illustrated in figure 4. “The nested character of these levels, means that regimes are embedded within landscapes and niches within regimes. Novelties emerge in niches in the context of existing regimes and landscapes with its specific problems, rules and capabilities.” (Geels, 2002, p. 1261).

This model depicts two ways how a transition can take place. First, the pressure of innovations at the niche level and developments at the landscape level can cause small adaptations in the existing regime. Second, niche developments can lead in a favouring landscape to the establishment of a new regime that competes with the old one.

The Transition Theory model is extremely open for all kinds of factors that influence the development of regimes. This approach helps to avoid a limited focus, e.g. on technological factors or consumer behaviour only. While it is certainly good to take an interdisciplinary perspective, an adequate transition-theoretical analysis is not possible in practice. Too many factors would have to be considered. What holds true for ex-post analysis is even more of a problem when it comes to predictions and policy recommendations. Transition Theory is too broad to base a selection of key determinants, leverage points and policy interventions on it.

A theoretical framework within the paradigm of socio-technical transitions that provides more guidance in analysing the development of technological innovations will be presented below. This framework will first be set into the context of EV city programs and Transition Theory. Then the different steps of analysis will be presented. Finally, the framework will be discussed and after this adapted according to the results of the discussion.

4.2 Functional Dynamics

In the context of Transition Theory cities could be seen as niches for EV programs. There is not much experience with EVs in the motorized road transport regime so far. But at the niche level established EV programs can function as show cases that reduce uncertainty. Uncertainty is important as it is “a fundamental feature of innovation, and we need to take account of institutions beyond the market alone to explain innovative activity and the dynamics of innovation.” (Berkhout, 2008, p. 134).

The market for EVs – characterized by extremely low supply and unpredictable demand – is just the ultimate expression of the uncertainties surrounding the EV. Neither simple market theories nor the three-layer-model of Transition Theory are adequate to explain why the EV market is still so small and why, nevertheless, on the level of cities EV programs are run. The Dutch researcher Frans Berkhout states: “The explanation of change [...] comes not only from changes in behaviour at the level of the innovating agent, but also from processes of change in actor networks, institutions, infrastructures and cultural phenomena such as expectations." (Berkhout, 2008, p. 138).

An analytical framework that addresses the shortcomings of Transition Theory and that is useful to guide research in the area of technology innovations, is provided by a group of Swedish researchers around Anna Bergek. They have identified "a need for a practically useful analytical framework that allows for the assessment of system performance as well as the identification of factors influencing performance." (Bergek et al., 2008, p. 408). Based on an extensive literature review Bergek et al. have found archetypes of TIS evolution and developed a scheme of analysis that consists of six steps (see figure 5).

As a first step it is important to define the TIS that is analysed. A **definition** is always a selection. According to Bergek et al. it is necessary to select between a focus on products and on knowledge fields, between breadth and depth of analysis and to select a spatial domain (Bergek Anna et al., 2008, p. 411). While the product focus and the breadth of this study have been explained in the scoping section above (see section 1.4) further elaboration on the spatial domain of the case studies is given at the beginning of the case descriptions.

The second step is to reveal the **structure** of the defined system, including relevant actors, existing networks and formal and informal institutions. Relevant actors are private and public firms, public bodies, research institutes, interest groups, banks or consumers. Networks are constituted by formal and informal links between different actors. Public-private partnerships (PPP), project consortia and links between research institutes and industry are some examples for such networks. The most challenging structural components of a TIS are the institutions. While formal institutions, such as regulations and laws, are explicit and can be researched by reviewing documents, informal institutions, such as culture, norms and routines, are usually implicit and just reflected in behaviour (Bergek et al., 2008, p. 413). Formal institutions that are not within the boundaries of the case studies, like national and state level laws and regulations, are presented in the context section of each case study. EV programs at the city level are just emerging. Therefore, there

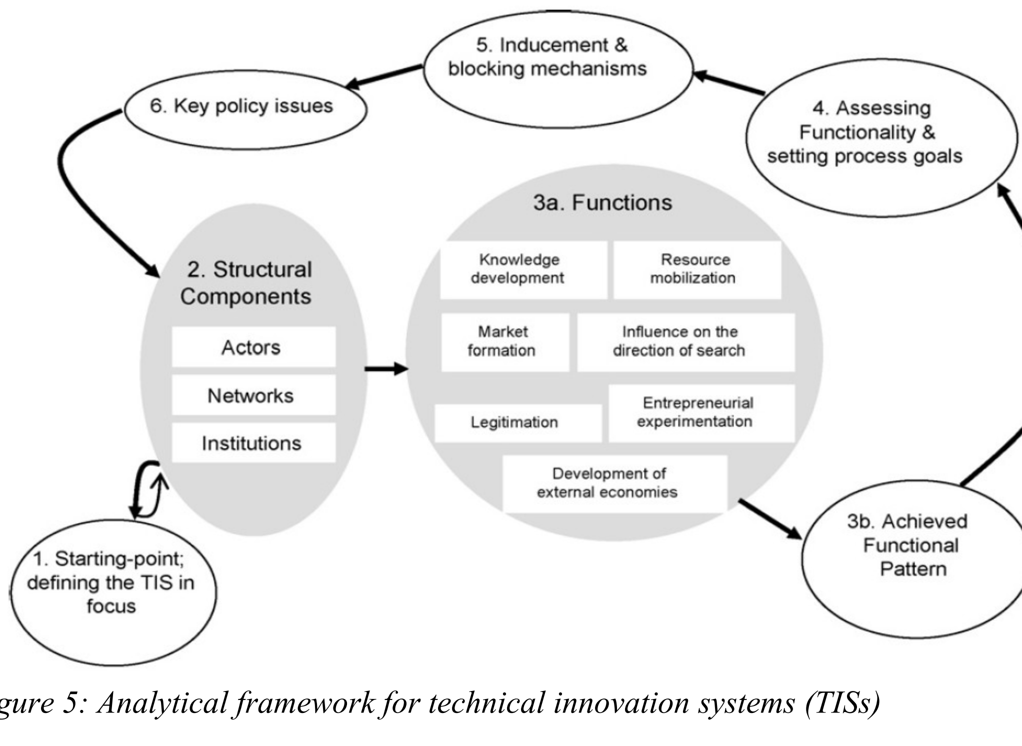

Figure 5: Analytical framework for technical innovation systems (TISs)

are still many "inherent uncertainties, implying that the identification of structural components is thorny" (Bergek et al., 2008, p. 414).

The structural analysis is fundamental for the analysis of **functional patterns**. Seven core functions have been identified by the researchers around Bergek. These functions have been synthesized from several academic studies in the field and represent archetypes that can be observed in TISs. The functions are not tailored to EV programs in cities. But it is assumed that for different technological innovations similar functions are relevant. Furthermore, the TIS framework is open for changes and not regarded as finished by the authors themselves. The seven functions under the framework are (Bergek et al., 2008, pp. 414-419):

- *Knowledge development and diffusion*
  This function deals with the depth and breadth of the knowledge base of a technical innovation. Different types of knowledge (e.g. scientific, technological, market) and different sources of knowledge (e.g. R&D and imitation) are considered.

- *Influence on the direction of search*
  Actors outside a TIS can choose to enter it and actors inside the TIS can favor different developments. This function subsumes all factors that determine the direction in which actors search for future activity within a TIS. Included are several kinds of incentives, e.g. policies and regulations, market prices, best practice examples elsewhere, the crisis of competing conventional technologies and demand by lead customers.

- *Entrepreneurial experimentation*
  This function addresses the uncertainty that exists around new technologies. Experimentation, even if seldom successful, is necessary to reduce uncertainty. New entrants into the TIS, different fields of application and the breadth of the technology that is applied are different expressions of entrepreneurial experimentation.

- *Market formation*
  The function market formation can be developed to different degrees. There is a long way from emerging markets for somewhat immature technologies to the development of established volume markets. A good understanding of the respective TIS is necessary to be able to assess the current state of the market and how future market formation can be facilitated.

- *Legitimation*
  This function means the social acceptance of a new technology and the establishment of relevant informal institutions. Different stakeholders within a TIS might come to varying conclusions about the legitimacy of a technology. Perceived legitimacy has a big impact on demand, new legislation and firm behaviour.

- *Resource mobilization*
  Resources subsume human capital, financial capital and other necessary assets such as infrastructure and complementary products and services. The degree to which required resources are mobilized indicates the development state of a TIS.

- *Development of positive externalities*
  This function stresses the systemic nature of a TIS. Experimentation can create legitimation, legitimation helps market formation, and knowledge diffusion might mobilize the resource human capital. The utilization of positive externalities can have different forms, e.g. pooled labour markets, an institutionalized flow of information or the division of specialization labour.

The fourth step of analysis is the **assessment** of the overall functionality of the TIS in focus, based on the seven functions mentioned above. This can be done by comparing several TISs against each other or looking into the development phase of a single TIS (Bergek et al., 2008, pp. 419-420). In this thesis the seven functions are assessed for three different case studies which allows for an analysis based on comparison.

Following the assessment, it is the fifth step to find out what are the **inducing and blocking mechanisms** that shape the functional pattern of the TIS. These mechanisms can both have internal and external sources. Actors, networks and institutions that are part of established technology systems are often decisive for the development of competing TISs (Bergek et al., 2008, pp.420-422).

The final step of the analysis is the specification of **key policy issues**. Depending on the goals that are followed in the context of a specific TIS, relevant policy interventions are related to the blocking and inducing mechanisms that are identified in step five. The aim of these interventions is to improve the functionality of the TIS (Bergek et al., 2008, p. 423).

The six-step analytical framework depicted above has been tested in empirical studies. Nevertheless, it does not provide a perfect match to all systems that are analysed under it. The preliminary character of the framework is acknowledged by the group of authors: “we expect further empirical studies [...] to induce several revisions of the framework” (Bergek et al., 2008, p. 424). While changes to the framework that are based on the empirical findings from the case studies will be discussed at the end of this thesis, some adaptations based on theoretical arguments will be discussed in the following.

Two of the seven functions of the framework have a different character than the other five. First, the “influence on the direction of search” depends on all other functions. Some factors that influence the direction of search are: availability of information (knowledge development and diffusion), successful or unsuccessful enterprises (entrepreneurial experimentation), rising or falling sales volumes (market formation), promising or discouraging opinion polls (legitimation), and capital availability (resource mobilization). One factor that is not included in this list is incentives from government intervention. The role of policy instruments is highlighted by Bergek et al. when discussing the function “influence on the direction of search”. For this research project “influence on the direction of search” shall be replaced by “government intervention” as it is more focussed and does not comprise all other functions. Well-designed policy instruments (permitting, standardization, incentive programs, regulation) can create incentives that have a strong influence on the direction of search. What it means for the functioning of a TIS to be supported through government intervention is not trivial. Government intervention could be regarded as an indicator for the malfunctioning of a TIS. On the other hand, government support could also be understood as a sign for a promising future of an innovation, since it is worth supporting it.

The second function that is different from all others is "development of positive externalities". What is described by Bergek et al. as positive externalities are links and synergies between different functions. The mobilization of resources in combination with entrepreneurial experimentation push for market formation. Market formation might as well be supported through political interventions. And the wide diffusion of knowledge helps legitimation of a new technology. But the appearance of synergies as such is not a function of TISs in itself, it is an indicator.

The function that is related to synergies and positive externalities is *interconnectivity*. A strong interconnectivity, e.g. much network activity, enables the flow of information, triggers mutually beneficial cooperation, and makes actors realize the potential of positive externalities. A high degree of interconnectivity does not only depend on the mere number of links between different actors, but also on the quality of the links, which means the frequency of interaction and the degree of collaboration. Just like other functions of a TIS, interconnectivity influences the direction of search by indicating a process of integration between different functions and the start of a development towards a well-functioning and resilient system around the new technology.

The analytical framework that includes the changes of "influence on the direction of search" and "positive externalities" to "government intervention" and "interconnectivity" has been applied throughout the case study research. Due to the abstract character of this analytical structure, specific indicators have been identified for the seven functions to make the framework operational. These indicators functioned as orientation during the case studies but were not used as a strict check-list. For this purpose existing ex-post and ex-ante analyses of city programs for EVs have been screened.

4.3 Operational Guide

In this section three different reports on EV introduction in cities are presented in a consolidated way these reports have been used to create a list of indicators that provides an operational guide for the case study research.

The first report summarizes the results of a European Commission co-funded project on "Zero and Low Emission Vehicles in Urban Society" (ZEUS). The ZEUS project was meant to investigate "how cities and regions can help overcome the market obstacles that restrain zero and low emission mobility" (Olsson, 2000). It involved eight project cities in eight different countries where EVs along with natural gas, biogas and ethanol propelled vehicles were tested. The list of recommendations from the ZEUS project is displayed in table 5 of the appendix. It was helpful to identify relevant indicators for the case study analysis.

The second report, that has been compiled for the "Hybrid and Electric Vehicle Implementing Agreement" of the International Energy Agency, is partly based on experiences from ZEUS cities but includes further case studies. It puts the focus on the role of different stakeholders, including administrators, at a city level (International Energy Agency, 2002). Drivers and barriers that have been identified in this report are summarized in table 6 of the appendix. These factors helped to come up with a list of relevant indicators.

The third report differs from the other two in that it is not an evaluation of past city projects but an ex-ante analysis of future projects. The "Project Get Ready Menu" of the Rocky Mountain Institute lists both barriers and actions to overcome these barriers at the city level. The aim is to prepare cities for the role-out of PEVs and, at the same time, create favouring conditions for EVs that reduce the uncertainties of vehicle manufacturers (Schewel & Wilson, 2009). The recommended actions that were inspiration for finding indicators for the operational guide are listed in tables 7 and 8 of the appendix.

Table 10 of the appendix brings together the indicators that could be extracted from the three reports. It also includes the general indicators that are mentioned in the analytical framework of Bergek et al. Furthermore, constraints and drivers that are related to the seven different functions are listed. Aspects that appear in more than one of the sources are just listed once. The list of indicators for the different functions is used in the analysis as orientation. It is not meant to be a rigid list that is executed indicator by indicator for all seven functions in the three case studies.

5 Case Studies

The following case studies about three cities that run EV projects have to be understood in their respective contexts. Without the context, the importance of factors within the boundaries of the case study might either be over- or under-estimated. The following section gives a brief outline of the global landscape. National and state level policies and the respective structures of energy systems are presented at the beginning of each of the case studies. The context is followed by a description of EV activities in the city, a summary of relevant actors and networks and an analysis of the seven different functions that are explained above in the analytical framework.

5.1 Global Landscape

Peak oil, climate change and economic crisis have changed the environment for EVs. These factors do not necessarily have an immediate influence on EV-related actions within the boundaries of the following case studies. However, they form the landscape in which national, regional and local policies are made, investments are decided, and consumer behaviour changes.

Peak Oil

The discussions about “Peak Oil” are not new. Reducing the dependence on oil (imports) was political mainstream after the two oil crises of the 1970s. Despite the awareness of the problem not much has changed. Oil consumption is higher than ever and demand is expected to increase significantly over the next 25 years. In its International Energy Outlook 2010 the U.S. Energy Information Administration (EIA) predicts an increase in the use of liquid fuels from 86.1m barrels per day in 2007 to 110.6m barrels per day in 2035. The main driver of this growth is the transportation sector with an expected annual growth of 1.3 %. Virtually all of this growth is expected to take place in non-OECD countries (U.S. Energy Information Administration, 2010c).

Whether there will be sufficient production capacity to satisfy the growing demand is far from clear. The most comprehensive piece of peak oil research, conducted by the UK Energy Research Centre (UKERC), comes to the conclusion: “On the basis of current evidence we suggest that a peak of conventional oil production before 2030 appears likely and there is a significant risk of a peak before 2020. Given the lead times required to both develop substitute fuels and improve energy efficiency, this risk needs to be given serious consideration.” (Sorrell et al., 2009, p. 171). A study of the German Federal Institute for Geosciences and Natural Resources comes to a very similar conclusion (Rempel et al., 2009, p. 19).

It is likely that there will be three main outcomes of the combination of increasing demand and peaking supply. First, prices will go up. Second, as prices go up, alternative fuel sources will be further exploited. Some alternatives to conventional oil production are oil production in the deep sea, oil production from tar sands, biofuels, coal-to-liquid (CTL) fuels or natural gas.[5] The third consequence of a demand surplus might be the reduction of fuel consumption by improving the energy efficiency of vehicles and systems. The more expensive fuels become the better the business case is for energy efficiency improvements.

[5] For some of the risks that are connected to alternatives to conventional oil production and for some of the most recent oil price predictions see Froggatt & Lahn (2010, pp. 12-15).

A similar statement could be made for EVs. A high oil price makes EVs more competitive. The Boston Consulting Group (BCG) has analysed the total cost of ownership of efficient EVs, HEVs, diesel and gasoline cars against the background of different oil price scenarios. The consultants of BCG clearly show that at an oil price of about $100 to $120 EVs and HEVs are not more expensive than CEVs if a total cost perspective is taken (Boston Consulting Group, 2009, p. 5).[6]

Climate change

Closely related to the combustion of oil is the issue of climate change. Irrespective of the question whether science around climate change is conclusive or not, the topic has had a big impact on policy making, societal norms and the business sector. The cost for emitting GHGs, be it in monetary or reputational terms, is a factor that influences decision-making at all levels.

Emissions from transportation make up a significant share of the world's GHG emissions caused by humans. "In 2004, transport energy use amounted to 26% of total world energy use and the transport sector was responsible for about 23% of world energy-related GHG emissions. The 1990–2002 growth rate of energy consumption in the transport sector was highest among all the end-use sectors." (Kahn Ribeiro & Kobayashi, 2007, p. 328). The growth of transportation and its high dependence on hydrocarbon fuels make it a significant challenge to reduce emissions from this sector.

It is a technological challenge to develop less-emitting vehicles. It is a challenge for politics to enact effective laws and regulations that are not always popular (e.g. carbon and fuel taxes and emission standards). It is a challenge for the transportation industry to implement new technologies and react to political reforms. And it is a challenge for everybody to reduce his or her impact from personal mobility. The challenge that climate change poses for the transportation sector is an important factor for the development of technological solutions like EVs.

Furthermore, climate change has triggered an ongoing trend towards more electricity production from renewable sources. The cleaner the electricity mix is that is used for charging EVs, the better are the life-cycle emissions associated with driving EVs (see calculations in section 3.4).

Economic and automotive crisis

It is very complex to assess the influence of the current economic crisis on the car industry and the development of the EV. Therefore, just some qualitative links shall be presented. The negative economic development and high fuel prices caused a drop in car sales. In combination with the credit crunch, this has been especially difficult for North American car manufacturers. The bail out of car manufacturers increased the influence of governments. In combination with tightening emission standards many automakers were forced to re-think their business models and shift the focus to smaller and more efficient vehicles and integrate electric propulsion (New York Times, 2010).

6 The oil price that is necessary to push the total cost for driving a BEV below the total cost for CEVs heavily depends on the battery price. A break even at $100 to $120 assumes a battery price of about $500 per kWh. Currently battery prices per kWh are some hundred dollars higher which would require an oil price of above $200 to break even.

In addition to the bail-out of the car industry, significant parts of economic stimulus packages were related to EV technology and production. Stimulus money was given to battery and car manufacturers, EV research projects, infrastructure projects, and demonstration and pilot programs.

But the economic crisis has also had a negative side for EVs. Many innovative companies had problems accessing venture capital to implement business ideas. For bigger companies it has been difficult to get money on the credit market to build up production capacity (see Overfelt, 2008). Poor economic development and stimulus packages have caused budget deficits in many countries. These deficits increasingly become a challenge for the implementation of national EV strategies, e.g. in the UK where the volume of the subsidy scheme has been reduced from €275 million to €50 million (Vaughan, 2010).

