



# Electric vehicles in action

Martina Wikström

Doctoral thesis 2015

KTH – Royal Institute of Technology

School of Chemical Science and Technology

Department of Chemical Engineering and Technology

Division of Energy Processes

Stockholm, Sweden

Akademisk avhandling som med tillstånd av Kungliga Tekniska högskolan framlägges till offentlig granskning för avläggande av teknologie doktorexamen, fredagen den 9 oktober 2015 klockan 13:30 i Kollegiesalen, Brinellvägen 8.

KTH – Royal Institute of Technology  
School of Chemical Science and Technology  
Department of Chemical Engineering and Technology  
Division of Energy Processes  
SE- 100 44 Stockholm  
Sweden

Copyright © Martina Wikström 2015

Printed by US-AB

All rights reserved

TRITA-CHE report 2015:50

ISSN: 1654-1081

ISBN: 978-91-7595-689-3

*This thesis is based on work conducted within the interdisciplinary graduate school Energy Systems. The national Energy Systems Programme aims at creating competence in solving complex energy problems by combining technical and social sciences. The research programme analyses processes for the conversion, transmission and utilisation of energy, combined together in order to fulfil specific needs.*



The research groups that constitute the Energy Systems Programme are the Department of Engineering Sciences at Uppsala University, the Division of Energy Systems at Linköping Institute of Technology, the Research Theme Technology and Social Change at Linköping University, the Division of Energy and Environment at Chalmers University of Technology in Göteborg as well as the Division of Energy Processes at the Royal Institute of Technology in Stockholm. Associated research groups are the Division of Environmental Systems Analysis at Chalmers University of Technology in Göteborg as well as the Division of Electric Power Systems at the Royal Institute of Technology in Stockholm.

*[www.liu.se/energi](http://www.liu.se/energi)*



## *Abstract*

This thesis analyses the political and practical conditions for introducing electric vehicles in Swedish public authorities and discusses the potential for using electric vehicles in public transport and public fleets. The work has been carried out using an interdisciplinary research approach. Such an approach brings new insights to energy studies; the combination of technical methods and methods from social science allows the technology to be studied in its societal context.

Local self-government enables Swedish public authorities to implement local solutions in order to achieve national policy goals. However, the results show that for energy and transport policy a clear allocation of responsibilities between local and regional levels is lacking – and this clarity is also lacking between the different policy areas. The lack of policy integration implies a risk that local policy development can miss the mark when it comes to the overall policy goal. Furthermore, findings show that so-called policy entrepreneurs can succeed in putting electric vehicles on the political agenda, and they can enforce decisions and deploy the vehicles within the public bodies.

The usage of plug-in electric vehicles in public fleets has been studied using (among other sources) logbooks, interviews, questionnaires and focus groups. Findings demonstrate a great potential to introduce plug-in electric vehicles through fleets. Although the usage varied slightly during the year, and winter conditions implied a general reduction in use, the results show that the deployment strategy is a central factor for the extent of the vehicle usage. Vehicles that are assigned a certain user or a specific task show a high degree of utilisation. Even though plug-in electric vehicles available through car-pools have a large potential group of users, the options also implies that users can instead choose a conventional vehicle. However, interventions to increase usage have proven to be successful. Policy entrepreneurial actions attract new users and revising organisational regulations, i.e. vehicle or environmental policies, shapes new behaviours. In this study, fleet vehicle users have proven to be relative indifferent to which fuel or technology they use, but acceptance for operation failure is very low.

Based on a demonstration project of series hybrid buses in regular service, the possibility of increased electrification of public transport is discussed. The contribution of hybridisation is analysed through assessment of different types of driving conditions. Results show that significant improvements in energy efficiency can be achieved but, because actual and optimal driving conditions differ, there is a risk of overestimating the contribution.

Sweden has set very ambitious national targets for its road transport system, i.e. to be fossil-fuel independent by 2030, and electrification is an important measure in reaching this goal. Given the magnitude of the challenge, it is not only the responsible thing to do; findings also show several advantages of introducing electric vehicles in the public sector first.