While car markets in Europe, North America and Japan were not very profitable for car manufacturers, other markets emerged. In 2009 China was for the first time the biggest car market in the world (Yan & Subler, 2010). In the process of setting up a domestic car industry China puts a big emphasis on EVs (Bradsher, 2009).

5.2 Case: Malmö, Sweden

Malmö is a city with 290,000 inhabitants in the region Skåne in the very south of Sweden. With about 30% of its population born abroad Malmö is a very international city. Since 2000 Malmö is connected through the Öresund bridge with Copenhagen, the capital of Denmark. Malmö and Copenhagen are part of the Öresund region that has more than three million inhabitants (Wikipedia contributors, 2010f).

In many ways Malmö is a frontrunner in environmental matters. The extensive network of cycling paths is one of the reasons that 30 % of all trips and about 40 % of all commutes are undertaken by bike (Malmö Stad, 2010b). A dense system of city buses adds to sustainable transportation in Malmö. Malmö has an integrated mobility strategy that promotes walking, biking and public transport, and – with a lower priority – also environmentally adapted cars. Air pollution has significantly dropped since the 1970s but at times the limit values are still exceeded in the city centre (Malmö Stad, 2009a). The city districts Western Harbour and Augustenborg are modern examples for sustainable city planning (Malmö Stad, 2010c).

5.2.1 Context

In 2006 Sweden published a vision for a fossil fuel free society (Commission on Oil Independence, 2006). This caused media attention around the world. In some regions of Sweden action plans have been started to work towards this vision. The transportation sector with its high dependence on oil is the most challenging area. The focus of sustainable transport policies in Sweden is on biofuels and biogas. EVs would be another option on the way to make Sweden fossil fuel free. But so far the country does neither have a comprehensive EV strategy nor an objective for EV penetration in the near future. The Swedish electrical industry has launched a vision of 600,000 EVs by 2020 (Power Circle, 2010). A report by the Swedish Energy Agency in 2009 recommends an integrated EV program for Sweden (Swedish Energy Agency, 2009a, pp. 85-94). Funding for EV R&D projects is available through the FFI partnership of the Swedish government and the automotive industry that has a total yearly volume of about €100 million (Vinnova, n.d.).

Further funding for pilot and demonstration projects is available but it is not organized in one dedicated program.

Sweden does not subsidize the purchase of EVs. With its tradition of target-based and technology-neutral (environmental) policy, subsidies solely targeted at EVs are not likely to be introduced in the near future (Mollstedt, Interview). Still an indirect subsidy for EVs does exist. Owners of BEVs or PHEVs do not have to pay the annual vehicle tax for the first five years. Depending on the weight of the car several hundred Euros vehicle tax can be saved compared to conventional CEVs (Skatteverket, 2010).

Furthermore, driving an EV in Sweden is taxed less than driving a CEV. Driving 1,000km in an efficient car of either type costs about €5.50 of energy and CO_2 taxes for EVs and €35 (diesel €23) for CEVs (see table 9 in appendix for calculation and references). If total fuel prices are considered the difference between driving an EV or a CEV in Sweden is smaller. This is due to the fact that the tax share of the electricity price is smaller than the tax share of the gasoline or diesel price.

CO_2 emission standards for Sweden are set in EU regulation No 443/2009, which is about the average emissions of cars that are produced and sold in Europe. The regulation mandates that cars sold in Sweden have to reach fleet average CO_2 emissions of 130 g/km by 2015 (European Commission, 2009).

In cooperation with the power utility Vattenfall and the City of Stockholm the Swedish government has started a national purchasing program for 6,000 EVs in which a part of the additional cost for these vehicles is paid by the Swedish government (Vattenfall, 2010).

Sweden imports all of its oil and all of the fuel for its nuclear power plants. Domestic energy sources are mainly hydro power and bioenergy. Electricity production from renewable energy sources had a share of 53 % in 2007 and shows an increasing trend (Swedish Energy Agency, 2009b, p. 40). The average CO_2 emissions of electricity production and distribution are 40 g/kWh (Econologie, 2008). This is an extremely low value that has to be seen in the context of the debate about (ecological) impacts of nuclear power in Sweden, which has a share of about 40% of total electricity production (World Nuclear Association, 2010). While CO_2 emissions from most sectors show a stable or a downwards trend, emissions from transportation have increased significantly compared to 1990 levels (Swedish Energy Agency, 2009b, p. 80).

5.2.2 EVs and electric mobility in Malmö

The City of Malmö is currently involved in two EV projects. They are called “E-Mobility Malmö” and “Plug-in City”. But this is not the first time EVs hit the streets of Malmö. At the end of the 90s the City of Malmö had a first EV trial. A case study from that time states that in “February 1999 [...] 52 of the 1143 municipal vehicles are electro or hybrid vehicles. [...] The project for introducing electro and hybrid vehicles expanded to the surrounding region of Skåne. The experience of Malmö shows that a strong municipal position can influence business activities and national policies.” (ICLEI, 1999). This appraisal of EV activity in and around Malmö in 1999 seems overly optimistic as a few years after the case study Malmö stopped the procurement of EVs due to a lack of cars and a lack of infrastructure and servicing capabilities (Hauksson, Interview). Nevertheless, many valuable experiences were made in this early EV project, that included electric car-sharing in the city district Augustenborg and a cooperation with several other communities in the Skåne region (ICLEI, 1999).

E-Mobility Malmö

E-Mobility started in November 2009 and will run for three years. The project could be seen as a continuation of the efforts in the late 1990s since it is again initiated by the City of Malmö and the power utility E.ON (which acquired the former project partner Sydkraft). The main objectives for the project are: greening transportation, creating a national demonstration case for fossil fuel free transport solutions, and integrating EVs in a comprehensive sustainable transport strategy. The grant proposal for E-Mobility Malmö was developed together with the consultancy firm WSP Environmental. The project receives 25 % of its funding (€1 million) from Energimyndigheten, the Swedish Energy Agency. The remaining €3 million are equally shared by the City of Malmö and E.ON. For the purchase of PEVs it means that Energimyndigheten pays 25 % of the additional cost for the vehicle as compared to similar CEVs (Mollstedt, Interview).

For E-Mobility Malmö a fleet of 70 PEVs, 60 scooters and e-bikes and one biogas-electric hybrid bus will be purchased. The plan for charging the vehicles includes 250 charging points of which 50-100 will be public. Some of the charging points will be designated charging posts that still need to be installed while other points will be existing outlets to which signage is added (Mollstedt, Interview).

The EV project is not isolated from other sustainable transportation efforts of Malmö that try to prioritize walking, biking and public transport to individual car traffic. There are three examples for the integrated approach Malmö is taking. First, car drivers shall be convinced to switch their means of transportation by introducing electric bikes and scooters. Second, charging points for EVs are strategically located at park and ride places to keep car traffic out of the city centre. And third, electric car-pooling shall make the utilization of EVs more efficient (Hauksson, Interview).

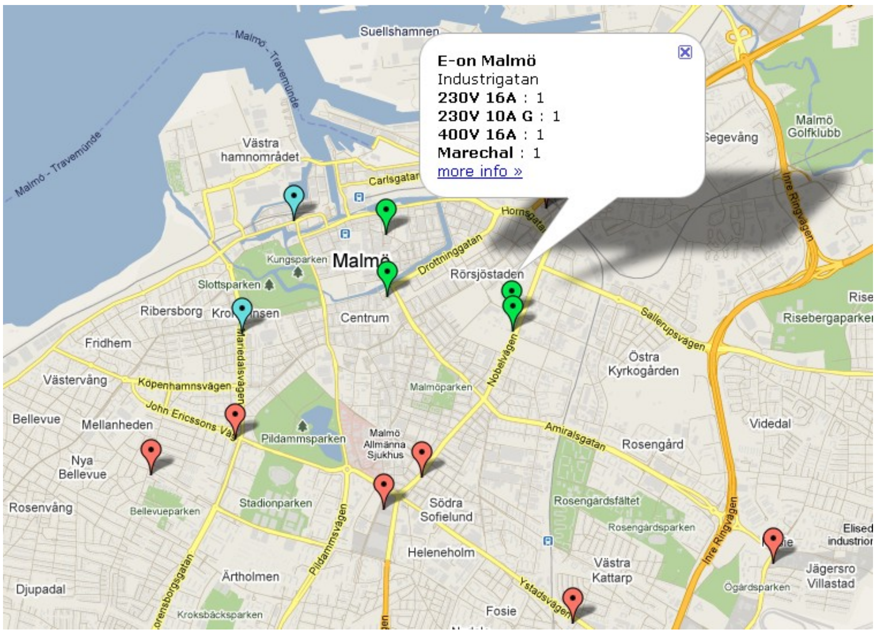

Figure 6: Charging stations in Malmö (Uppladdning.nu)

Plug-in City

The City of Malmö runs a second EV project that is closely related to E-Mobility. Plug-in City receives funding from the European Development Fund (EDF) for a three year period. The main objective is to improve the charging infrastructure for EVs and to investigate if EVs can be deployed on a large scale for the needs of Malmö City, in order to reduce the emission of GHGs and air pollutants. Furthermore, a feasibility study for an electrically propelled shuttle bus will be done. The areas of focus are the sustainable city district Western Harbour and the commercial district Svågetorp (Malmö Stad, 2009b).

Private and corporate EV use

There is no data about private and corporate use of EVs in Malmö which does not mean that there is no private and corporate use of EVs. More information exists about the public charging infrastructure that can be used by EV owners. The website “uppladdning.nu” gives an overview of charging points in Sweden and their specifications (see figure 6).

5.2.3 Actors and networks

The two main actors in EV deployment and EV readiness are the City of Malmö and E.ON Nordic. **Malmö Stad** (City of Malmö) is a large organization which had an administrative staff of 1350 people in 2006 (Malmö Stad, 2010a). Several departments are involved in the EV projects (e.g. Environmental Department, City Planning Office, Street and Parks Department). Malmö Stad wants to get off fossil fuels by 2030. This includes the greening of the municipal vehicle fleet. Per-Arne Nilsson, head of the Environment Strategic Division at Malmö Stad, explains: “Malmö's vision is that the future of car transport in the city is operated by biogas and electricity. Electric vehicles are preferred as they produce less noise and emissions. They will also positively support Malmö as it aims to improve environmental and air quality standards in the city.” (in City of Stuttgart, 2010, p. 5). Furthermore, for Malmö Stad EV projects function as an instrument to raise awareness amongst the city's inhabitants for EVs.

E.ON Nordic is an energy and energy-service provider with about one million customers. It is part of the international E.ON concern, one of the biggest energy companies in Europe. The headquarters of E.ON Nordic is in Malmö and its operations focus on the south of the country. EV (and biogas) projects fit into E.ON's strategy to abandon the simple “produce electricity and sell it”-model and increase activities downstream by offering more services. In Malmö E.ON's objectives are to green their own fleet, test billing systems for charging EVs and to explore a new business area by collecting and evaluating data from the EV trial. The main future benefit from an involvement in the EV and charging market is to improve customer relations and strengthen customer ties. The margins of selling electricity for charging EV batteries are too low to alone justify the investments. With increasing EV penetration rates also demand side management and grid balancing can become a beneficial aspect of EVs for E.ON (Mollstedt, Interview).

Further actors in the field of electric mobility are the consultancy WSP Environmental that accompanied the grant application process and the initial phase of E-Mobility and the Swedish Energy Agency that provided funding for the E-Mobility project.

One network that has been established for EV projects in Malmö is the **E-Mobility reference group**. In addition to Malmö Stad and E.ON it has the following members:

Skåne Region, Volvo, WSP Environmental, IKEA, McDonalds, Sunfleet, Trafikverket, IIIEE. The group meets three to four times a year. But exchange of information also happens outside regular meetings. The reference group is mainly used for consultancy and advice in technical questions and planning of charging infrastructure. Furthermore, the City of Malmö itself can be seen as a network. Malmö Stad is part of many public-private partnerships, e.g. a parking company of which Malmö owns 50 % (Hauksson, Interview).

5.2.4 Functioning of EV system in Malmö

Knowledge development and diffusion

The EV knowledge base in Malmö can just be described in relative terms since the depth of the case study does not allow for more. Malmö is ahead of other communities as it has the experience from earlier projects. One example for this is the issue of vehicle maintenance and servicing. High service frequencies and long service times were a problem of Swedish EV projects in the late 90s (Koucky, 2000). Because of this experience the project partners now try to address that problem early in the process (Hauksson, Interview). Furthermore, technological progress has solved some of the problems, e.g. Li-Ion batteries do not require refilling of water (Koucky, 2000). How EVs will fit in the transport system of Malmö and how supportive infrastructure, billing systems and permitting processes will work is not clear, yet. It is one of the main goals of the current projects to gather data, evaluate it and therewith increase the knowledge base for further integration of EVs into Malmö's transportation system.

Government intervention

Government intervention is a developed function within Malmö's EV system. Much of the EV activity in Malmö would not be possible without the involvement of Malmö Stad. In the context of the projects E-Mobility and Plug-In City, the city government is active in EV procurement, infrastructure installation and awareness raising. But so far most activities are restricted to funded projects. There are no incentives for the private EV user. Free parking and free charging for EVs and the access to environmental zones (that might be implemented in Malmö) are policy options that are considered for the time when the roll-out of EVs on the Swedish market starts (Mollstedt, Interview).

Entrepreneurial experimentation

Entrepreneurial experimentation with EVs and EVSE is not widespread in Malmö and its surroundings. Almost all experimentation takes place within the EV projects that were described above. There are virtually no new entrants into Malmö's EV system. One exception is Evol Technology AB which is a small start-up that develops a business idea around infrastructure for EVs (Mollstedt, Interview). Research institutes in the area do not give much push for entrepreneurial experimentation around EVs. The School of Technology at Malmö University does not do research in automotive or electrical engineering, and at Lunds Tekniska Högskola, the technical University in the neighbouring city of Lund, just little research in EV related areas takes place (Lund University, 2010).

Market formation

The state of the EV market formation in Malmö is easily exemplified by describing the purchasing process of vehicles that are used in the projects described above. There are no dealerships in the region that offer PEVs (except for a Tesla dealership in Copenhagen). To get vehicles the project partners have to resort to conversions of CEVs or HEVs or small city cars like the Think City. A popular conversion vehicle is the Fiat 500 BEV that is produced by EV Adapt close to Gothenburg (Karlberg, 2009). To increase the chances of getting some of the first series production models Malmö is also participating in a national procurement initiative for EVs (Vattenfall, 2010). With a lack of supply it is difficult to assess the demand in the area. One way could be to take the number of Toyota Prius HEVs or other alternative fuel vehicles as an indicator for future PEV demand.[7] The general interest in EVs is dealt with in the section about legitimation below. But already from the vague description of EV supply and demand above it becomes clear that EV market formation is not a well-developed function in the area of Malmö.

Legitimation

There are no studies that research the acceptance of EVs specifically in Malmö. Therefore, the analysis of EV legitimation in Malmö is based on a poll for the whole of Sweden and on impressions from expert interviews. Elforsk and Kairos Future have conducted a consumer study about interest in BEVs and PHEVs in Sweden (see Bandhold et al., 2009). The result of "Plug In Road 2020" is that 28 % of the participants are very interested in buying a BEV and 54 % in buying a PHEV. These numbers are even higher when quick charging is available (BEV: 73 %; PHEV: 84 %). The interest in PEVs was found to be higher in cities and industrial areas (Bandhold et al., 2009). That means that the interest in buying PEVs in Malmö is likely to be high. Furthermore, the study indicates that environmental legitimation of PEVs is bigger than technological legitimation. The results of the consumer study are supported by the findings of expert interviews. The environmental benefit of EVs has not been challenged by any interviewee, while technological issues and "of course, the battery" were topic of all talks. One interviewee identified the bad publicity caused by problems with EV technology in earlier trials as one of the barriers of private EV adoption in Malmö.

Resource mobilization

The EV projects in Malmö have received grants of the Swedish Energy Agency and of the EDF. With E.ON and Malmö Stad, two actors are involved that have the financial capabilities to dedicate an own budget for EV activities. Because of low entrepreneurial activity in the field of EVs the question of mobilizing financial resources for companies is not very relevant. When it comes to human resource mobilization much know-how can be found in the area of demonstration projects and organization. Malmö has had a pilot study before and the current project is supported by the know-how of a reference group. Human resources in technology aspects are minor in Malmö. The conversions that are used in Malmö have not been produced locally. No car manufacturer is part of the project team. And servicing and maintenance has already been an issue in earlier projects. Further assets that are relevant for EVs in Malmö are complementary products like public and private charging technology. The public charging infrastructure is planned for and some financial resources are available for it. The supply with EVSE is not a constraining factor. Most private households do not have to invest in charging equipment as the standard 220V outlet is sufficient to charge batteries over night. Many houses and also companies in Sweden even have outlets outside at their parking lots to feed the engine heaters in winter.

[7] A study in the U.S. has shown that owners of HEVs stated much more often that they would "definitely" purchase a PHEV than owners of conventional vehicles (EPRI, 2010, p. 3-2)

Throughout the country more than 600,000 of these outlets are installed (Swedish Energy Agency, 2009a, p. 81).

Interconnectivity

The actors that are active in the area of EVs in Malmö are linked with each other. The energy utility E.ON and Malmö Stad collaborate and consult with the members of the E-Mobility reference group. Furthermore, Malmö Stad is a big organization with a lot of network activity. Despite the existence of a network some links are weak and some actors are missing. One example is the Region of Skåne that is involved in several sustainable transportation projects (see Region Skåne, 2010) but is not a partner in one of the Malmö projects. A collaboration was planned for but decision-making in the process of setting up the project was too slow. Furthermore, no original equipment manufacturer (OEM) is involved. Volvo is part of the reference group but not a project partner. Without OEM it is difficult to get the number of PEVs that is stated in the project's objective. Björn Mollstedt of E.ON summarizes the situation as follows: "The project as it is run now should either have a smaller scale or, with such a big scale, also involve OEMs! It was a mistake to exclude the OEMs in the beginning just to start off more quickly." (Mollstedt, Interview). The collaboration between E.ON and Malmö Stad is in the centre of EV activities in Malmö. E.ON benefits by getting access to public funding and local contacts and Malmö Stad profits from the technological know-how and the financial participation of E.ON. The challenges of the collaboration are mainly rooted in organizational differences. In case of conflicts decisions are made at a higher management level within E.ON, while at Malmö Stad there is no clear hierarchy and conflicts are debated across departments which is a more democratic but also time consuming process that can delay progress.

5.3 Case: Aachen, Germany

Aachen is a German city in the west of the state North Rhine-Westfalia (NRW), close to the Dutch border. Nearly 40,000 of Aachen's 250,000 inhabitants are students. The Rheinisch-Westfälische Technische Hochschule (RWTH), the technical university of Aachen, is Germany's leading university in the areas of engineering and natural sciences (Stadt Aachen, 2010a).

Aachen started early to do climate protection at a local level and had its first climate action plan in 1992. But climate protection is not the only local driver for sustainable transport measures in Aachen. In Aachen the EU threshold for air pollutants has been exceeded several times so that Aachen had to present a plan how to reduce air pollution (Stadt Aachen, 2010b). Except for encouraging people to use the public buses and trains this plan also includes the introduction of EVs.

In Aachen several EV projects have been carried out. Before these projects are explained and analysed the following section gives an overview of the federal and state level context of the case study. This context includes EV-related policies and the structure of German energy supplies.

5.3.1 Context

In August 2009 the German National Electromobility Development Plan was published and the goal of one million registered EVs by 2020 was set (German Government, 2009). The second economic stimulus package that was set up by the Federal Government as a response to the economic crisis includes €500 million to the Ministry of Transport for the development and roll-out of EVs from 2009-2011. About one fourth of this money is used to support eight "Model Regions for Electric Mobility". In these model regions several pilot studies are carried out and infrastructure for charging EVs is installed. The rest of the stimulus money is used for R&D in the areas of batteries, EV components, grid integration and information and communication technologies (ICT) for EVs (German Ministry of Transport, 2010a).

In Germany no subsidies are available for the purchase of EVs. Nevertheless, some policies are in place to incentivise the use of EVs. For the first five years drivers of EVs do not have to pay the annual car tax. After five years a reduced tax applies to EVs. The annual tax for CEVs depends on the size of the engine and the CO_2 emissions and can amount to a couple of hundred Euros (German Ministry of Finance, 2010).

Furthermore, taxes for automotive fuels and electricity differ. At the current tax rates driving 1,000 km is €3.68 of taxes for EVs and €39 for CEVs (diesel €23.50) (see table 9 in appendix for calculation). If total fuel prices are considered the cost differential for driving 1,000 km is not that big (see for the fuel price differential of selected countries John Gartner, 2010a).

Like in Sweden cars made in Germany have to reach fleet average CO_2 emissions of 130 g/km by 2015 (EU regulation No 443/2009). As a result of an EV dialogue between the German government and industry representatives, Germany intends to lobby for multiple accounting of cars with tailpipe emissions below 50 g/km, e.g. EVs, when calculating the fleet averages (German Ministry of Transport, 2010b). This could be an incentive for car manufacturers to produce more EVs. On the other hand, it could also allow them to produce still many cars with high emissions. As another result of the industry dialogue the German government established a platform for information exchange about electric mobility.

Electric mobility is also dealt with at the state level. "NRW is the Auto-State", says Andreas Ziolek, responsible for EVs at the NRW Energy Agency. About 50% of the exports of NRW are related to cars. As a reaction to the crisis in the automotive industry the State NRW has developed an electric vehicle plan that is similar to the federal plan. It sets a goal of 250,000 EVs by 2020 and puts a focus on attracting OEMs and suppliers of EV components (Autocluster.NRW, 2009). The state government funds 22 EV projects that have a focus on technology with €46.5 million (NRW Ministry of Economy, 2010). Furthermore, the Rhine-Ruhr region in NRW is one of the eight model regions of Germany. Deploying innovative technologies in NRW is an expression of the State's structural change from coal and steel production to an innovation and service based economy.

Figure 7: STAWAG charging station (Pfeiffer, 2010b)

Today Germany imports most of its energy resources. Of all the petroleum that was used in Germany in 2008 just 3 % came from own production, the rest had to be imported. Germany is somewhat more self-sufficient in producing its electricity. Almost 100 % of the lignite that was used in Germany in 2008 was domestic. Coal (28 %) and natural gas (16 %) had smaller self-sufficiency rates and nuclear power was completely run on imported sources (German Federal Agency for Geo-Sciences, 2009). Renewable energy sources provided 16.3 % of the electricity that was consumed in Germany in 2009 (German Ministry for the Environment, 2010). The average CO_2 emissions caused by one kWh of the German grid mix were 575 g in 2009 (German Federal Environment Agency, 2010). The potential for radical cuts of CO_2 emissions (> 90 %) from electricity production by 2050 has been analysed and confirmed in two recent studies (Klaus, Vollmer, Werner, Lehmann, & Müschen, 2010; Prognos & Ökoinstitut, 2009).

5.3.2 EVs and Electric Mobility in Aachen

In the city of Aachen there are many activities in the field of EVs and electric mobility. Besides several projects that deal with R&D of EV technology there are two big projects that include the deployment of EVs in the city. They are called Smart Wheels and E-Aix. Below the two projects are presented and further projects are summarized.

Smart Wheels

At the core of this project is the R&D of ICTs for electric mobility. Smart Wheels is subdivided into nine parts. The project is run by a consortium of private and public companies and partly funded by the Federal Ministry of Economics and Technology. It is not the main goal of the project to create the infrastructure and institutional environment for the actual roll-out of EVs, but to research the communication between different modes of transportation, between EVs and charging stations, and between EVs and the local grid. The project includes the test of billing systems for battery charging and models for battery financing. Furthermore, it shall be investigated how EVs can be used as fleet vehicles (FEV Motorentechnik GmbH, 2010). In order to be able to collect enough data to test ICT solutions, hardware has to be tested in a real life setting. In this case the hardware includes one electric bus, 12 BEVs that are conversions of the Fiat 500, and 20 electric scooters that are available on the market. In addition to the vehicles, charging infrastructure is installed and tested. The Smart Wheels project is a sister project of Smart Watts that deals with smart grid solutions in Aachen. The project leader of Smart Wheels is FEV Motorentechnik GmbH, an automotive service company. Further partners are the local utility STAWAG, the RWTH and Mennekes GmbH, a company for plugs, wiring and switches.

E-Aix

Despite a different geographical location the project *E-Aix* in Aachen is part of the model region Rhine-Ruhr that is funded by the Federal Ministry of Transport. The core of the project is to test if it is possible to realize a comprehensive traffic concept based on electric mobility in a middle sized city like Aachen. This includes two-wheelers, four-wheelers, vehicles for the public transport system and utility vehicles (Pfeiffer, 2010a). The project has a volume of nearly €6 million and several public and private actors are involved. This again includes STAWAG and the RWTH. Furthermore, the innovation centre for mobility InnoZ, in which the Deutsche Bahn AG is involved, is one of the project partners (see InnoZ, 2010).

Further initiatives

In addition to the two big EV projects there are several other electric mobility initiatives in Aachen. RWTH and STAWAG are testing electric scooters. The local public utility STAWAG also subsidizes the purchase of an electric two-wheeler, scooter or pedelec, with either €100 or a six months ticket for the public transport system. For customers of STAWAG charging both two-wheelers and cars is free. Currently there are three public chargers with several outlets each.

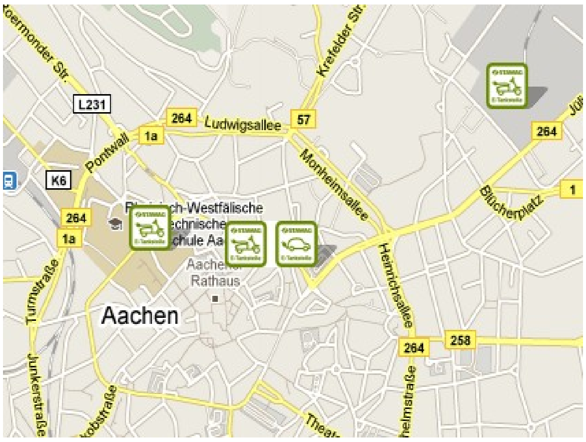

Figure 8: STAWAG charging stations in Aachen (STAWAG, 2010a)

Private and corporate EV use

It is difficult to assess the private use of EVs in Aachen. While there are already many private users of scooters and pedelecs the use of electric cars is mainly restricted to participants of the EV projects.

5.3.3 Actors and networks

The main actors in Aachen's EV projects are the local public utility STAWAG, the RWTH, the City of Aachen and the automotive service company FEV Motorentechnik GmbH. There are various additional companies that are involved in electric mobility activities in Aachen.

The local public utility **STAWAG** is completely owned by the City of Aachen. It is the most active player in Aachen's EV efforts. STAWAG is leader of the E-Aix project and partner of Smart Wheels. For STAWAG the topic electric mobility is important for strengthening consumer ties and developing sustainable transport solutions (Pfeiffer, 2010b).

As mentioned above the **RWTH** is one of the leading technical universities of Germany. It has departments for automotive engineering, for city planning, for production engineering and for power electronics and electrical drives. The RWTH is project partner of both Smart Wheels and E-Aix and brings in its expertise in the above mentioned fields. For the Smart Wheels project the RWTH builds the electric bus. In the E-Aix project it is researching the driving behaviour of the test vehicles. As a public university the RWTH does not have resources to take part in the funding of the projects. In addition to being partner in the two projects RWTH does R&D of EV components, e.g. the development of a new electric motor in collaboration with the companies Audi and Bosch.

The **City of Aachen** plans a city-wide EV task-force that enables coordination between different projects. The City is the owner of the utility STAWAG, the public transport company ASEAG, the parking company APAG and the IT service provider regioIT that are all involved in EV activities in the city. The City of Aachen supports the EV activities of STAWAG with €26,000 per year which is part of the strategy to decrease air pollution (Stadt Aachen, 2010b).

The automotive service company **FEV** is active in the field of EVs and hybrids for more than five years. In addition to conventional engine technology it develops drive-train solutions for BEVs, PHEVs and REVs. Because of its know-how in auto making FEV does the conversions of the Fiat 500 for the Smart Wheels project. FEV is the leader of this project (Wolters, Interview).

Another important actor is the **Mennekes** company that is one of the world market leaders for plugs, wiring and switches. The company which is based in Germany has also started to position itself in the business area of EVSE. It offers a variety of different charging posts and wall-mounted charging solutions (Mennekes, 2010).

In addition to the project groups around the topic electric mobility different other **networks** exist in Aachen. The Trianel GmbH, a group of 47 communal public utilities that is located in Aachen, started a sub-group for advancing electric mobility (Trianel GmbH, 2010). The association CAR Aachen bundles competencies in the automotive sector in Aachen and explicitly aims at synergies from networking and cooperation (CAR e.V., 2010).

5.3.4 Functioning of EV system in Aachen

Knowledge development and diffusion

Technological expert knowledge is very developed in Aachen. The automotive engineers of the technical university RWTH and professionals in the field of EV engineering know about and develop state-of-the-art technology. Two professors of RWTH developed the first hybrid car of the world in 1972 (Alt, 2007). In addition, the know-how in related areas like ICTs and plugs and wiring technology forms a good basis for EV projects in Aachen. With the city-owned companies STAWAG and regioIT Aachen also has organizations that are familiar with the execution of this kind of projects. The process of EV knowledge diffusion from the experts to the inhabitants of Aachen is described in the legitimation section.

Government intervention

There is no explicit strategy for EVs in Aachen that contains objectives for the city. The institute for city planning (ISB) at Aachen's University has tried to transfer Germany's target of one million EVs by 2020 to Aachen. If Aachen aims for its proportionate share it would need about 2,700 registered EVs by 2020 (Pfeiffer, 2010a). The City is mainly active through its utility STAWAG which is involved in all major projects. In cooperation with the city they offer a subsidy for the purchase of electric two-wheelers and for customers free charging. The City itself is mainly involved when it comes to city planning, e.g. the City issues the permits for public charging stations. This is not a mere formality since EV charging (and parking) lots take away valuable parking space for other cars that might use the parking more frequently. This became clear when STAWAG made a request to build several new charging stations at seven different places (Eimer, 2010). In cooperation with its partners the City is also active in raising awareness for EVs. One example for this is the EV exhibition it organized this summer which was accessible for the general public (STAWAG, 2010b).

Entrepreneurial experimentation

Dr. Peter Wolters, who leads the Smart Wheels project for his company FEV, is sure that the vivid entrepreneurial environment in Aachen and several innovative companies are very advantageous for the EV development in the city. Electric mobility is a boom topic and many new actors want to join the movement. It is clear that the RWTH with one of the world's leading automotive engineering institutes plays a core role in the entrepreneurial development. Many researchers bring their know-how to companies, some of which are in the region, or spin-off their research activities in small start-ups. The Street Scooter is a fully functional BEV for the city that is developed at RWTH (RWTH, 2010). Also in the area of utilities there is entrepreneurial activity in Aachen. In cooperation with the local utility of Duisburg STAWAG has founded a company for the transfer of knowledge from EV projects. The smartlab innovation enterprise wants to develop and offer business models for local utilities in the area of electric mobility (Smartlab, 2010).

Market formation

In Aachen, and in other cities alike, it is not possible to go to a car dealer and choose the EV that you want. While there is a mature market for electric scooters and pedelecs, supply of electric cars is very scarce. For the demonstration projects in Aachen the FEV does conversions of conventional cars. An all electric bus called “Cityliner” is built by the university. But only one Cityliner instead of initially planned four buses can be delivered to the public transport company ASEAG because of its exorbitant costs (Strauch, 2010a). It is impossible to assess the (potential) private demand for plug-in electric cars in Aachen. The current demand is conditioned by demonstration projects and the electrification of company fleets. Demand for electric two-wheelers is increasing.

Legitimation

Legitimation in Aachen is improved through the presence of EVs in media and show cases of EVs in everyday mobility. The local newspaper “Aachener Nachrichten” had a series about EVs beginning of 2010 (Aachener Nachrichten, 2010). STAWAG advertises its activities in the area of EVs. The first project vehicles are on the streets. As part of the strategy electric two-wheelers function as a means of introducing electric mobility in Aachen and make it visible for everybody. One example is free pedelec test weeks for companies in the region. Commuters of the companies can test the bikes and the charging equipment one week for free (Stadt Aachen, 2010c). Opinion polls that disclose the public acceptance of EVs in Aachen do not exist.

Resource mobilization

The EV projects in Aachen are funded by different federal ministries. But this kind of funding requires industry partners to participate with about 50 % of the total project volume. “That means corporate partners need to have a utilization perspective”, stresses Peter Wolters, whose company FEV is in charge of the Smart Wheels group. If big automakers were involved in the project much more financial resources could be mobilized. But their financial power would be accompanied by strong interests that might diverge from other project partners. Compared to other places Aachen has attracted many financial resources. More public financing might be available if Aachen's proposal for participating in a big EU initiative called “Electric Vehicles for Advanced Cities” is successful (Strauch, 2010b). As can be seen in the section about entrepreneurial experimentation human resource mobilization is not a problem in Aachen, which has the RWTH with its tradition in automotive engineering. Mobilization of further assets like EVSE functions very well in Aachen. One of the project partners, Mennekes, is a leading European EVSE producer. The Mennekes EV charging plug is standard in Europe at the moment and allows for a quick charging process (Wikipedia contributors, 2010a). Home charging for private EV owners is possible with conventional 220V outlets that are in place in all homes. If private households want to invest in quicker charging at home the technology for this exists.

Interconnectivity

The main advantage of the EV network in Aachen is that "many local partners are involved who know each other from earlier collaboration" (Wolters, Interview). In the Smart Wheels project official meetings happen every four months but actual interaction takes place almost every working day. This shows that there are not just many links between actors in the EV field but also high quality links with frequent interactions and collaboration. To coordinate scattered EV efforts better and to be able to market the progressive location Aachen the City plans to install a "Taskforce" for electric mobility. The EV network in Aachen is not restricted to the region. As part of the Model Regions program Aachen exchanges information within the Model Region Rhine-Ruhr and other participating regions in Germany. Several actors in Aachen are part of networks that do not exclusively deal with EV, like the CAR Aachen association and the Trianel GmbH that were mentioned above.

5.4 Denver, USA

Denver is the capital of the State of Colorado and it is located just east of the Rocky Mountains. Because of its elevation of 1,609 meters it is often referred to as the "Mile-High City". Denver has about 600,000 inhabitants and more than three million people live in the metropolitan area (Wikipedia contributors, 2010d).

Several research institutes are based in the metropolitan area of Denver. The National Renewable Energy Laboratory (NREL) has its facilities in the suburb Golden. In Boulder the National Institute of Standards and Technology (NIST), the National Center for Atmospheric Research (NCAR) and the University of Colorado (CU) with more than 30,000 students are located.

The City of Denver has a climate action plan that puts a focus on energy efficiency in buildings. Within transportation planning of Denver the focus is on cycling and public transport, not on EVs. The transportation system of Denver is heavily based on individual car traffic. Public transport has just a minor share of all commutes (see figure 9). A public bus and a public light-rail network exist. An expansion of the light-rail grid is planned. Furthermore, cycling in Denver will be promoted by increasing the network of cycling paths and extending the bike-sharing program. The neighbouring city of Boulder is one of the most bike-friendly cities in the U.S. and serves as a role model for its bigger sister Denver in several environmental questions (Marshall, Interview).

5.4.1 Context

The Obama administration has announced a goal of one million EVs by 2015. To reach this goal several support policies have been put into place. Of the stimulus money under the American Recovery and Reinvestment Act the U.S. Department of Energy (DOE) invested more than $5 billion in the electrification of the transport sector. About $2.4 billion were given to EV battery and component manufacturers. Furthermore, the DOE sponsors "The EV-Project", a project for the deployment of EVs and charging infrastructure in 16 U.S.

cities, with \$115 million. In addition to about 15,000 charging stations in the EV-Project, Coulomb Technologies got a \$15 million grant of the DOE to install another 5,000 chargers. The federal administration gave \$2.6 billion of loans to big EV manufacturers like Nissan, Tesla and Fisker to establish production plants (U.S. Department of Energy, 2010a). Within the energy bill, that is currently for discussion in the U.S. Senate, a set of further PEV support policies with a volume of \$4 to \$6 billion has been suggested (McDonald, 2010).

The PEV support under the energy bill might include a continuation or even increase of current PEV subsidies. The federal government gives up to \$7,500 in tax breaks to buyers of PEVs. The size of the subsidy depends on the storage capacity of the battery. At a battery capacity of 16 kWh the maximum subsidy is reached (U.S. Department of Energy, 2010c). In Colorado there is another subsidy for alternative fuel cars of up to \$6,000 in tax credits. This credit "is a percentage of the difference between the cost of the vehicle and the cost of the same or most similar vehicle that uses a traditional fuel."(Colorado Department of Revenue, 2010, p. 2). Before the tax credit was limited to \$6,000 some buyers of the Tesla Roadster had benefited from a tax reduction of \$42,000.

The taxes for automotive fuels and electricity in the U.S. differ from state to state. In Colorado gas and diesel taxes are a mixture of federal excise duty and state tax. There is no specific tax for electricity except for the general sales tax that differs from county to county or even from city to city. Driving 1,000 km in Colorado costs less than €1 of taxes for EVs and €5 for CEVs (diesel €4.65) (see table 9 in appendix for calculation). If instead of just taxes total fuel prices are considered the relative cost differential for driving 1,000 km is not that big any more. Because of low fuel taxation the potential savings from driving an EV in the U.S. are low compared to other countries (for an international comparison of the fuel price differential see Gartner, 2010a).

The CO_2 emissions of cars and trucks in the U.S. are indirectly regulated by the Corporate Average Fuel Economy (CAFE) standards. For the model years 2012-2016 the CAFE standards will be merged with a fleet average CO_2 emission standard of 155 g/km (250 g/mi) for all passenger cars, light-duty trucks, and medium-duty passenger vehicles. If this emission average was to be reached just by improving the fuel economy it would mean a CAFE of 6.6 l/100km (35.5 mpg) (U.S. Environmental Protection Agency, 2010).

Electric vehicle policies and fuel economy standards are ways to reduce the dependence on foreign oil. In 2005 transportation accounted for about 70% of total petroleum use in the U.S. More than 60% of the transportation petroleum was used for light-duty vehicles (U.S. Energy Information Administration, 2007). The share of imported liquid fuels (mainly oil and petroleum) was about 60 % in 2009. Because of rising oil prices there is a trend towards a higher share of domestic production of oil and therewith a higher degree of self-sufficiency (U.S. Energy Information Administration, 2010a, p. 77). Since many domestic oil reserves are expensive to exploit and the risk for the environment has been shown in accidents like the oil spill in the Gulf or the Exxon Valdez catastrophe in Alaska, domestic oil production will not be the solution for high oil prices and high import dependency.

Electricity production in the state of Colorado is mainly based on coal. Renewable energy sources (including hydro power) had a share of 10 % of the electricity production in 2008 (U.S. Energy Information Administration, 2010b). In the same year the average CO_2 emissions in Colorado were 776 g/kWh (U.S. Energy Information Administration, 2010b). Until 2030 the state will gradually increase its Renewable Electricity Standard for big utilities to 30 % (Bartels, 2010). Furthermore, legislation that pushes utilities in Colorado to replace coal-fired power plants with natural gas plants was passed in 2010 (Slevin, 2010).