**Keywords:** *electric vehicles, interdisciplinary approach, public fleets, public transport*

## *Sammanfattning*

Avhandlingen analyserar de politiska och de praktiska förutsättningarna för en elfordon-introduktion i kommunal regi och möjligheterna med elfordon inom kollektivtrafiken och offentliga fordonsflottor diskuteras. Detta görs med ett tvärvetenskapligt angreppssätt. Ett sådant angreppssätt möjliggör nya insikter till energistudier, då man genom att kombinera samhällsvetenskapliga metoder med tekniska möjliggör att studera tekniken i samverkan med omgivningen.

Det kommunala självstyret ger kommunerna stort handlingsutrymme att själva arbeta fram lokala lösningar på nationella åtaganden. Dock framgår det från resultaten att ansvarsfördelningen på transportområdet är otydlig, dels mellan lokalt och regionalt ansvar, dels mellan policyområdena energi respektive transport. Bristen på policyintegration innebär att kommunens policyutveckling riskerar att missa det övergripande målet. Avhandlingen har även studerat hur s.k. policyentreprenörer lyckas placera laddfordon på den politiska agendan och hur de på olika sätt underlättar införandet i fordonsflottan.

Användningen av laddfordon som verksamhetsfordon har studerats genom att använda bl.a. loggböcker, intervjuer, enkätundersökningar och fokusgrupper. Resultatet visar på att initialt introducera laddfordon i fordonsflottor är ett bra sätt att införa denna teknologi i transportsystemet. Även om användningen varierat något under året, där vinterförhållanden har inneburit en minskad användning, visar resultatet att placeringsstrategin med vilken fordon allokeras som framförallt styr hur fordonen används. Laddfordon som tilldelats en specifik användare eller ett specifikt uppdrag används mycket. Laddfordon tillgängliga genom en bilpool har en teoretiskt stor användargrupp, men valbarheten innebär också att den kan bli bortvald till fördel för en konventionell bil. Insatser för att öka användningen har visat sig lyckats. Policyentreprenören har visat sig viktig för att attrahera nya användare och reviderade styrdokument formar nya beteenden. Resultatet visar att användare av verksamhetsfordon är tämligen ointresserade av vilket bränsle eller teknik de använder, då deras primära syfte med bilanvändning är att utföra sina arbetsuppgifter, medan däremot acceptansen för ett misslyckat genomförande är mycket låg.

Utifrån ett demonstrationsprojekt av seriehybridbussar i reguljär trafik diskuteras här möjligheterna med ökad elektrifiering av kollektivtrafiken. Bidraget av hybridisering analyseras med hänsyn till olika körförhållanden. Resultatet visar att betydande förbättringar av fordonets energieffektivitet kan uppnås men att verklig körning skiljer sig från optimala förhållanden och då riskerar man att överskatta bidraget.

Sverige har ambitiösa nationella mål för sin fordonsflotta, nämligen att vara fossiloberoende till 2030, och elektrifiering är en viktig pusselbit. Givet omfattningen av utmaningen är det inte bara ansvarsfullt utan även, vilket resultaten från denna avhandling visar, fördelaktigt att introducera laddfordon i den offentliga sektorn först.

**Nyckelord:** *elfordon, laddfordon, kollektivtrafik, offentlig fordonsflotta, tvärvetenskaplig ansats*

## List of papers included in this thesis

- Paper I      Bridging the implementation gap: Combining backcasting and policy analysis to study renewable energy in urban road transport.  
Olsson L, Hjalmarsson L, Wikström M, Larsson M.  
Transport policy. 37 (2015) 72–82
- Paper II:      First experiences of ethanol hybrid buses operating in public transport;  
Wikström M, Folkesson A, Alvfors P;  
Proceedings of the World Renewable Energy Congress 2011, May 8-13 2011,  
Linköping, Sweden
- Paper III:     Analysis of the Fuel Economy Improvement Potential of Ethanol Hybrid Buses;  
Wikström M, Folkesson A, Alvfors P;  
Proceedings of the 24<sup>th</sup> International Conference on Efficiency, Cost,  
Optimization, Simulation and Environmental Impact of Energy Systems,  
July 4-7 2011, Novi Sad, Serbia – Awarded Best Paper.
- Paper IV:     Socio-technical experiences from electric vehicle utilisation in commercial fleets.  
Wikström M, Hansson L, Alvfors P.  
Applied Energy 123 (2014) 82–93
- Paper V:      Investigating barriers for electric vehicle deployment in commercial fleets.  
Wikström M, Hansson L, Alvfors P.  
Submitted to Transportation Research Part D: Transport and Environment
- Paper VI:     **An end has a start** – investigating the usage of electric vehicles in commercial  
fleets.  
Wikström M, Hansson L, Alvfors P.  
Energy Procedia. 75 (2015) 1932-1937
- Paper VII:    Introducing electric vehicles in public authorities  
Hjalmarsson L, Wikström M, Hansson L.  
Submitted to Research in Transportation Business and Management.