5.4.2 EVs and electric mobility in Denver

The City of Denver has some activity in the field of EVs and electric mobility – despite the fact that Denver has not received any grants for demonstration and infrastructure projects so far. A grant proposal to the U.S. DOE called "FEVER – Funding Electric Vehicle Expansion in the Rockies" that was put together by the Clean Cities Coalition of Denver in cooperation with several communities in the area did not receive funding. Denver is partner city of "Project Get Ready" of the Rocky Mountain Institute (RMI), which is located close to Denver in Boulder.

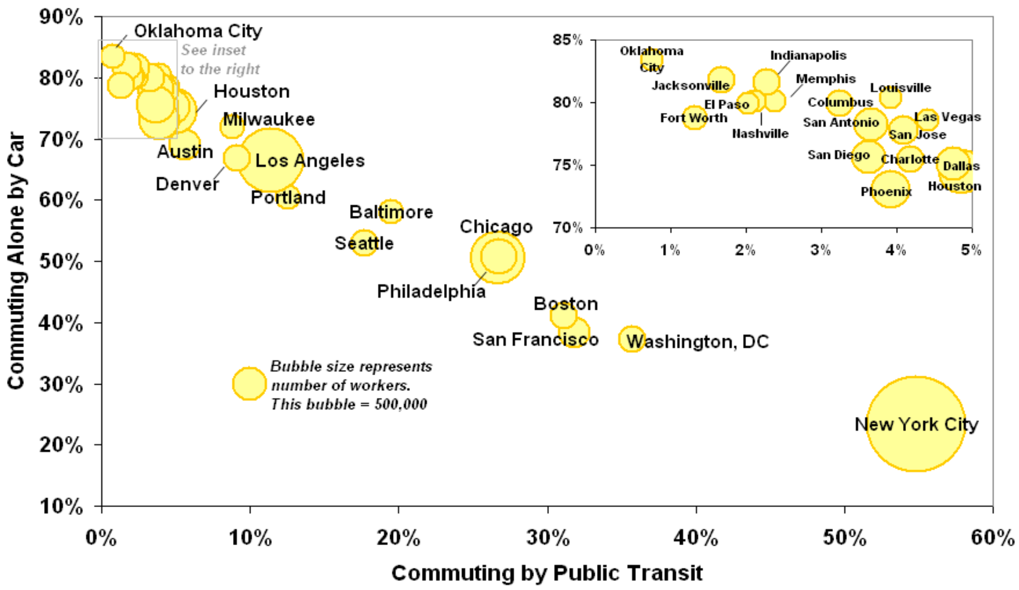

Figure 9: Commute patterns of major U.S. cities 2008 (Wikipedia contributors, 2010e)

Project Get Ready

The Project Get Ready (PGR) initiative of RMI has created a set of actions to be taken by cities to get “plug-in ready”. PGR functions as a platform for the exchange of information between technology advisers, city planners and industry representatives. PGR Denver is run by the Colorado Plug-In Vehicle Working Group that consists of several public and private actors of the region. The actions under the PGR framework are all voluntary and depend on the willingness and the capabilities of the project partners (Mattila, Interview).

The City of Denver has installed one charging station so far. There are some additional private charging points that are publicly available. The goal of Denver is to install another 5-10 charging stations in 2011. While the municipal fleet has many alternative fuel vehicles there are few PEVs so far. Denver has converted one jeep to a PHEV. Additional PEVs will be added to the fleet if the conversion proves successful and when vehicles will be available on the market (Marshall, Interview).

Private and corporate EV use

Environmentalist, early adopters, organizations that research EVs – that could be the summary of actors who own PEVs in the Denver area. The Tesla dealership in Boulder, favouring federal and state policies, and a liberal and green surrounding could be reasons why 60-70 Tesla Roadsters, $109,000 sports BEVs, have been sold in the area. The power utility Excel has six PHEV conversions and also NREL has converted PEVs in its fleet that are tested and evaluated for their research. It is hard to get an overview of how many additional PEVs and conversions are owned by private persons and company fleets (Marshall, Interview).

5.4.3 Actors and networks

Several actors in the Denver area deal with EVs. They can be roughly divided into two groups, R & D of EVs and local implementation of EVs. The **City of Denve**r is the organization that is responsible for the implementation of EV related infrastructure and institutions in Denver. The City leads the PGR project team. But except for some labour time for exploration and planning the city does not put many resources in EV readiness and deployment.

The second major actor for local EV adoption is the **Denver Metro Clean Cities Coalition** at the American Lung Association in Colorado. The Clean Cities partnership between government and industry has been started by the U.S. DOE in 1993 and consists of about 90 coalitions throughout the country. Their main objective is to reduce petroleum consumption and promote alternative fuels and vehicle technologies (American Lung Association, 2010). The Clean Cities coalition in Denver is pushing for EVs which have the big advantage of improving urban air quality. Clean Cities works in the fields of organization and awareness raising but does not have a budget for implementing EV projects themselves (Swalnick, Interview).

Likewise the **RMI** is not involved in the actual implementation of EV projects. The trademark of RMI is to be an “independent, entrepreneurial nonprofit think-and-do tank” in the field of energy efficiency and restorative resource use (Rocky Mountain Institute, 2010a). In the Denver PGR team RMI has the role of a consultant. It offers technical information, policy options and connections to further experts and practitioners.

Some of these experts and practitioners can actually be found in the Denver area itself. **NREL** runs several research projects around EVs, e.g. about vehicle batteries, thermal aspects of power electronics, and grid integration of EVs (National Renewable Energy Laboratory, 2010).

Xcel Energy is the biggest power utility in the region and, like all actors mentioned above, member of the Colorado Plug-In Vehicle Working Group. Within a Smart Grid research project that Xcel runs in collaboration with NREL in Boulder, PHEVs are deployed and the V2G technology is researched. While V2G is still far away from being a mature technology Excel has successfully tested demand side management by switching off customers' air conditioning for 15 minutes when demand peaks occurred (Xcel Energy, 2010).

Another group of actors that is involved in the development of EVs are **small and innovative companies**. Bright Automotive is a spin-off of the RMI and develops lightweight PHEVs (but has moved away from the Denver area). Boulder Electric Vehicles will start to produce purely electric, small delivery trucks by the end of the year. EEtrex does plug-in conversions and develops V2G technology.

The companies mentioned above are all members of the transportation group within the **Colorado Cleantech Industry Association** (CCIA). This group meets regularly every four month to deal with regulatory issues, tracking of latest developments, issues they want to promote, ways to get into (public) fleets and the exchange of business ideas. The CCIA is one of the networks of the EV system in the Denver area (Shapard, Interview).

Furthermore, both the Clean Cities coalition and PGR are not restricted to Denver. They are part of **networks**: in case of Clean Cities a network with the other 90 coalitions most of which deal with EVs, and in case of PGR a network with other PGR cities, technology advisers, associations and the EV industry. An international network which Denver is part of is the U.S.-China "Eco-Partnership". It connects the City and County of Denver, City of Chongqing, Ford Motor Company and Chang'an Motors (Rocky Mountain Institute, 2010b).

5.4.4 Functioning of EV system in Denver

Knowledge development and diffusion

The Denver area is a place with a high concentration of technological EV know-how. Research institutes and companies have worked with the topic for several years. But so far no bigger demonstration or pilot project has taken place in Denver. Practical experience with EVs is restricted to few early adopters, some researchers and scattered fleet vehicle users. It is not clear how the concentrated knowledge within specialized organization will diffuse to EV deployment on the ground in Denver. At least the importance of educating service and maintenance staff in EV matters, as well as raising awareness amongst the general public has been recognized by several members of the PEV working group in Denver. Natalia Swalnick of the Clean Cities Coalition states: "I would not put a grant proposal together without an educational perspective in it."

Government intervention

Denver does not have a comprehensive EV strategy that could give orientation for political interventions at the city level. Nevertheless, Denver is active in several areas. Green procurement of vehicles has a long tradition in Denver and the municipal fleet has many vehicles that run on bio-fuels, compressed natural gas (CNG) and HEVs. When PEVs are available on the market at non-prohibitive costs the green procurement policies and practices in Denver are in place. Denver does not have a dedicated budget for EV procurement and infrastructure installation. Financing is decided on a case to case basis. There are almost no local incentives for private EV users. Denver has considered preferential parking for EVs and created one parking lot that is reserved for HEVs. This might be changed to preferential PEV parking in the future (Marshall, Interview). For people who want to install Level II charging to charge their EVs at home more rapidly, the City of Denver "has developed a plan to allow quick turnaround […] to obtain permits" (Rocky Mountain Institute, 2010b).

Entrepreneurial experimentation

This function has a high degree of development in the Denver area. "Many different research institutes [mentioned above] make it an appealing EV test market", states Matthew Marshall from the City and County of Denver, and continues: "There are many companies that work on innovative technologies – Boulder EV, engine manufacturers and companies that make plug-in conversions." In addition to innovative technologies coming from research institutes, Christine Shapard, Executive director of the CCIA, adds relatively low taxes, technology incubators and successful entrepreneurs that attract venture capital to the list of reasons why this region of Colorado has one of the best environments for start-ups in the whole country.

Market formation

The supply with electric cars in Denver is not zero. There is a Tesla dealership in Boulder, an EV dealer called "Smart Wheels" in Denver and different companies that offer conversions. But the supply is either very exclusive (Tesla and conversions) or does not offer the full functionality of cars (scooters, NEVs). A mass-produced PEV city or family car is not offered, yet. The Nissan Leaf and Chevy Volt will be offered in Denver from end of 2011 on. The market introduction of the first PEVs will happen in other states than

Figure 10: Denver's EV plan from a competition in 1993

Colorado which can be taken as an indicator of the expected demand. There are no studies about EV demand in Denver. But 60-70 Tesla Roadsters in the area and hundreds and thousands of Toyota Prius give a hint that there is at least initial demand for PEVs (Marshall, Interview). The process of market formation has started in the Denver area. But it is still driven by the supply side and big uncertainties about the demand for EVs remain.

Legitimation

Wide acceptance of EVs is important for the dissemination of EVs. Natalia Swalnick of Clean Cities finds a risk in supporting EVs too early "It is risky if public charging infrastructure is in place but nobody ever uses it. That gives EVs a bad image. In the 1990s CNG has been tested in Denver, but it didn't work. This caused a bad image of CNG that it has until today in the region." Mike Simpson of NREL also sees a legitimation problem with insufficient performance of EVs: "Redundancy is an important value here. People in the U.S. often want big cars with a big range." There is no opinion poll for the Denver area that could support these statements. A survey by the consultancy Ernst&Young show that in the whole of the U.S. about 75 % consider access to charging stations, price and battery driving range as factors that make them hesitant to buy a PEV. Still there are many potential early adopters. About 13 % consider buying a PEV once they are available. More than 90 % see fuel saving as a favourable factor in the purchase decision (Ernst & Young, 2010).

Resource mobilization

The mobilization of financial resources for EV technology and EV deployment in Denver is different for the City itself and other actors. The City of Denver has, partly because of the economic downturn, a very tight budget. So far roughly $30,000 have been spent for EV equipment. The acquisition of grants has not been successful so far. With proceeding market formation more money, that is spent on other alternative fuel vehicles at the moment, might be diverted towards PEVs (Marshall, Interview). It is hard to get a general idea of the financial situation of the companies and research organization in the area. While companies like Boulder Electric Vehicle are in need of more financial resources through loans, grants or venture capital to ramp up production (Dameron, Interview), NREL and Xcel have the budget or funding for R&D projects in the area. According to several members of the CCIA transportation group, the lack of venture capital is a problem but not a problem that is characteristic for the EV sector. Venture capital funds in general have dried up during the financial crisis. The mobilization of human resources is not a problem in the area, yet. The lack of specialized power engineers was identified by some members of the CCIA transport group as a nationwide issue. But the high quality of life and the innovative environment make it easy to get workers to Colorado once they have been identified. A lack of human resources in the areas of EV development, EV production and EV servicing might occur when the industry keeps on growing (CCIA group meeting, personal communication, July 19, 2010). Mobilizing further assets like infrastructure has not been a bottleneck of EV deployment in Denver, yet. The market for charging stations, steering software and further complementary products is much better developed than the market for EVs itself. As long as financial resources are available the necessary further assets are available as well. For private PEV drivers charging their vehicle requires investments in charging equipment if they want to avoid long charging times via regular 110V outlets.

Interconnectivity

Several networks around EVs in the Denver area exist. The CCIA brings together industry actors but it is also open for organizations like Clean Cities and RMI as well as the City of Denver. The Colorado Plug-In Vehicle Working Group comprises all important actors that are relevant for the implementation of programs in Denver. This group is connected to the PGR network of RMI in which important EV stakeholders from all over the country are connected. Furthermore, direct collaborations like the one of NREL, Xcel and the City of Boulder in a Smart Grid project increase the interconnectivity. While all important actors in the region are connected with each other and platforms for the exchange of information and collaboration exist, actual collaboration and the flow of information are limited. One example is the PEV working group. Matthew Marshall of the City of Denver, that takes the lead in this group, is aware of the low activity of the group and speaks about "reviving it soon again". Clean Cities representative Natalia Swalnick agrees with that: "We have not met in a while and definitely should meet more often." She adds that "it takes time to manage big coalitions and to set up a worthwhile agenda." A second example for the limited usage of the EV network in the region is the role of the power utility Xcel that is both a member of the CCIA and the PEV working group. Several stakeholders in the region criticize Xcel as being passive and not utilizing its opportunities with respect to EVs. Xcel could play a much bigger role in EV grid integration, demand side management and the build-up of charging infrastructure. It is not clear which actor is in the core of the Denver EV network. This situation can be exemplified by the consideration of merging the PEV working group into the CCIA. So far there is no single actor or organization with the necessary expertise, structure and leadership qualities to mobilize the network.

6 Analysis

Following the framework that is outlined above, the analysis will consist of four parts. First, different goals for the development of EV city systems will be presented and discussed. Because of the involvement of different stakeholders and varying settings this cannot result in a framework that works for all cities and all actors. Second, a summary assessment of the functioning of the three EV systems will be given. This will be followed by an evaluation of the blocking and inducing mechanisms that influence the functioning in the three cases. Finally, some critical issues that have emerged from the analysis will be discussed more in-depth. The basis for the analysis is the data from the three case studies. But in addition to that, data from other cities that have been researched in the course of this study will be consulted where it adds to the analysis.[8]

6.1 Goals for the functioning of EV systems in cities

Different stakeholders have different goals, for themselves, for the whole EV system, short-term or long-term, general or specific. For this study, individual interests were separated from goals that refer to the whole EV system by asking stakeholders two different types of questions. The first one was about the individual motivation to participate in an EV project or to be active in the field of EVs. The second one was what outcome of an EV project or EV efforts in a city could be considered a success. While many interviewees gave conclusive answers to the first type of question, the answers to the second question were mostly vague and abstract or referring to the first type of question.

The most distinct goal could be detected for the **power utilities**. At first glance power utilities sell electricity, EVs consume electricity and power utilities, therefore, support the dissemination of EVs to sell more electricity. But the market for EV electricity is difficult. For many years the additional electricity demand through EVs will remain marginal. Björn Mollstedt of E.ON is very explicit about this point: “The business case is definitely not selling more electricity. The margins on this market are very low.” Susanne Stark of the public local utility of Düsseldorf, which is another project city in the Model Region Rhein-Ruhr, comes to the same conclusion. The real motivation is to “strengthen customer ties and improve customer relations” (Stark, Interview). Offering mobility services, e.g. subscriptions for green EV electricity, can tie customers to a utility and its whole set of services and products. Furthermore, EVs are good for the (green) image of a utility. Less prominent goals of utility participation in EV projects are the accumulation of know-how and grid services that EVs might provide in the future (Simpson, Interview).

The goal of **Car manufacturers** is to sell more cars. EV projects are used to collect data about consumer behaviour and technological aspects of the vehicles. Integrated transportation solutions are usually not the focus of automakers. The strong business interest of car manufacturers was repeatedly brought up by different stakeholders in EV project groups as a reason not to include them in the project.

Researchers have also an interest in data collection and evaluation of pilot projects. The type of data differs between technology related information, e.g. battery capacity and additional grid load caused by charging vehicles, and drivers' behaviour. The interest in

[8] The additional locations that were researched are Copenhagen, Düsseldorf and several places in the USA (Portland, State of Rhode Island, San Francisco Bay Area). The data for these locations was obtained from further interviews and secondary literature.

data collection is part of the greater goal of finding ways to make mobility more sustainable that drives much of the research in this field.

City governments and regional governments follow different goals with EV projects. Primarily the goals are environment-related. In Denver EVs are part of the City's climate action plan. In Malmö the context for EV deployment is also the reduction of GHG emissions. Aachen views the potential of EVs in reducing urban air pollution. Andreas Ziolek, who is the coordinator of the Model Region Rhein-Ruhr, views air pollution as one of the main drivers in Düsseldorf as well. Noise pollution has not been brought up by any of the city planners. An additional goal of cities and regions is the positioning as attractive business locations. Andreas Ziolek names the goal of creating an environment for long-term efficient (EV) companies when asked for the motivation behind EV efforts in the Model Region Rhein-Ruhr. In Malmö and the neighbouring city of Copenhagen another central goal of EV projects is to create show cases, both for the inhabitants of the city and for other cities. Casper Harboe, who led the EV program of Copenhagen until early 2010, states: “What's really important is that the City acts as a driver.”

For many stakeholders the question of how **overall success of EV efforts** could look like is difficult to answer. The most frequent answer is very pragmatic: It is a success if we can carry out the project as it was planned, with all the vehicles on the streets, some charging infrastructure in place and data collection for evaluation (expressed in a similar way by Wolters, Stark, Mollstedt, Swalnick). Furthermore, some stakeholders explain what success does not look like: “A comprehensive charging infrastructure is not what is needed for success.” (Wilke, Interview). Matthew Marshall of the City of Denver, which does not have a funded EV project, has a longer term perspective: “It is a success if we start seeing EVs having the penetration that HEVs have right now in Denver. It would be great if EVs have a similar adoption curve as HEVs and they are on the streets as hundreds and thousands.” Peter Wolters, leader of the Smart Wheels project in Aachen, adds to his pragmatic answer by referring to the bigger picture: “It would be a success if we can make a contribution to finding out how the future of transportation could look like.” Peter Wolters' statement is a good summary for this section. Most actors are still in the process of “finding out”. There are too many uncertainties for most stakeholders to be confident about formulating ambitious and visionary goals.

6.2 Summary assessment of the functioning of EV systems in cities

Since it is hard to define success for the development of EV city systems, there is little orientation for the assessment of their functioning. Hence, just the relative strength or weakness of each of the seven functions is assessed for the three case studies. Furthermore, some differences and commonalities between the case studies are presented.

The functioning of **Malmö's EV system** is limited. The main reason is the poorly developed market formation. There is virtually no supply. Furthermore, little entrepreneurial experimentation around EV technology and business models takes place. Accordingly, the knowledge base around vehicle technology and conversions is small. Because of earlier projects the knowledge in project organization, infrastructure planning and accompanying policy measures is available. The city government is active in the context of the current EV projects but does not intervene any further. A major strength of the EV system in Malmö is the high degree of legitimation of alternative fuel vehicles like EVs by the general public. Another strength is the mobilization of financial resources that resulted in two large EV projects in the city. The interconnectivity between the project partners E.ON and Malmö City and the reference group is well-developed. The absence of an OEM in the project and in the region affects several functions of Malmö's EV system. An OEM could bring further technological knowledge to the region, mobilize and attract further resources and, most importantly, bring cars.