## My contribution to the papers

Paper I was a joint effort by all four authors and supervised by Professor Jenny Palm, my supervisor Professor Per Alvfors, my co-supervisor Associate Professor Lisa Hansson, Associate Professor Mats Söderström, Associate Senior Lecturer Elisabeth Wetterlund and post-doc Magdalena Falldé.

I am the main author of papers II – VI and the work was carried out under the supervision of Associate Professor Lisa Hansson and Professor Per Alvfors.

Paper VII was written together with Linnéa Eriksson and supervised by Associate Professor Lisa Hansson.

**Related publication, not included in this thesis**

Wikström M., Alvfors P.; Biogas or Electricity as Vehicle Fuels Derived from Food Waste - the Case of Stockholm, Proceedings of the 25<sup>th</sup> International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, June 26-29 2012, Perugia, Italy

Wikström M, Sunnerstedt E; Experiences from the operation of 50 electric vehicles during one year in Sweden, Proceedings of the 2<sup>nd</sup> European Electric Vehicle Congress, November 19-22 2012, Brussels, Belgium

Wikström M, Sunnerstedt E. Elbilsupphandlingen – Hur fungerar fordonen? Vad tycker förarna? National Conference on Transportation Research, January 9-10 2013, Linköping, Sweden

Wikström M, Sunnerstedt E, Alvfors P. **Obstacle 1:** Capture experience generation of Swedish electric vehicle users, Proceedings of the 27th Electric Vehicle Symposium, November 17-20 2013, Barcelona, Spain

Wikstrom M, Sunnerstedt E. Elbilsupphandlingen – Botemedlet mot räckviddsångest? National Conference on Transportation Research, January 8-9 2014, Linköping, Sweden

Wikström M, Alvfors P. Assessing the impact of a plug-in electric vehicle technology procurement scheme. Proceedings of the 3<sup>rd</sup> European Electric Vehicle Congress, December 3-5 2014, Brussels, Belgium

Wikström M. Elbilsupphandlingen - Socio-teknisk utvärdering av laddfordonen och deras användare 2011-2014. December 2014. KTH report.

Wikström M. Hur Elbilsupphandlingen har positionerat den svenska elfordonsmarknaden - en intervjustudie av elfordonstillverkare. KTH report.

Wikström M. Enkätstudie av inköps-/upphandlingsansvariga inom Elbilsupphandlingen. KTH report.

Wikström M. Elbilsupphandlingen - Delårsrapport 1: januari – juni 2012. KTH report.

Wikström M. Elbilsupphandlingen - Delårsrapport 2: juli – december 2012. KTH report.

Wikström M. Elbilsupphandlingen - Delårsrapport 3: januari – juni 2013. KTH report.

Wikström M. Elbilsupphandlingen - Delårsrapport 4: juli – december 2013. KTH report.

Wikström M. Utvärdering av Elbilsupphandlingens demonstrationsflotta samt förslag på fortsatt utvärderingsplan. KTH report.

Wikström M. Utvärdering av etanolhybridbussar i SL-trafiken. Ett fältförsök mellan maj 2009 och juni 2010. KTH report.