There are several similarities between the EV systems in **Aachen** and in Malmö. Aachen has attracted financial resources for large demonstration projects, many local partners are involved that form a well-connected network, there is some support for EVs by the city government, the legitimation for EVs is high and there is no market for electric cars. But there are some major differences as well. Because of the promotion by STAWAG a market for electric two-wheelers in Aachen has formed that helps to increase legitimation for other types of EVs. Technological knowledge and entrepreneurial experimentation are better developed in Aachen which is due to the excellent technical university RWTH and several companies in the field of automotive and electrical engineering. Still the overall functioning of the EV system in Aachen is limited as most activity can be found within projects and not among private individuals, i.e. on a forming market.

Denver is somewhat different from the EV systems in Malmö and Aachen. Similar to Aachen a large knowledge base in EV technology and organization of EV projects can be found. Entrepreneurial experimentation is very pronounced as well. Interconnectivity is high which is mainly due to some wide networks, like the Clean Cities coalitions or the Project Get Ready adviser team. It is hard to assess how legitimation in Denver compares to the other case studies. There seem to be at least as many early adopters but the broad acceptance seems to be lower. The main differences to the other case studies can be found in the functions resource mobilization, government intervention and market formation. Denver could not attract grants for EV projects so far and the city has a tight budget due to the economic crisis. This results in little mobilization of financial resources which also reduces the range of interventions through the city government. Nevertheless, the market for EVs is further developed than in Malmö and Aachen. Some EVs for rich early adopters are available in the area. Despite a small emerging market, the overall functioning of Denver's EV system is limited. This is due to a lack of resources to build up supportive infrastructure and create local incentives. Furthermore, there are some uncertainties about legitimation.

6.3 Blocking and inducement mechanisms

The overall functioning of EV systems in cities depends heavily on interrelations between various functions. The mobilization of financial resources can, for example, induce government intervention, while on the other hand, the lack of resources constrains government intervention. A generic overview of these interrelations is given in table 4. The table contains interrelations that can take effect both as a driver and as a constraint. Not all of the interrelations that are mentioned in the table have (already) appeared in the researched cases. Those that have not appeared, yet, are expectations of stakeholders within the EV systems and assessments of transportation experts. Below some of the blocking and inducement mechanisms that were brought up in the case study research are discussed.

Both the case studies and the general EV discourse show that EVs are still too expensive for their performance, so that little happens without **government intervention** at different levels. The federal and state level subsidy schemes in Colorado have induced EV activity in Denver. National grants for demonstration and research projects have triggered activity in Aachen and Malmö. In the USA, Germany and Sweden both the annual car tax and the fuel tax are lower for EVs than for CEVs. Both in Aachen and in Denver there are publicly funded research facilities that deal with EVs. At the city level public procurement programs exist, e.g. Copenhagen City will exclusively purchase EVs or fuel cell vehicles in some vehicle classes starting January 2011 (Harboe, Interview). Further incentives, like free parking and charging or the use of bus lanes, have been introduced or are planned to be introduced in some cities. The Clean Cities coalitions in the USA and the Energy Agency NRW in Germany are organizations that bring together stakeholders in EV systems and receive public funding.

Their work is not just an example for how government intervention can drive the development of EV systems, but also for the inducing effect of **interconnectivity**. Another example is the connection between E.ON and the City of Malmö that had cooperated on several occasions, before they successfully applied for a grant of the Swedish Energy Agency. A similar grant application in Denver, which was put together by a group of stakeholders around the Clean Cities coalition, was not successful. Nevertheless, the connections of Clean Cities and the network of RMI have helped to form a stakeholder group for EV readiness in Denver that keeps the issue on the agenda. But a high degree of interconnectivity also creates complexity. The collaboration and coordination of several stakeholders is a challenge that can be a real obstacle by delaying progress. Oliver Wilke, a senior researcher at the Wuppertal Institute, has experienced this obstacle in an EV project group: “It is a real challenge of a practical project to keep actors together and going. Sometimes it seems to be like a flea circus, everyone is heading in different directions.” But multi-stakeholder projects are not just an organizational challenge. Mike Simpson of NREL observes an additional problem “in the great variety of sometimes very strong interests of different project partners”.

In addition to government intervention and interconnectivity, the **mobilization of resources** is the third big driver of EV dissemination. In a city context it is mostly governments and utilities that mobilize the financial resources. At this stage of market formation it is crucial to have financial resources to start an EV project, since the electric cars that are available are too expensive to be acquired from regular budgets. But running an EV project is not just about money but also about know-how. The mobilization of human resources at all levels, from servicing staff to project organizers, from researchers to engineers, is absolutely vital. Lack of qualified servicing staff has created problems in early EV trials in Malmö. Thanks to dedicated project organizers and much technological knowledge, Aachen has a dynamic EV system. Excellent researchers in the Denver area attract funding for research projects. Some bright ideas have been spun off in innovative companies. So far there is just no funding for a large EV trial.

Political support, connections, money, know-how – there is no big surprise amongst the drivers of EV systems. Accordingly, the lack of these factors is a constraint. But there are more constraints than that. Even if there is political support the continuance of this support is not always clear. Susanne Stark of the city utility of Düsseldorf lacks “long-term planning security. If this does not change half of the actors will leave the projects [Model Regions]. The transaction and administration costs are out of all proportion to the result. If there is planning security for financial support the market reacts.” Oliver Braune of NOW GmbH, which coordinates and implements the Model Regions program in Germany, has discovered the same problem: “Many project partners are hesitant to start the

Table 4: Interrelations between the functions of an EV system (A influencing B)

A \ B	**Knowledge Development & Diffusion**	**Government Intervention**	**Entrepreneurial Experimentation**	**Market Formation**	**Legitimation**	**Resource Mobiliz. (financial, human, further assets)**	**Interconnectivity**
Knowledge Development & Diffusion			Spin-offs of research facilities	State of EV technology	Media coverage	Investment risks	Complexity of multi-sector projects
Government Intervention	R&D projects Research facilities Education campaign		Grant and loan programs for innovation	Public procurement Taxes and subsidies Local incentives	Show cases Awareness campaign	Planning security	Local facilitator/ transport adviser
Entrepreneurial Experimentation	Testing in practice			Business models		Success of new enterprises	
Market Formation					Availability of EVs		
Legitimation		Popularity of political intervention		Articulation of demand			
Resource Mobiliz. (financial, human, further assets)	EV experts in the area	Grants for EV projects	Automotive and electrical engineers Venture capital	Availability of EVs Investments of OEMs	Local infrastructure		
Interconnectivity	Diffusion-enabling networks	PPPs		New supply chains EV Procurement groups		Co-financing	

implementation as long as the grant money has not been transferred – even if the support decision has long been made." With all the technological uncertainties around EVs and an initial market that still has to develop, **planning insecurity** because of the risk of discontinuation of political support schemes is a major constraint for the development of EV systems. On the other hand, it is an inherent problem of subsidies that they "always have to be limited in time" (Wilke, Interview), i.e. there has to be a time horizon for the marketability of EVs to make a well-designed political support scheme possible.

Like political support needs continuity, money needs something to buy. The **unavailability of electric cars** is one of the most cited problems in the case study research. The market launch of several electric cars has been postponed various times. "Postponing the market introduction dates of EVs is one of the biggest problems" (Harboe, Interview). But not just the series electric cars pose problems. Also conversions and small EVs that are already in production have long waiting times. Projects that involve OEMs or companies that can do the conversions might still be affected by delays because of the limited availability of spare parts and batteries. But slowly the market seems to react. Furthermore, projects partially switch to electric two-wheelers that also serve the purpose of testing charging infrastructure and billing systems and of raising public awareness. Nevertheless, car availability, which is a problem caused by the production side, blocks the development of EV systems. As long as there are no cars also other elements of EV projects are often postponed.

Another challenge that has been pointed at in the case study research is the existence of **established institutions** and the lack of some EV-specific new institutions. EVs have to be fitted in the existing purchasing process of public and private companies, which can cause difficulties and delays (Mollstedt, Interview). Moreover, several standards for EVs and EV related technologies are still in the making. Safety standards, standards for charging plugs and outlets, standards for the necessary software – the list is long. A challenge in the standardization process is that different technological solutions have different interests behind them. "If we introduce public charging infrastructure, which is not a large challenge, roaming standards are necessary. And you can already observe big companies [e.g. RWE in Germany] dashing ahead to push their own standards." (Wolters, Interview). Another frequently cited issue is permitting. The rationale behind it is that when the first cars arrive, people, especially in the USA, will need home charging equipment. For this equipment they will need a permit, which might take so long to obtain that the dissemination of EVs is blocked. This scenario is taken very seriously and several cities in the USA have already educated their permitting departments. In the European case studies permitting is not perceived as an issue. The big challenge in the context of permitting will be to supply owners of EVs that live in multi-storey dwellings in densely populated areas with charging infrastructure (Mattila, Interview).

6.4 Critical Issues

Single inducement and blocking mechanisms, as presented above, give a good idea about what people that are involved in EV projects deal with, about what makes their work a struggle and about what drives progress. In addition to these individual drivers and constraints, there are some large cross-cutting issues that govern the general discourse: How can the problem of range anxiety be addressed? What will happen to high vehicle costs? And what is the actual environmental score of EVs? These questions are discussed below in a bigger context but with reference to the case studies.

6.4.1 Range anxiety and driving patterns

In a study by Ernst & Young the "Access to charging stations" and "Battery driving range" were two of the three factors that make people most hesitant to choose a PEV as their next vehicle (Ernst & Young, 2010, p. 12). According to a study by the consulting firm Deloitte "70% of drivers surveyed [in the USA] would expect an electric vehicle to travel 300 miles [483km] before they would consider purchasing one" (Deloitte, 2010, p. 11). The same study shows that more than 85% of the people claimed to have a daily driving distance of under 100 miles (161km) (Deloitte, 2010, p. 10). Similar statistics can be found for Sweden (Bandhold et al., 2009, p. 13) and Germany (Technomar GmbH, 2009, p. 8). Overall there is strong empirical evidence that the current range of BEVs matches the usage patterns of most drivers but does not match their expressed demand. The problem is not range but range anxiety.

This observation is consistent with the statements of many experts within the case study research. The tenor is that public charging infrastructure is not very important for actual charging but because of its symbolic meaning. According to Matthew Marshall "public infrastructure has not much more than a signalling function. Home charging is more important." Casper Harboe speaks about "the symbolic value" of visible charging stations. Susanne Stark refers to "the psychological effect of public charging infrastructure" but also thinks that charging will happen at home or at work. Mike Simpson of NREL generally agrees with that but sees a potential role of public infrastructure in charging smaller PHEV batteries to allow them to go further in all-electric mode.

So what are the arguments against installing public charging stations in very visible locations to signal people with range anxiety that they can charge their EVs in case the batteries are running low? Björn Mollstedt of E.ON refers to the poor business case of public charging, when it is considered a stand-alone business and not integrated with other products or services: "First, there are the costs of the equipment itself. Second, there are the opportunity costs of the public space that is needed. Parking space for EVs which is idle means a loss. Third, there is just very little revenue from the electricity for charging." Idle charging stations do not just have high opportunity costs but also display a risk for the reputation and legitimation of EVs. Therefore, Natalia Swalnick of Clean Cities claims: "No rush, no hurry! Vehicles and infrastructure have to move at the same time. It is risky if public charging infrastructure is in place but nobody ever uses it. In the 1990s CNG has been tested, but it didn't work. This caused a bad image of CNG that it has until today in the region." Andreas Ziolek has made a similar experience with hydrogen cars in Germany: "The push came to early and has done a lot of harm. We should not repeat that with BEVs." Susanne Stark is concerned as well that "the risk to be confronted with idle charging stations within the next ten years is rather high. And if that happens the topic EV is dead for the general public."

Despite several counter-arguments the build-up of charging infrastructure has started both in the USA and in Europe – in contrast to the mass roll-out of vehicles that will not begin before the end of 2010. The main reason for the early build-up of infrastructure is not so much range anxiety but the economic crisis. The Model Regions program in Germany was part of Germany's second stimulus package and in the USA most subsidies, grants and loans in the EV field were part of the American Recovery Act (U.S. Department of Energy, 2010a). The economic crisis did not coincide with the availability of mass-produced EVs. Still it was a good opportunity to mobilize resources for building up the infrastructure of an innovative technology.

The timing of policy interventions for innovative technologies is often coupled with the maturity of the respective technology. R&D funding is followed by early pilot and demonstration projects and then temporary subsidies for market introduction if the technology is mature (Goldemberg, 2000, p. 434). As mentioned above, some of the experts that were interviewed for the case study research are of the opinion that EV support comes to early. “Yes and no”, says Mike Simpson, “there are not many cars available right now. But on the other hand big subsidy schemes can trigger actions by automakers. It is a chicken-or-the-egg type of problem. Vehicles are the central aspect, but for the production and roll-out of vehicles infrastructure must be in place, permitting must work and education and awareness has to be there.” Peter Wolters refers to the same phenomenon: “We have a classical chicken-or-the-egg situation. Therefore, it makes sense to give some initial support. Whether that is done by subsidizing the purchase or supporting the development is a political decision.”

There is no consensus on the chicken-or-the-egg dilemma. Some people claim that car manufacturers just wait for the right conditions to start the mass production, while others say that what is referred to with the “right conditions”, infrastructure and subsidies, is either not necessary or comes too early, since there are no cars, yet. Johan Konnberg, who is in charge of the PHEV program at Volvo, certainly belongs to the first group: “I believe manufacturers could accelerate the roll-out mainly driven by political decisions, incentives, and help with technology investments, etcetera. If our governments really mean to decrease GHG emissions, the technology is there, and can be rolled out to the markets within 3-5 years, in large scale.” (NAATBatt, 2010). For the roll-out of the Nissan Leaf and the Chevrolet Volt, two of the first mass-produced PEVs, the two manufacturers of the cars systematically screen different markets for the best conditions (Mattila, Interview).[9] On the other hand, there is the view that charging can take place at home and subsidies come too early or are not fair. Oliver Wilke explains: “If you look at the price of EVs, they are €10,000 more expensive and probably purchased by rich people. Therefore, it does not make sense from a distributional perspective to subsidize them. Rich people will probably buy anyway.” Björn Mollstedt thinks as well that the first electric cars can do without much support for public infrastructure: “Infrastructure and cars do not have to be there at the same time. The market of early adopters is big enough and they do not depend on public infrastructure as they usually live in their own house where they can charge the car.”

Even if there is no consensus on the chicken-or-the-egg dilemma there are some things most actors can agree on. Range anxiety is a bigger problem than the range of EVs. Some public charging infrastructure makes sense to address this anxiety. Most charging will take place at home and at the workplace. At the moment electric cars are not widely available. And good timing of political intervention is important. The conclusion from this is that whether or not there is a potent chicken (sufficient infrastructure), or rooster, people have to believe that there is a chicken, or rooster, so that they start producing and buying eggs (EVs). How much is “sufficient” and what is the right time for intervention, is heavily debated and has to be decided by politicians, supported by researchers.

9 The unavailability of electric cars has resulted in a competition between different countries and regions to be high on the roll-out schedule for the first cars. Göran Lundgren, in charge of the electric car project at Vattenfall, said in the context of a Swedish EV procurement program: “Today there is tug-of-war to become a prioritized country for the electric car producers and this grant will contribute considerably to putting Sweden on the electric car map” (Vattenfall, 2010).

6.4.2 EV price and total cost of ownership

In addition to the limited range of EVs that was discussed in the previous section, a major drawback is the high price that is due to high battery costs. For 32% of the participant of the Deloitte survey that was cited above the higher price is the top factor that prevents them from purchasing an EV (Deloitte, 2010, p. 7). The international study of Ernst & Young comes to a similar conclusion, with the price for PEVs being the factor that makes people second most hesitant to purchase such a vehicle (Ernst & Young, 2010, p. 12). Despite subsidy schemes that are intended to trigger economies of scale and despite financial support to battery manufacturers, the price for EVs is expected to stay significantly higher than for comparable CEVs. Just as range anxiety is the problem rather than range, there is also a problem with "upfront cost anxiety" when it comes to the EV price.

EVs are often cheaper in annual taxes (see context sections of the case studies), they have lower fuel costs per kilometre (see Gartner, 2010a), less maintenance is required (U.S. Department of Energy, 2010b), but the insurance is expected to be slightly more expensive (Blanco, 2010). The total cost of ownership (TOC) for driving an EV is still higher than the total cost of driving a CEV. But the difference is not as big as the difference between the purchase prices (see Brooker et al., 2010).[10]

The combination of high upfront costs and some saving opportunities in the use phase allows for several strategies to make EVs more cost competitive. First, the EV price can be decreased through technological advancements, economies of scale etc. Second, the EV price can be lowered with subsidies. Third, the EV price can drop because some of the benefits of the use phase are moved upfront. Fourth, the use of CEVs can be made more expensive as taxes are raised or charges are introduced. While technology development and subsidies are mainly determined by OEMs and national or state level governments, the other two strategies can be implemented at a more local level.[11]

Working on EV readiness in a city context does not just mean to build charging infrastructure and organize permitting processes, but also to try and address the problem of the high EV price. Throughout the case study research the price of EVs was not brought up very frequently. There are two potential explanations. First, city planner might reason that the price issue is already dealt with at a higher level. Matthew Marshall states this view: "There is not need for further incentives. We have the subsidy in Colorado which come in addition to the federal subsidy." The second potential explanation is that so few cars are available that the high price has not been relevant so far. But the price will be very relevant for the dissemination of EVs and it is worthwhile discussing strategies to deal with it – also in case the early subsidy schemes do not bring down the price close to parity with CEVs.

There are several ideas how to utilize cost advantages that EVs have during the use phase. The most prominent example is the company Project Better Place that plans to sell the service of electric driving instead of just cars or just electricity. The batteries are owned by Better Place and can be swapped at newly developed stations. The customer pays for the miles that are driven and not for battery and electricity. In that way upfront costs for EVs (without the battery) can be lowered significantly (Better Place, 2010). While Better Place

[10] A TCO calculator can be accessed at http://projectgetready.com/js/tco.html . It could be worthwhile incorporating externalities, like GHG emissions, air and noise pollution and resource depletion, into the TCO in order to determine an efficient level of political support.

[11] Another important determinant of the TCO difference is the oil price. Its significance for EVs is discussed in the context of peak oil in section 5.1.

is a company that collaborates with whole countries like Israel and Denmark, and plans to deploy a vast infrastructure of charging and swapping stations, there are also some approaches for a more local context. EVs can be deployed as fleet vehicles. It is easier to organize the charging of fleets, city fleets with many start-stop operations can make use of the high efficiency of electric propulsion, and fleet managers have a better awareness of the TCO of vehicles and know how to organize the financing. The financing could be done through leasing the vehicles. Leasing rates are expected to be relatively low in the beginning. Whether this is due to a high residual value of the vehicles or due to a marketing strategy is heavily debated (see Berman, 2010; Chambers, 2010). Furthermore, it is possible to separate vehicle and battery at a more local level than Project Better Place. Local utilities could be the battery owners – selling driving electricity with a premium for battery use. That this is possible, despite many challenges, has already been shown about 100 years ago when a station in Hartford, Connecticut, offered the subscription to a "Battery Service System" scheme for which customers had to pay a monthly service fee and their mileage (Mom, 2004, p. 233ff.). Another way to utilize cost advantages of EVs during the use phase is to introduce electrical car-sharing. In car-sharing vehicles have shorter idle periods than in private ownership. Therefore, the relative importance of the costs during the use phase increases.

A different way towards EV competitiveness is to make CEVs more expensive. As taxes around CEVs are usually not in the authority of local governments, other ways to make CEVs more expensive have to be explored. One way is to introduce differential charges for EVs and CEVs. London has proven with its congestion charge zone that big incentives for alternative fuel vehicles can be created by charging them less for entering the centre of the city (see Hall, 2010). Among the case studies the city of Malmö is the only one that already has an environmental zone that excludes the most polluting heavy goods vehicles (HGV) from the area within the inner ring road (Malmö Stad, 2009a). The neighbouring city of Copenhagen considers the introduction of an environmental zone with discounts for EVs (Harboe, Interview).

Many surveys show that the price of EVs is one of the largest constraints for their dissemination. At the same time the price is decided outside the boundaries of the EV system city. Nevertheless, clever business models and interventions of city governments can help even at the local level to make EVs more competitive.

6.4.3 Environmental score of EVs

The third large topic that governs the debate around the EV is its environmental score. The public opinion about this is very positive. The international consumer study of Ernst & Young finds that two thirds of the respondents state that the environmental impact of PEVs is favourably influencing their purchase decision (Ernst & Young, 2010, p. 10). Similar results can be found in a German consumer study (Technomar GmbH, 2009, p. 11).

Most stakeholders that were interviewed for this case study research shared the view that EVs are beneficial from an environmental perspective. The main points of disagreement were the GHG emission and congestion, while zero tailpipe emissions, less noise, and breaking the dependence on oil were not contested as environmental benefits of EVs. Wolfgang Lohbeck, senior project manager at Greenpeace Germany, is convinced that the view EVs emit less GHGs, which is spread by politicians and energy companies, is wrong if the current grid mix of countries like Germany or the USA is considered (Lohbeck, Interview; see also Lohbeck, 2010). As could be shown above in section 3.4, a very efficient diesel car is as clean as a BEV that charges in the grid of Germany or Colorado. At least for Germany one can say that the energy supply is in transition. As with every transition to harvest the full benefits it takes some time. In five to ten years the CO_2 balance of the electricity mix will look differently. A similar statement can be made about Colorado where a Renewable Electricity Standard of 30% by 2030 and investments in natural gas power plants have been decided (see 5.4.1). Because of emission advantages already today and further advantages in the future, Susanne Stark of the local utility in Düsseldorf states: "If people dissipate their energy in discussions about the right electricity mix, they miss the point."

But the criticism of the environmental score of EVs does not just centre on current and future GHG emissions but on the alternatives. Walking, cycling and public transport are alternatives to car-based transport that all have the advantage of very low emissions and, moreover, reduce congestion and the impact from car production. "A 1.5t electric Golf that costs a fortune is the strategically wrong product." (Lohbeck, Interview). So why should EVs, a technology that is very costly and not much cleaner than conventional vehicles, be supported? Some answers can be found in the EV demonstration projects in cities.

Many transportation planners are aware of the short-comings of EVs. Therefore, EVs are never the only element of a sustainability strategy. "Ideally in Denver we would like to see more public transport, biking, walking; and then, as a secondary solution, if driving a car then an alternative fuel vehicle", says Matthew Marshall, City of Denver. Like in other cities, where EVs are introduced, they do not have first priority. "The comprehensive sustainable transport strategy for Malmö is first, to get rid of cars by supporting public transport, biking and walking, and second, to support environmentally adapted cars." (Hauksson, Interview). This ranking of priorities is reflected in the planning of charging infrastructure both in Denver and Malmö. Charging spots will be installed on the outskirts of the city, possibly in connection with Park & Ride availability, to keep cars out of the city centre. Furthermore, both Aachen and Malmö include electric bicycles in their planning to convince car drivers to switch their mode of transport. These city planning efforts illustrate a big difference between CEVs and EVs: CEVs are already there, EVs are not. That means the necessary infrastructure can be planned from scratch and account for the specific advantages and disadvantages of EVs.

That there is more to electric mobility than the electric car is made clear by Wolfgang Lohbeck: "The understanding of E-mobility is important. There is almost no talk about mobility but cars, cars, cars. Cities should not focus on cars, they should focus on mobility." Because of a high oil price and the high price for electric cars "the all-purpose vehicle will die out. Small city cars or shared cars might still be affordable, but not a car that is standing 23 hours a day." (Lohbeck, Interview). The integration of public transport, car sharing, and different forms of individual transport is called a multi-modal or inter-modal transport system. Typical examples are park and ride places and linked rail and bus networks. But also the option to take a bike on the bus or train, taxicabs and rental cars that make the link between the home and an airport or the station, and car-pooling and bike-pooling programs are elements of inter-modal passenger transport. Mike Simpson, transportation researcher at NREL, states: "Ongoing urbanization creates the opportunity for more mass-transit and car-sharing. But not just a multi-modal solution is needed. Opti-modality becomes more and more important. Opti-modality refers to the connecting tissue between different modes of transportation, the software and the interface for both users and operators, in order to always have the quickest and cheapest transport option available."

There seems to be a place for EVs in a comprehensive transportation system that is more sustainable than the current system. On the other hand, EVs might become a competitor of public transport. Andreas Ziolek believes that this risk is rather low: "Public transport and electric vehicles are complementary. Electric mobility may even become a driver for public transport. Furthermore, electric propulsion within public transport has a potential." Both the deployment of EVs in public transport and the interface between public transport and EVs are tested in the German Model Regions program (Braune, Interview). EV charging stations and electric car-pools at train stations and park and ride places help to strengthen both public transport and EV dissemination (Verkehrsclub Österreich, 2009, pp. 32-33).

Although EVs might have the best environmental performance when they are part of a well-organized inter-modal transportation systems, it might be useful to spread the initial support across a broader range of applications, including private car users, in order to foster technology development and economies of scale. These initial support policies can later be adapted. In this context Casper Harboe refers to the access of EVs to a potential environmental zone in Copenhagen: "It is a question of break even. We want to support EVs but at the same time we have the strategy to get cars out of the city centre. There will be a critical mass of EVs when a discount for EVs has to stop." A similar process takes place in California where HEVs have access to high occupancy vehicle (HOV) lanes. With PEVs soon to arrive on the Californian market, a discussion has started whether HOV lanes are getting to busy and access should just be given to PEVs and not to HEVs any longer (Richard, 2010). Oliver Wilke from the Wuppertal Institute also addresses the issue of changing EV policies: "On the long run I expect a tax on electricity for driving, in addition to the regular taxes on electricity." But reducing EV support because of too many EVs in the centre of a city is even more a thing of the future then the EV itself.

The discussion above shows that the environmental score of EVs is positive. Even if EVs are analysed against the background of other low-impact modes of transport, they remain an option to make current transportation systems more sustainable. From an environmental perspective EVs are neither the panacea nor without any effect. Accordingly, comprehensive transport strategies and solutions are necessary in order to support EVs where they make most sense and integrate them with other environmentally friendly modes of transport.

7 Conclusion

EVs are coming! – that is the belief of most people who have been involved in this research. They have not arrived, yet! – that is the conclusion after conducting the case study research. Despite the lack of cars, several conclusions can be drawn from this study, since the main objective was to research EV systems and not the EV, its driving patterns, charging behaviour etc.

The first research question of this study was about the main elements of EV systems in cities. Although few electric cars actually drive in the case study cities, first physical elements of the EV systems can be observed: charging posts, special signage, EV parking, electric two-wheelers and the electricity grid. Furthermore, the most important actors, City governments and local utilities, and relevant networks have been identified. Relevant institutions of EV city systems can both be found at higher levels, e.g. the U.S. subsidy scheme and the EU emission standards, and within the cities, e.g. parking regulations and permitting procedures.

The second research question asked for the factors that induce or constrain the dissemination of EVs in a city context. The main inducing factors are successful resource mobilization, an actively intervening city government and a high degree of interconnectivity and collaboration; while the lack thereof, the unavailability of electric cars and planning insecurity were major constraints (see section 6.3).

What are the coordinating and supportive interventions at the city level that can help the dissemination of EVs, was the third research question. The interventions that have already been made can also be considered as inducing factors: cities appoint staff to organize EV activities, they team up with other stakeholders, they apply for grants, install charging posts, allow free charging and free parking, they organize awareness raising events etc. In order to stress some of the interventions that have already been done and to better address the three critical issues range, costs and environmental performance, some additional recommendations are given below.

To set up an EV project requires investments but also a lot of organization, networking, gathering of know-how etc. Many of these efforts have to be taken just once in the beginning. When networks exist, collaboration is established and the knowledge around EVs has been gathered, project work gets more efficient. Hence, it makes sense to have a long time-horizon for EV projects. Additionally, long-term support creates trust in EV technology. The experience with CNG and hydrogen shows that the lack of continuity can cause lasting damage of the legitimation of a new technology. Therefore, PPPs, public grant programs and subsidy schemes at all levels should:

Assure planning security for the stakeholders who are involved!

Within EV projects it is important to place the emphasis on the most effective measures. As has been shown above, the necessity of public charging infrastructure at the current state of EV development is questionable. The main rationale behind it, to reduce range anxiety, can also be tackled with other measures, without running the risk of empty charging stations. The show case effect, i.e. as many EVs on the streets as possible, helps to reduce range anxiety as well. As long as cars are not available electric scooters can be deployed as show case vehicles. But the goal should always be to have many EVs on the streets, not EV charging posts. In different regions the role-out of EVs starts at different times and the convenience of home charging differs from region to region as well. Therefore, the following recommendation also depends on the respective setting:

Focus more on the vehicles than on the charging infrastructure!

EVs alone do not make a transport system more sustainable. Many city centres have problems with congestion. Furthermore, the future of expensive car-ownership is heavily contested. The price for EVs is expected to remain high. Other forms of low-impact transportation, like buses and trains, are often already in place. And ICTs facilitate the effective organization of inter-modal transport systems. Thus, it is important to:

Make EVs part of a comprehensive transportation strategy (including car-pooling, public transport integration and alternative business models around EVs)!

Especially in the phase of market formation it is important to support entrepreneurial activity around EVs. Garages with educated EV service staff, new EV business models and the electrification of company fleets are opportunities for not just greening transportation in a city but also creating job opportunities. Some of the factors that influence entrepreneurial activity are hard to change. Research institutes are not established from one day to another. Other factors like technology incubators, consultancy for start-ups, business taxes and the formation of associations, are easier to influence. In order to get specialist knowledge into the region and create job opportunities, it is therefore recommendable to:

Create favourable conditions for investments in the EV sector!

The recommendations listed above are mainly based on expert interviews and the observations and interpretations of the author. Therefore, the list is neither comprehensive nor are the recommendations very specific. A more thorough analysis of EV systems will be possible when the first projects are fully implemented and the roll-out of mass-produced PEVs has started.

Already now, there are some research topics in the field of EV systems that are relevant from a social science perspective and have not been researched in-depth. The experience with other alternative fuel vehicles has been brought up in several interviews, without even being included in the set of interview questions. A further comparison between the development of CNG, hydrogen, E85 and electrically propelled vehicles could be useful to identify risks, plan the timing of policy interventions and find out who the key actors are. Another fruitful research area is the somewhat mysterious occurrence of range anxiety. A deeper understanding of the discrepancy between consumer needs and consumer wishes can help to develop strategies to reconcile the one with the other, even if large improvements of EV range are not to be expected very soon. Limited range and a high EV price could be the starting point for another field of research: innovative business models. These are necessary to deal with the two constraints. Economic simulations and trials of electric car-pooling programs, battery leasing, fleet deployment etc. help to understand in which application EVs are (most) profitable. It is not to mention that in natural science and engineering still many research opportunities exist.

Looking at the long list of research areas around EV systems it becomes clear that all projects, investments and policy interventions in this field have to go along with a high degree of uncertainty. In an investment evaluation about Ecotality, one of the leading EVSE companies, it says: “As a truly nascent industry, sizing of the [PEV] market is as much art as science at this early stage.” The investment bankers who published this evaluation touch upon a critical point. It is impossible to differentiate between communication and reality, between what is said, written and predicted, and what is done, implemented and followed-up. The hype around electric cars does not match the current reality on the ground. Nevertheless, all communication, evaluation and research around it has (had) a large influence on decision-making and the future of transportation systems.

Wolfgang Lohbeck of Greenpeace points out the discrepancy between the charm of the EV hype and its reality: “It's a seductive thing to think of a big transition. But the quick EV transition won't happen. Not in 10-15 years. The most important aspect of EVs is that they put a pressure on the traditional automotive industry.” It will take time until EVs have a significant share of transportation in cities. That also means most of the benefits of today's efforts will take effect in the future. The implication of this should not be to reduce activity but to remain ambitious. Casper Harboe stresses the importance of setting high goals when talking about the procurement policy of Copenhagen: “100% EVs, that's an ambitious goal. But if you don't set ambitious goals nothing will happen. And if you reach 50% in the end that's a good result, too.”

Figure 11: The author after test-driving an all-electric delivery truck ... It was fun!

Bibliography

Aachener Nachrichten. (2010). Dossier - Mobil mit Elektroautos. Retrieved September 2, 2010, from http://www.an-online.de/dossier/liste-an?cmsvar[_rubrik]=1174774&id=1174774?_link=zMobilmitEle

Alt, F. (2007). Die deutschen Autobauer wollen weiter schlafen [Web log post]. *Readers Edition*. Retrieved September 2, 2010, from http://www.readers-edition.de/2007/12/22/die-deutschen-autobauer-wollen-weiter-schlafen

American Lung Association. (2010). Denver Metro Clean Cities Coalition. Retrieved September 2, 2010, from http://www.lungcolorado.org/CleanCities.htm

Archie, L. (2006, June 24). The Principle of Charity. *Nature of Philosophy*. Retrieved September 2, 2010, from http://philosophy.lander.edu/intro/charity.shtml

Autocluster.NRW. (2009). Masterplan Elektromobilität Nordrhein- Westfalen. Retrieved from http://www.autocluster.nrw.de/fileadmin/images/PDF/Masterplan_NRW_Elektromobilitaet.pdf

Bandhold, H., Carragher Wallner, J., Lindgren, M., & Bergman, S. (2009). *Plug In Road 2020*. Elforsk and Kairos Future. Retrieved from www.powercircle.org/se/Attachments/34/org/09_40_rapport_screen.pdf

Bartels, L. (2010, March 23). Ritter signs bill requiring greater use of renewable energy by 2020. *The Denver Post*. Retrieved from http://www.denverpost.com/news/ci_14735606

Bergek Anna, Jacobsson Staffan, Carisson Bo, Lindmark Sven, & Rickne Annika. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy*, *37*(3), 407.

Berkhout, F. (2008). Innovation theory and socio-technical transitions. In *Managing the Transition to Renewable Energy* (pp. 129-147). Cheltenham: Edward Elgar.

Berman, B. (2010, July 27). Thoughts on Low Lease for Chevy Volt [Web log post]. Retrieved September 7, 2010, from http://www.plugincars.com/thoughts-low-lease-chevy-volt-49781.html?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+PluginCars+%28PluginCars.com+RSS+Feed%29

Better Place. (2010). A comprehensive electric vehicle solution. Retrieved August 25, 2010, from http://www.betterplace.com/the-solution

Blanco, S. (2010, July 12). Do electric cars need different (or more) insurance than "regular" cars [Web log post]? Retrieved September 7, 2010, from http://green.autoblog.com/2010/07/12/do-electric-cars-need-different-insurance-than-regular-cars/

Boston Consulting Group. (2009). *The Comeback of the Electric Car? How Real, How Soon, and What Must Happen Next*. Retrieved from http://www.bcg.com/documents/file15404.pdf

Boston Consulting Group. (2010). *Batteries for Electric Cars. Challenges, Opportunities, and the Outlook to 2020*. Retrieved from http://www.bcg.com/documents/file36615.pdf

Brooker, A., Thornton, M., & Rugh, J. (2010). *Technology Improvement Pathways to Cost-Effective Vehicle Electrification*. Retrieved from http://www.afdc.energy.gov/afdc/pdfs/47454.pdf

C40 Cities. (2009, May 20). Seoul Declaration. Retrieved September 3, 2010, from http://www.c40cities.org/news/news-20090522.jsp

CAR e.V. (2010). Competence center automotive region Aachen. Retrieved September 2, 2010, from http://www.car-aachen.de/

Chambers, N. (2010, September 2). Refuting The BBC's Claims That EVs Are Costlier Than Gas Cars In The Long Run [Web log post]. Retrieved September 7, 2010, from http://www.plugincars.com/refuting-bbcs-claims-evs-are-costlier-gas-cars-long-run-65915.html

Chameides, B. (2010, July 28). Update: A Global Rare Earth Element Crisis on the Horizon [Web log post]? Retrieved September 3, 2010, from http://www.nicholas.duke.edu/thegreengrok/china-rareearths

Chan, C. (2002). The state of the art of electric and hybrid vehicles. *Proceedings of the IEEE*, *90*(2), 247-275.

City of Stuttgart. (2010). Malmö Plug-In City. *Cities for Mobility*, (1), 5-6.

Colorado Department of Revenue. (2010). *Income 9: Alternative Fuel Income Tax Credits*. Retrieved September 2, 2010, from http://www.colorado.gov/cs/Satellite/Revenue/REVX/1193047059436

Commission on Oil Independence. (2006). *Making Sweden an Oil-Free Society*. Retrieved from www.sweden.gov.se/content/1/c6/06/70/96/7f04f437.pdf

Commuter Cars. (n.d.). Stability - Watch the Tango at the Autocross. Retrieved September 3, 2010, from http://www.commutercars.com/stability.html

Deloitte. (2010). *Gaining traction. A customer view of electric vehicle mass adoption in the U.S. automotive market*. Retrieved from http://www.deloitte.com/assets/Dcom-UnitedStates/Local %20Assets/Documents/us_automotive_Gaining%20Traction%20FINAL_061710.pdf

Deutsche Bank. (2010). *Vehicle Electrification*. Retrieved from www.gm-volt.com/files/DB_EV_Growth.pdf

Econologie. (2008, March 7). Europe, émissions de CO_2 par pays et par kWh électrique. Retrieved September 3, 2010, from http://www.econologie.com/europe-emissions-de-co2-par-pays-et-par-kwh-electrique-articles-3722.html

Eimer, G. (2010, June 6). Mehr Elektrotankstellen in der Stadt. *Aachener Nachrichten*. Retrieved from http://www.an-online.de

Electrification Coalition. (2009). *Electrification Roadmap. Revolutionizing transportation and achieving energy security*. Retrieved from http://electrificationcoalition.org/535928473533888957466293/EC-Roadmap-screen.pdf

Elgowainy, A., Burnham, A., Wang, M., Molburg, J., & Rousseau, A. (2009). *Well-to-Wheels Energy Use and Greenhouse Gas Emissions Analysis of Plug-in Hybrid Electric Vehicles*. Argonne National Laboratory. Retrieved from www.transportation.anl.gov/pdfs/TA/559.pdf

EPRI. (2010). *Characterizing Consumers' Interest in and Infrastructure Expectations for Electric Vehicles: Research Design and Survey Results*. Retrieved from http://my.epri.com/portal/server.pt? Abstract_id=000000000001021285

Ernst & Young. (2010). *Gauging interest for plug-in hybrid and electric vehicles in select markets*. Retrieved from http://www.ey.com/Publication/vwLUAssets/Gauging-interest-for-plug-in-hybrid-and-electric-vehicles/ $FILE/Gauging-interest-for-plug-in-hybrid-and-electric-vehicles.pdf

European Commission. (2009). *Reducing CO_2 emissions from light-duty vehicles*. Retrieved September 2, 2010, from http://ec.europa.eu/environment/air/transport/co2/co2_home.htm

FEV Motorentechnik GmbH. (2010). *Smart Wheels*. Retrieved September 2, 2010, from http://www.smart-wheels.de/index.php?article_id=1&clang=1

Friedman, D. (2003). *A New Road. Technology and Potential of Hybrid Vehicles*. Union of Concerned Scientists. Retrieved from http://www.ucsusa.org/assets/documents/clean_vehicles/hybrid2003_final.pdf

Froggatt, A., & Lahn, G. (2010). *Lloyd's 360° Risk Insight - Sustainable Energy Security*. Retrieved from http://www.lloyds.com/~/media/Lloyds/Reports/360%20Energy %20Security/7238_Lloyds_360_Energy_Pages.pdf

Gaines, L., & Nelson, P. (2009). *Lithium-Ion Batteries: Possible Material Demand Issues*. Argonne National Laboratory. Retrieved from http://www.transportation.anl.gov/pdfs/B/583.pdf

Gartner, J. (2010a, May 24). *U.S. Environment Not the Best for EVs* [Web log post]. Retrieved August 26, 2010, from http://www.pikeresearch.com/blog/u-s-environment-not-the-best-for-evs

Gartner, J. (2010b, July 14). *EVs Seek Smart Communications with the Grid* [Web log post]. Retrieved September 3, 2010, from http://www.plugincars.com/evs-seek-smart-communications-grid-49697.html? utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+PluginCars+ (PluginCars.com+RSS+Feed)

Geels Frank W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy*, *31*(8-9), 1257-1274.

Gerdes, K., & Skone, T. (2009). *Consideration of Crude Oil Source in Evaluating Transportation Fuel GHG Emissions*. National Energy Technology Laboratory. Retrieved from http://www.netl.doe.gov/energy-analyses/refshelf/detail.asp?pubID=264

German Federal Agency for Geo-Sciences. (2009). *Importabhängigkeit und Selbstversorgungsgrad Deutschlands bei einzelnen Primärenergieträgern in den Jahren 1998 und 2008*. Retrieved September 2, 2010, from http://www.geozentrum-hannover.de/nn_322848/DE/Themen/Energie/Bilder/Kurzstudie2009/Ene__Kurz2009__Abb1__Import__g.html

German Federal Environment Agency. (2010). *Entwicklung der spezifischen Kohlendioxid-Emissionen des deutschen Strommix 1990-2008 und erste Schätzung 2009*. Retrieved from http://www.umweltbundesamt.de/energie/archiv/co2-strommix.pdf

German Government. (2009). *German Federal Government's National Electromobility Development Plan*. Retrieved from http://www.bmvbs.de/Anlage/original_1103793/National-Electromobility-Development-Plan.pdf

German Ministry for the Environment. (2010). *Development of renewable energy sources in Germany2009*. Retrieved from http://www.erneuerbare-energien.de/files/pdfs/allgemein/application/pdf/ee_in_deutschland_graf_tab_2009_en.pdf

German Ministry of Finance. (2010, April 14). *Kraftfahrzeugsteuer*. Retrieved August 24, 2010, from http://www.bundesfinanzministerium.de/nn_312/DE/Wirtschaft__und__Verwaltung/Steuern/Veroeffentlichungen__zu__Steuerarten/Kraftfahrzeugsteuer/node.html?__nnn=true

German Ministry of Transport. (2010a). *Electric Mobility*. Retrieved August 24, 2010, from http://www.bmvbs.de/en/-,1872.1129174/Electric-Mobility.htm

German Ministry of Transport. (2010b). *Etablierung der Nationalen Plattform Elektromobilität am 3. Mai 2010*. Retrieved September 2, 2010, from http://www.bmvbs.de/SharedDocs/DE/Artikel/IR/etablierung-der-nationalen-plattform-elektromobilitaet-am-3-mai-2010.html?nn=36210

Goldemberg, J. (Ed.). (2000). *World Energy Assessment: Energy and the Challenge of Sustainability*. UNDP. Retrieved from http://www.energyandenvironment.undp.org/undp/indexAction.cfm?module=Library&action=GetFile&DocumentAttachmentID=1020

Goldman Sachs. (2010). *Advanced Batteries: Light, but the tunnel is long*. Retrieved from http://www.docin.com/p-61696011.html

Gorman, S. (2009, August 31). As hybrid cars gobble rare metals, shortage looms. *Reuters*. Retrieved from http://www.reuters.com/article/idUSTRE57U02B20090831

Hall, D. (2010, June 2). *Combustion Charge Zone* [Web log post]. Retrieved September 7, 2010, from http://www.neohouston.com/2010/06/combustion-charge-zone/

Herminghaus, H. (2009, April 9). *Vergleich der CO_2-Emissionen pro kwh bei der Stromerzeugung*. Retrieved September 3, 2010, from http://www.co2-emissionen-vergleichen.de/Stromerzeugung/CO2-Vergleich-Stromerzeugung.html

Horst, J., Frey, G., & Leprich, U. (2009). *Auswirkungen von Elektroautos auf den Kraftwerkspark und die CO_2-Emissionen in Deutschland*. WWF Germany. Retrieved from http://www.wwf.de/fileadmin/fm-wwf/pdf_neu/wwf_elektroautos_studie_final.pdf

ICLEI. (1999). *Green fleets and traffic concept. Integrating environmental criteria into purchasing practices*. Retrieved from http://www.procuraplus.org/fileadmin/template/projects/procuraplus/New_website/Case_Studies/Malmoe_Sweden_Green_fleets___traffic_concept_en.pdf

Ingram, A. (2010, August 17). Charging your electric car at home: What you need to know. *Reuters*. Retrieved from http://www.reuters.com/article/idUS3859067020100817

InnoZ. (2010). *E-Aix: Elektromobiles Aachen*. Retrieved September 2, 2010, from http://www.innoz.de/e-aix.html

International Energy Agency. (2002). *Implementing Agreement on Hybrid and Electric Vehicles - Annex VIII/XXI "Deployment Strategies for Hybrid, Electric and Alternative Fuel Vehicles"*. International Energy Agency. Retrieved from http://www.ieahev.org/pdfs/annex_8_final_report.pdf

Ipakchi, A., & Albuyeh, F. (2009). Grid of the future. *Power and Energy Magazine, IEEE*, *7*(2), 52-62.

ISO. (2010, August). *Electrically propelled road vehicles*. Retrieved August 2, 2010, from http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_tc_browse.htm?commid=46946

Kahn Ribeiro, S., & Kobayashi, S. (2007). Transport and its infrastructure. In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Karlberg, L. (2009, December 10). Svenska el-Fiaten löser elbilsbristen. *NyTeknik*. Retrieved September 2, 2010, from http://www.nyteknik.se/nyheter/fordon_motor/bilar/article693520.ece

Kemp, R., Schot, J., & Hoogma, R. (1998). Regime Shifts to Sustainability Through Processes of Niche Formation: The Approach of Strategic Niche Management. *Technology Analysis & Strategic Management*, *10*(2), 175. doi:Article

Kim, C. (2010, August 25). Toyota plans 5 million cumulative hybrid sales by 2015. *Reuters*. Retrieved September 3, 2010, from http://www.reuters.com/article/idUSTRE67O15X20100825

Klaus, T., Vollmer, C., Werner, K., Lehmann, H., & Müschen, K. (2010). *Energieziel 2050: 100% Strom aus erneuerbaren Quellen*. German Federal Environmental Agency. Retrieved from http://www.umweltdaten.de/publikationen/fpdf-l/3997.pdf

Koucky, M. (2000). *Service of Electric Cars in Sweden*. Retrieved from www.kfb.se/pdfer/R-00-73.pdf

Lemoine, D. M., Kammen, D. M., & Farrell, A. E. (2008). An innovation and policy agenda for commercially competitive plug-in hybrid electric vehicles. *Environmental Research Letters*, *3*, 014003.

Lohbeck, W. (2010, June 26). *Sind E-Autos klimafreundlicher als Konventionelle* [Web log post]? Retrieved September 3, 2010, from http://blog.greenpeace.de/blog/2010/06/26/sind-e-autos-klimafreundlicher-als-konventionelle/

Loveday, E. (2010, September 1). *Nissan now accepting orders for Leaf; thousands expected in coming weeks* [Web log post]. Retrieved September 3, 2010, from http://green.autoblog.com/2010/09/01/nissan-now-accepting-orders-for-leaf-thousands-expected-in-comi/

Lund University. (2010). *Industrial Electrical Engineering and Automation*. Retrieved September 2, 2010, from http://www.iea.lth.se/research/index.html

Malmö Stad. (2009a). *Improving Malmö's traffic environment*. Malmö Stad. Retrieved from http://malmo.se/English/Sustainable-City-Development/PDF-archive/pagefiles/SMILE_Malmo_-final-brochure.pdf

Malmö Stad. (2009b). *Malmö Plug-in City*. Retrieved September 2, 2010, from http://www.malmo.se/Medborgare/Miljo--hallbarhet/Miljoarbetet-i-Malmo-stad/Projekt--natverk/Projekt/Plug-in-City.html

Malmö Stad. (2010a). *About the City of Malmö*. Retrieved September 2, 2010, from http://www.malmo.se/English/About-the-City-of-Malmo.html

Malmö Stad. (2010b). *Mobility in Malmö*. Retrieved September 5, 2010, from http://malmo.se/English/Sustainable-City-Development/Mobility.html

Malmö Stad. (2010c). *Sustainable City Development*. Retrieved September 2, 2010, from http://malmo.se/English/Sustainable-City-Development.html

McDonald, Z. (2010). *Senate Drafts Plug-ins into Energy Bill, But Time for Action May Be Running Out* [Web log post]. Retrieved August 30, 2010, from http://www.plugincars.com/senate-drafts-plug-ins-energy-bill-time-action-may-be-running-out-49783.html

Mennekes. (2010). *Mennekes - Plugs for the World*. Retrieved September 2, 2010, from http://mennekes.com/

Mini USA. (n.d.). *MINI E*. Retrieved September 3, 2010, from http://www.miniusa.com/minie-usa/

Mom, G. (2004). *The electric vehicle : technology and expectations in the automobile age*. Baltimore: Johns Hopkins University Press.

Motavalli, J. (2010, August 6). Killer App forE.V.'s: 30-Minute Recharges. *The New York Times*. Retrieved from http://www.nytimes.com/2010/08/08/automobiles/08CHARGE.html

National Renewable Energy Laboratory. (2010, June 9). *NREL's Center for Transportation Technologies and Systems*. Retrieved September 2, 2010, from http://www.nrel.gov/vehiclesandfuels/ctts.html

National Research Council. (2002). *Effectiveness and impact of corporate average fuel economy (CAFE) standards*. Washington D.C.: National Academy Press.

New York Times. (2010, September 9). *Times Topic - Automotive Industry Crisis*. Retrieved September 9, 2010, from http://topics.nytimes.com/top/reference/timestopics/subjects/c/credit_crisis/auto_industry/index.html

NHTSA. (2009). *Incidence of Pedestrian and Bicyclist Crashes by Hybrid Electric Passenger Vehicles*. National Highway Traffic Safety Administration. Retrieved from http://www.nrd.nhtsa.dot.gov/Pubs/811204.pdf

Nill, J., & Kemp, R. (2009). Evolutionary approaches for sustainable innovation policies: From niche to paradigm? *Research Policy*, *38*(4), 668–680.

Nissan. (2010a, June 11). *The 'new car' experience*. Retrieved August 2, 2010, from http://www.nissanusa.com/leaf-electric-car/news/technology#/leaf-electric-car/news/technology

Nissan. (2010b). *Nissan LEAF Specs*. Retrieved September 3, 2010, from http://www.nissan-zeroemission.com/EN/LEAF/specs.html

Notter, D. A., Gauch, M., Widmer, R., Wäger, P., Stamp, A., Zah, R., & Althaus, H. (2010). Contribution of Li-Ion Batteries to the Environmental Impact of Electric Vehicles. *Environmental Science & Technology*, doi: 10.1021/es903729a

NRW Ministry of Economy. (2010). *Förderwettbewerb „ElektroMobil.NRW" erfolgreich abgeschlossen: 22 Projektideen sollen mit insgesamt 46,5 Millionen Euro gefördert werden*. Retrieved September 2, 2010, from http://www.ziel2.nrw.de/0_2_Aktuelles/2010_01_22_ElektroMobil_Sieger/index.php

Olsson, A. R. (2000). *Reducing Barriers to Zero and Low Emission Mobility*. European Commission. Retrieved from http://www.zeus-europe.org/news.html#

Overfelt, M. (2008, December 5). *Why electric vehicles have stalled* [Web log post]. Retrieved September 9, 2010, from http://money.cnn.com/2008/12/02/smallbusiness/electric_cars_stalled.smb/index.htm

Petersen, J. (2010, July 4). *Goldman's Advanced Battery Report: A Contrarian View*. Retrieved July 16, 2010, from http://seekingalpha.com/article/213037-goldman-s-advanced-battery-report-a-contrarian-view

Pfeiffer, A. (2010a, March 25). *E-Aix – Elektromobiles Aachen*. Retrieved from http://www.stawag.de/privatkunden/mobilitaet/elektromobilitaet/Pr__sentationen_E-Aix1/100325_Vortrag_1_E-Aix-pfeiffer.pdf

Pfeiffer, A. (2010b, May 11). *Elektromobilität – Wie kommen die Elektrofahrzeuge an die Steckdose?*. Retrieved from http://www.berliner-energietage.de/fileadmin/Redaktion/Berliner%20Energietage/2010/Vortraege/3.6_Pfeiffer.pdf

Plug In America. (2010, May 27). Plug-in Vehicle Tracker. Retrieved September 8, 2010, from http://www.pluginamerica.org/vehicles/

Power Circle. (2010). *Swedish Electric Mobility Initiative*. Retrieved September 2, 2010, from http://www.powercircle.org/en/display/Projects/swedish-electric-mobility-initative.aspx

Prognos, & Ökoinstitut. (2009). *Blueprint Germany. A strategy for a climate safe 2050*. WWF. Retrieved from http://www.wwf.de/fileadmin/fm-wwf/pdf_neu/WWF_Blueprint_Germany.pdf

Rahim, S. (2010, May 7). Will Lithium-Air Battery Rescue Electric Car Drivers From 'Range Anxiety'? *The New York Times*. Retrieved from http://www.nytimes.com/cwire/2010/05/07/07climatewire-will-lithium-air-battery-rescue-electric-car-37498.html?pagewanted=all

Region Skåne. (2010). *Miljö och klimat*. Retrieved September 2, 2010, from http://www.skane.se/templates/Page.aspx?id=5945

Rempel, H., Schmidt, S., & Schwarz-Schampera, U. (2009). *Reserves, Resources and Availability of Energy Resources - Annual Report 2009*. Federal Institute for Geosciences and Natural Resources. Retrieved from http://www.bgr.bund.de/cln_116/nn_335082/EN/Themen/Energie/Downloads/annual__report__2009__en,templateId=raw,property=publicationFile.pdf/annual_report_2009_en.pdf

Richard, M. (2010, September 1). *California To Extend Carpool-Lane Access To 40,000 Plug-In Hybrids* [Web log post]. Retrieved September 7, 2010, from http://www.treehugger.com/files/2010/09/california-carpool-hov-lane-stickers-plug-in-hybrids-phevs.php

Rocky Mountain Institute. (2010a). *Rocky Mountain Institute*. Retrieved September 2, 2010, from http://www.rmi.org/rmi/

Rocky Mountain Institute. (2010b). *Project Get Ready: Greater Denver, Colorado*. Retrieved September 2, 2010, from http://projectgetready.com/city/partner-city/greater-denver-colorado

Roland Berger. (2010, March). *Automotive battery manufacturers are threatened by overcapacity*. Retrieved July 30, 2010, from http://www.rolandberger.com/news/2010-03-09-rbsc-news-Batteryovercapacity.html

Rotmans, J., Kemp, R., & van Asselt, M. (2001). More evolution than revolution: transition management in public policy. *foresight*, *3*(1), 15-31.

RWTH. (2010). *Street Scooter*. Retrieved September 2, 2010, from http://www.streetscooter.rwth-aachen.de/en

Schewel, L., & Wilson, J. (2009). *Project Get Ready - The Menu*. Rocky Mountain Institute. Retrieved from http://www.projectgetready.com/docs/Project_Get_Ready_Menu_Mar16.pdf

Skatteverket. (2010). *Bil och trafik*. Retrieved September 2, 2010, from http://www.skatteverket.se/privat/skatter/biltrafik/

Slevin, C. (2010, April 19). Colorado Natural Gas Legislation Signed With Motley Crew Of Supporters On Hand. *Huffington Post*. Retrieved from http://www.huffingtonpost.com/2010/04/19/colorado-natural-gas-legi_n_543408.html

Smartlab. (2010). *Smart Lab Innovationsgesellschaft mbH*. Retrieved September 2, 2010, from http://www.smart-lab.de/

Sonnenschein, J. (2010, March). *Learning from Electric Vehicle History* (unpublished article). Lund University, IIIEE.

Sorrell, S., Speirs, J., Bentley, R., Brandt, A., & Miller, R. (2009). *Global Oil Depletion - An assessment of the evidence for a near-term peak in global oil production*. Sussex: UK Energy Research Centre.

Stadt Aachen. (2010a). *Stadtportal Aachen*. Retrieved September 2, 2010, from http://www.aachen.de/

Stadt Aachen. (2010b). *Zuschuss für Elektrobikes und Elektroroller*. Retrieved September 2, 2010, from http://www.aachen.de/DE/stadt_buerger/umwelt/energie/elektromobilitaet/index.html

Stadt Aachen. (2010c). *Pedelec-Testwochen für Betriebe*. Retrieved September 2, 2010, from http://www.aachen.de/DE/stadt_buerger/verkehr_strasse/clevermobil/100628_pedelec_testwochen.html

Stake, R. (1995). *The art of case study research*. Thousand Oaks: Sage Publications.

STAWAG. (2010a). *Tankstellen für Elektro-Fahrzeuge*. Retrieved September 8, 2010, from http://www.stawag.de/privatkunden/mobilitaet/elektromobilitaet/Tankstellen_fuer_Elektro-Fahrzeuge.html

STAWAG. (2010b, July 26). *Ausstellung zu Elektromobilität in der Sparkasse am Münsterplatz*. Retrieved September 2, 2010, from http://www.stawag.de/presse/meldungen/Ausstellung_zu_Elektromobilitaet.html

Strauch, B. (2010a, March 2). Leiser Minibus rollt durch enge Straßen. *Aachener Nachrichten*. Retrieved from http://www.an-online.de/dossier/detail-an/1225813?_link=&skip=&_g=Leiser-Minibus-rollt-durch-enge-Strassen.html

Strauch, B. (2010b, February 1). Stawag setzt voll auf die Europa-Karte. *Aachener Nachrichten*. Retrieved from http://www.an-online.de/dossier/detail-an/1194702?_link=zMobilmitEle&skip=&_g=Stawag-setzt-voll-auf-die-Europa-Karte.html

Swedish Energy Agency. (2009a). *Knowledge base for the market in electric vehicles and plug-in hybrids*. Retrieved from http://www.energimyndigheten.se/Global/Forskning/Transport/Hearing%20elbilar%20och%20laddhybrider%20maj-09/Report%20on%20electric%20vehicles%20and%20plug-in%20hybrids.pdf

Swedish Energy Agency. (2009b). *Energy Indicators 2009*. Retrieved from http://www.energimyndigheten.se/en/Facts-and-figures1/Publications/

Taylor, P. (2010, July 23). Rush On for 'Rare Earths' as U.S. Firms Seek to Counter Chinese Monopoly. *The New York Times*. Retrieved from http://www.nytimes.com/gwire/2010/07/23/23greenwire-rush-on-for-rare-earths-as-us-firms-seek-to-co-58814.html?pagewanted=all

Technomar GmbH. (2009). *Kurz-und mittelfristige Erschließung des Marktes für Elektroautomobile*. Retrieved from http://www.technomar.de/studien/studie_emobil_allgemein.pdf

Tesla Motors. (2010). *Increasing Energy Density Means Increasing Range*. Retrieved July 29, 2010, from http://www.teslamotors.com/roadster/technology/battery

Trianel GmbH. (2010). *Netzwerk e-Mobilität*. Retrieved September 2, 2010, from http://www.trianel-emobil.de/netzwerk-e-mobilitaet.html

U.S. Department of Energy. (2009). *BMW Motors Mini E 2009 - Vehicle Specifications*. Retrieved from http://avt.inel.gov/pdf/uev/fact2009bmwmini.pdf

U.S. Department of Energy. (2010a). *The Recovery Act: Transforming America's Transportation Sector. Batteries and Electric Vehicles*. Retrieved from www.whitehouse.gov/files/documents/Battery-and-Electric-Vehicle-Report-FINAL.pdf

U.S. Department of Energy. (2010b). *Maintenance and Safety of Hybrid, Plug-in Hybrid, and All-Electric Vehicles*. Retrieved September 7, 2010, from http://www.afdc.energy.gov/afdc/vehicles/electric_maintenance.html

U.S. Department of Energy. (2010c). *Tax Breaks*. Retrieved September 2, 2010, from http://www.energy.gov/taxbreaks.htm

U.S. Energy Information Administration. (2007). *Annual Energy Outlook 2007*. Retrieved from tonto.eia.doe.gov/ftproot/forecasting/0383(2007).pdf

U.S. Energy Information Administration. (2010a). *Annual Energy Outlook 2010*. Retrieved from http://www.eia.doe.gov/oiaf/aeo/pdf/0383(2010).pdf

U.S. Energy Information Administration. (2010b, August). *Colorado Renewable Electricity Profile*. Retrieved September 2, 2010, from http://www.eia.doe.gov/cneaf/solar.renewables/page/state_profiles/colorado.html

U.S. Energy Information Administration. (2010c, May 25). *2010 International Energy Outlook*. Retrieved September 9, 2010, from http://www.eia.doe.gov/oiaf/ieo/highlights.html

U.S. Environmental Protection Agency. (1994). *Automobile Emissions: An Overview*. Retrieved from http://www.epa.gov/oms/consumer/05-autos.pdf

U.S. Environmental Protection Agency. (2010, April 14). *EPA and NHTSA Finalize Historic National Program to Reduce Greenhouse Gases and Improve Fuel Economy for Cars and Trucks*. Retrieved September 2, 2010, from http://www.epa.gov/otaq/climate/regulations/420f10014.htm

U.S. EPA. (2005). *Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel*. Retrieved July 29, 2010, from http://www.epa.gov/oms/climate/420f05001.htm#1

U.S. Geological Survey. (2002). *Rare Earth Elements—Critical Resources for High Technology*. Retrieved from http://pubs.usgs.gov/fs/2002/fs087-02/fs087-02.pdf

Union of Concerned Scientists. (2007). Hybrids Under the Hood [Web log post]. Retrieved July 28, 2010, from http://www.hybridcenter.org/hybrid-center-how-hybrid-cars-work-under-the-hood.html

United Nations Population Fund. (2007). *UNFPA state of world population, 2007 : unleashing the potential of urban growth.* Retrieved from http://www.unfpa.org/webdav/site/global/shared/documents/publications/2007/695_filename_sowp2007_eng.pdf

Uppladdning.nu. (n.d.). *Map with charging sites*. Retrieved September 9, 2010, from http://www.uppladdning.nu/Map.aspx

Vattenfall. (2010, May 25). *The City of Stockholm and Vattenfall Group starting biggest Swedish purchasing of electric cars*. Retrieved September 2, 2010, from http://www.cisionwire.com/vattenfall/the-city-of-stockholm-and-vattenfall-group-starting-biggest-swedish-purchasing-of-electric-cars13839

Vaughan, A. (2010, July 28). UK electric car grant scheme 'cut by 80%'. *The Guardian*. Retrieved September 2, 2010, from http://www.guardian.co.uk/environment/2010/jul/28/electric-car-grant-scheme

Verkehrsclub Österreich. (2009). *Multimodale Mobilität als Chance*. Retrieved from http://www.vcoe.at/docudownload.asp?id=6252&dlc=

Vinnova. (n.d.). *FFI - Strategic Vehicle Research and Innovation*. Retrieved September 9, 2010, from http://www.vinnova.se/en/FFI-English/

Voelcker, J. (2009). How Green Is My Plug-In? *IEEE Spectrum*, *46*(3), 42.

Wikipedia contributors. (2010a). IEC 62196. In *Wikipedia, The Free Encyclopedia*. Wikimedia Foundation. Retrieved from http://en.wikipedia.org/wiki/IEC_62196

Wikipedia contributors. (2010b). Lithium. In *Wikipedia, The Free Encyclopedia*. Wikimedia Foundation. Retrieved from http://en.wikipedia.org/w/index.php?title=Lithium&oldid=382514331

Wikipedia contributors. (2010c). Tesla Roadster. In *Wikipedia, The Free Encyclopedia*. Wikimedia Foundation. Retrieved from http://en.wikipedia.org/w/index.php?title=Tesla_Roadster&oldid=382256474

Wikipedia contributors. (2010d). Denver. In *Wikipedia, The Free Encyclopedia*. Wikimedia Foundation. Retrieved from http://en.wikipedia.org/w/index.php?title=Denver&oldid=382336481

Wikipedia contributors. (2010e). Transportation in the United States. In *Wikipedia, The Free Encyclopedia*. Wikimedia Foundation. Retrieved from http://en.wikipedia.org/w/index.php?title=Transportation_in_the_United_States&oldid=382051482

Wikipedia contributors. (2010f). Malmö. In *Wikipedia, The Free Encyclopedia*. Wikimedia Foundation. Retrieved from http://en.wikipedia.org/w/index.php?title=Malm%C3%B6&oldid=382189593

World Nuclear Association. (2010, July 13). *Nuclear Power in Sweden*. Retrieved September 2, 2010, from http://www.world-nuclear.org/info/inf42.html

Xcel Energy. (2010). *Smart Grid City*. Retrieved September 2, 2010, from http://smartgridcity.xcelenergy.com/

Yan, F., & Subler, J. (2010, January 11). China tops global auto market in 2009, challenges ahead. *Reuters*. Retrieved September 2, 2010, from http://www.reuters.com/article/idUSTRE60A12220100111

Yonhap News. (2010, July 11). *South Korea aims to become dominant producer of rechargeable batteries by 2020*. Retrieved July 29, 2010, from http://english.yonhapnews.co.kr/business/2010/07/10/38/0501000000AEN20100710002600320F.HTML

Appendix

Table 5: Policy recommendations after the ZEUS project (Olsson, 2000)

Policy Recommendations
1. Reduce and manage the high marginal cost of zero and low emission vehicles by buying in bulk together with other cities. Take advantage of any available purchase subsidies, and factor both long and short term costs into the equation.
2. Take an active role in facilitating refuelling and recharging accessibility. This may include financing infrastructure directly or partially, planning sites, and monitoring use, or creating partnerships with competent organisations in the public and/or private sector
3. When monitoring vehicles, test vehicles in ”real world” situations and complement automatic systems with manual log-book systems.
4. Use fairly mature alternative fuel technologies when using vehicles in municipal service or car sharing. When retrofitting a large fleet, rely on fairly mature alternative fuel technologies. However, you may also want to test one or two vehicles using experimental or prototype technology in cooperation with a local university or national research board.
5. Introduce one type of fuel at a time to avoid complications and confusion in the transition to zero and low emission vehicles. Consider single-supplier contracts to further simplify service and maintenance planning.
6. Plan for service and maintenance of alternatively fuelled vehicles. At the procurement stage, ensure that maintenance, training support, and spare parts accessibility issues are adequately dealt with. Allow for extra time during the transition period, and train all technicians, drivers, and safety personnel.
7. Increase user acceptance for new vehicle technologies by conducting market surveys, clearly signing vehicles and infrastructure with clear signage, and providing direct experience by lending vehicles or offering test drives using loaner or demonstration vehicles.
8. Improve pre-trip and real-time information using telematics to increase public transit and car sharing customer satisfaction.

Table 6: Barriers and drivers from International Energy Agency (2002)

Barrier/ blocking mechanism (page)	**Driver/ inducing mechanism** (page)
Concern for local traditional business 47	Legislation 46
High investment risks 47	Taxation 46
Access to service 47	R&D funding 46
Inadequate local service support 49	Market opportunities for local production 47
Retailers have to do the service but don't profit from selling the cars 49	New job opportunities 47
Fragmentation of roles and responsibilities in deregulated (public transport) markets 49	Environmental image/ prestige 47
Media focus on problems rather than possibilities 51	Environmental concern 47
Lack of understanding by the general public and decision-makers 53	Free parking 47
Conflict between budget pressures and environmental goals of local governments 53	Access to bus lanes 47
	Environmental Zoning 47
	Local transport advisor 47
	Subsidised electricity 48, 52
	Utilities leasing subsidised vehicles to users 48
	Information and education campaigns 48, 52
	Close contacts between vehicle industry and fleet owners 48
	Involvement of retailers in procurement process 49
	Fleet deployment (public, post, utilities) 49
	Newspaper articles 50
	Word of mouth 50
	NGO lobbying and promotion 50
	Stimulating media contacts 51
	Exception from restrictions applying to conventional vehicles 52
	Combination of local measures 53
	On-road demonstration of new vehicle types 54
	Technology procurement 54
	Forming buyer groups 55
	Setting up a forum for frontline stakeholders 55
	Clear city objectives and a transparent strategy 56
	Stakeholder cooperation 57
	A facilitator 57

Table 7: Barriers and "Must Have" actions of the PGR Menu (Schewel & Wilson, 2009)

Not enough cars in the pipeline, OEMs need proof of future consumer demand
1. Corporate/city/state fleets commit to buy a certain number of plug-ins 2. Stakeholder group provides a place for interested consumers/fleets to register early, and put cash down to reserve plug-ins
How can we manage this as a multi-sector, city-wide project?
3. Create collaborative stakeholder group within the community to help regulatory, commercial, and community interests align 4. Have one "champion" whose job it is to keep this group moving forward
How can we bring down upfront costs for consumers?
5. Work with banks and dealers to offer low-interest loans for plug-ins 6. Bundle all key incentives at vehicle point of purchase (home charger vouchers, rebates, etc.)
Consumer hesitation at diving into a new paradigm for mobility
7. Perks: access to HOV lanes, free tolls/downtown parking, reserved airport parking 8. Create consumer, city government, local business and utility education plans including test drives and "quick lease" options to individual and fleet consumers as well as high profile drivers. 9. Reduced (or free) electricity rates for charging.
Red tape around infrastructure installation
10. Fast-track permitting for charging stations 11. Ensure new and reconstruction/renovation building codes support the operation of plug-ins
What if these cars exacerbate my peak load?
12. Tie provisions of free home and public charge spots, as well as free or cheaper electricity, to either utility override power or "no charge" times.
Who will pay for infrastructure?
13. Local employers/retailers provide some charge stations at parking decks 14. Install public charge spots in high-traffic zones and parking areas, either with public money or private money that uses the stations to market 15. Provide affordable and available—or free—Level 2 home-charger/driveway circuit installation

Table 8: Barriers and "Nice to Have" actions of the PGR Menu (Schewel & Wilson, 2009)

Not enough vehicles in the pipe-line
1. Support non-traditional OEMs, conversion shops, and other plug-in manufacture businesses with tax incentives, contracts.
Who will service my plug-in?
2. All xEV owners get access to a "plug-in concierge" call service for info on trained mechanics/ electricians, where to charge, how to deal with technological issues, for the first five years of vehicle ownership. Plug-in service is better than traditional service. 3. Invest in technical education and worker transition assistance needed to rapidly train plug-in service technicians, encourage plug-in curricula in trade/technical colleges and community colleges, as and create/fund modules in plug-in crash safety training for fire/police
How can we bring down upfront costs for consumers?
4. Provide direct cash incentives to consumers for vehicle (including tax rebate, waiving of registration fee/sales tax, etc.) so that plug-in-premium is eliminated or so that plug-in are markedly cheaper than comparable ICEs 5. Introduce a government/ 3rd party sponsored battery warranty program to share the risk and to reduce the near-term cost of advanced batteries
Consumers have limited understanding of plug-ins
6. Launch large scale marketing plan to highlight the "empowerment, fun and energy independence" associated with plug-in, including viral, hands-on, TV, and radio advertising as well as a website. 7. Bundle plug-in purchase with a "green power only" utility contract and discounts on home solar, AMI installation, a smart grid upgrade, bike, bus pass, and/ or light rail pass to high-light plug-in role in the green lifestyle 8. Foster early roll-out in taxi fleets and rental cars 9. Develop materials to educate the drivers of tomorrow by reaching students of all levels (elementary- college) with related curricula
What if this exacerbates my peak load?
10. Install sub-meters (or Smart Grid) for plug-ins

Table 9: Fuel tax comparison Sweden, Germany and USA

	Sweden[12]	Germany	USA (Colorado)[13]
Fuel tax (in €/l)	0.58 (gas) 0.46 (diesel)	0.65 (gas) 0.47 (diesel)	0.084 €/l (gas) 0.093 €/l (diesel)
Electricity tax (in €/MWh)	30.60	20.50	(just regular sales tax)
Tax for driving 1,000km on gas (efficiency 0.06 l/km)	0.06 * 1000 * 0.58 = 34.8	0.06 * 1000 * 0.65 = 39	0.06 * 1000 * 0.084 = 5.04
Tax for driving 1,000km on diesel (efficiency 0.05 l/km)	0.05 * 1000 * 0.46 = 23	0.05 * 1000 * 0.47 = 23.5	0.05 * 1000 * 0.093 = 4.65
Tax for driving 1,000km on electricity (0.175 kWh/km)	0.175 * 30.6 = 5.36	0.175 * 20.5 = 3.59	---

12 The tax is a combination of energy and CO_2 taxes. The exchange rate of August 25 was used (1 EUR = 9.46 SEK). In the north of Sweden a different electricity tax applies.

13 These are the tax rates for the State of Colorado. 1 gallon is 3.78542 litre. The exchange rate of August 25 was used (1 EUR = 1.27 USD).

Table 10: TIS functions with respective indicators, constraints and drivers

Function	Indicator	Constraint/ Blocking Mechanism	Driver/ Inducing Mechanism
Knowledge development and diffusion	Documentation (number and orientation of publications) R&D projects (number, size and orientation) Assessments by managers and others	Lack of understanding by the general public and decision-makers	R&D funding Information and education campaigns Word of mouth Newspaper articles Plug-in curricula in trade/technical colleges
Government intervention	Objectives, goals, action plans Tax and subsidy regimes Relevant regulations Public purchasing policy Permitting procedures Infrastructure investment Education and campaigns	Red tape around infrastructure installation Conflict between budget pressures and environmental goals of local governments	Ensure new and reconstruction/renovation building codes support the operation of plug-ins New job opportunities Environmental image/ prestige Clear city objectives and a transparent strategy
Entrepreneurial experimentation	Number and variety of new entrants Different types of technology applications Character of the complementary technologies employed	(Local) Government concern for local traditional business	Support non-traditional OEMs, conversion shops, and other plug-in manufacture businesses with tax incentives, contracts Environmental image/ prestige
Market formation	Product availability Articulation of demand User profile/ structure of demand Producer profile/ structure of supply Purchasing processes	Not enough cars in the pipeline High upfront costs for consumers	(Joint) Public procurement Fleet deployment (public, post, utilities) Early plug-in EV registration (consumers/ fleets) Taxation Combination of local measures Low-interest loans for plug-ins (banks and dealers) Bundle all key incentives at vehicle point of purchase

			Provide direct cash incentives to consumers for vehicle Government/3rd party sponsored battery warranty program to share the risk and reduce battery cost
Legitimation	Opinion polls Advance booking of vehicles Media coverage	Consumer hesitation to dive into a new paradigm for mobility Inadequate local service support Media focus on problems rather than possibilities Consumers have limited understanding of plug-ins	City incentives (free/ less restricted parking, free charging, access to bus lanes, environmental zoning) Environmental image/ prestige/ concern On-road demonstration (leasing subsidized vehicles to users, foster early roll-out in taxi fleets and rental cars, test drives) Good media attention (stimulating media contacts, marketing) NGO lobbying and promotion Plug-in EV call service (closest charging station, service garage etc.) Plug-in EV plus X offers ("green" electricity contract, a smart grid upgrade, a bike, a bus or light rail pass) Educate drivers of tomorrow at all levels (elementary- college)
Resource mobilization	Volume of (venture) capital Volume and quality of human resources Volume and quality of complementary assets.	No planning security Economic Risks associated with plug-in EVs High investment risks	Grant programs
Interconnectivity	Number and size of formal and informal networks Workshops, seminars, meetings Specialized intermediates	Complexity of managing a multi-sector, city-wide project Fragmentation of roles and responsibilities in deregulated (public transport) markets Retailers have to do the service but don't profit from selling the cars	Create collaborative stakeholder group within the community Have a dedicated local transport advisor, facilitator, champion (who keeps the stakeholder group moving) Form buyer groups (joint procurement) Word of mouth Involvement of retailers in procurement process

Table 11: List of interviews

Name	**Organization**	**Position**	**Date**
Braune, Oliver	NOW GmbH	Coordinator of Model Regions in Germany	August 26, 2010
Dameron, Gerry	Boulder Electric Vehicle	Sales Manager (Utility)	July 9, 2010
Harboe, Casper	Öresund Region (2008-2010 City of Copenhagen)	Transportation planner	July 29, 2010
Hauksson, Charlotte	WSP Environment	Consultant	June 9, 2010
Lohbeck, Wolfgang	Greenpeace Germany	Senior Manager Special Projects	July 26, 2010
Ma, Fenglei	Rocky Mountain Institute	Transport Consultant, Project Get Ready	July, 2010
Marshall, Matthew	City of Denver	Project Leader	July 30, 2010
Mattila, Matt	Rocky Mountain Institute	Project Leader “ProjectGetReady”	July, 2010
Mollstedt, Björn	E.ON Sverige AB	E.ON responsible for E-Mobility Malmö	July 23, 2010
Shapard, Christine	Colorado Cleantech Industry Association	Executive Director	July 14, 2010
Simpson, Mike	National Renewable Energy Laboratory	Researcher (Transportation)	July 6, 2010
Stark, Susanne	Stadtwerke Düsseldorf	Project Leader „E-Mobil NRW“	July 12, 2010
Swalnick, Natalia	American Lung Association	Air Quality/ Clean Cities Manager	July 12, 2010
Wilke, Oliver	Wuppertal Institute	Project Leader Mobility	June 2, 2010
Wolters, Peter	FEV Motorentechnik GmbH	Project Leader “Smart Wheels” Aachen	July 9, 2010
Ziolek, Andreas	Energieagentur.NRW	Coordinator Model Region Rhein-Ruhr	June 7, 2010

Table 12: List of workshops and seminars

Title	Topic	Participants	Date
Project Get Ready Webinar Rhode Island	Progress and planning of Rhode Island PEV readiness program	Multi-stakeholder project team	June 22, 2010
Project Get Ready City and Tech Adviser Meeting	Update on PGR, FAQs, update on federal policy development	Technology advisers, Rocky Mountain Institute, City planners	June 29, 2010
Colorado Cleantech Industry Association – transport group meeting	Legislative Agenda for 2011 (lobbying) with respect to clean transport and especially EVs, Cleantech state plan, cooperation with Project Get Ready	Clean Cities Denver, CCIA, companies in the EV sector from Colorado	July 19, 2010
U.S. Department of Energy – Plug-in vehicle and infrastructure community readiness workshop	Gather of information and lessons learned from communities in the process of launching programs to deploy electric drive vehicles	Government officials, associations, city planners, research institutes, OEMs ...	July 22, 2010