Hjalmarsson L, Larsson M, Olsson L, Wikström M (2011), Pathways to a renewable transport system in Stockholm 2030, Report no. 48, Energy Systems Programme, Linköping University, Sweden, ISSN 1403-830



## Table of contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	<i>Electricity as vehicle fuel</i>	1
1.2	<i>Scope of research</i>	2
1.3	<i>Description of definitions</i>	3
1.4	<i>Thesis outline</i>	4
<b>2</b>	<b>Background</b>	<b>5</b>
2.1	<i>EU energy and transport policies</i>	6
2.1.1	Swedish energy and transport policies	7
2.2	<i>Energy use in the Swedish road transport system</i>	8
2.3	<i>The plug-in electric vehicle market</i>	9
2.4	<i>Situating the study</i>	11
2.4.1	Local policy practice	11
2.4.2	Public fleets	12
2.4.3	Public transport	14
2.4.4	Interdisciplinary research and a systems approach	15
<b>3</b>	<b>Method</b>	<b>17</b>
3.1	<i>Conducting interdisciplinary research</i>	17
3.1.1	Introduction to the papers and the combination of methods	17
3.2	<i>Methods for policy analysis</i>	19
3.2.1	Document analysis	20
3.2.2	Interview study	20
3.2.3	Backcasting	20
3.3	<i>Methods for studying the technical perspective</i>	20
3.3.1	CAN bus logs	21
3.3.2	GPS data	21
3.3.3	Vehicle logbooks	21
3.3.4	Duty cycle tests	21

3.4	<i>Methods for studying the user perspective</i>	22
3.4.1	Questionnaires	23
3.4.2	Single interviews and focus group discussions	23
3.5	<i>Designing interdisciplinary research</i>	24
<b>4</b>	<b>Results</b>	<b>28</b>
4.1	<i>Possibilities for plug-in electric vehicles in public fleets</i>	28
4.1.1	Introduction to the study case – <i>Elbilsupphandlingen</i>	28
4.1.2	Fleet vehicles in action	29
4.1.3	What are the possibilities for public fleets?	38
4.2	<i>Opportunities for public transport</i>	40
4.2.1	Ethanol series hybrid buses	40
4.2.2	Opportunities for electrification of public transport buses	43
4.3	<i>Political conditions for an electric vehicle introduction</i>	46
4.3.1	Local energy and transport policy conditions	46
4.3.2	Political agenda-setting	48
4.3.3	Local public authorities as forerunners	49
4.4	<i>The future is interdisciplinary or not at all</i>	51
<b>5</b>	<b>Conclusions and recommendations</b>	<b>53</b>
5.1	<i>Recommendations for future research</i>	57
5.2	<i>Policy recommendations</i>	58
<b>6</b>	<b>Acknowledgements</b>	<b>61</b>
<b>7</b>	<b>Appendix 1</b>	<b>62</b>
<b>8</b>	<b>References</b>	<b>63</b>

# 1 Introduction

The title of this thesis, *Electric vehicles in action*, is a Latourian flirt to recognise the relationship between technology and society (Latour, 1987). An interdisciplinary systems approach rejects a separation between a technology and its societal context (Hughes, 1983) and provides a framework for studying the adoption of a new technology. This doctoral thesis discusses the conditions and opportunities for a resilient road transport system based on the experiences of the real policy practice, actual users and authentic operating conditions – with the special emphasis on electric vehicles.

Energy studies are traditionally based on a technical perspective, providing quantitative knowledge about the functionality of a component, artefact or physical system (D'Agostino et al, 2011). The sociology of technology, i.e. the economic, political and social drivers of energy usage, is a topic that has been neglected in the energy research field (Sovacool, 2014). To combine technical energy studies with social science enables better understanding of how human behaviour influences energy demand and the adoption of technologies. Social barriers tend to be overlooked and factors such as social and cultural values, business practice and political interest have been shown to be influential on users. To comprehend the society surrounding the technology is fundamental: thus it can be argued that it is the society that constructs the technology (Latour, 1987). An interdisciplinary research approach, it has been argued, is an important approach for effective decarbonisation of the transport system (Schwann et al, 2011; IEA, 2012).

## 1.1 Electricity as vehicle fuel

Electricity is a central yet controversial energy carrier. The European Union (EU) recognises electricity as a main measure to achieve a sustainable road transport system (EC, 2009a) but even though the electricity market resembles other markets, certain theoretical imperatives surround CO<sub>2</sub> emission accounting. As the traditional vehicle emission classification system is based on tail-pipe emissions, which for a vehicle with an electric engine is zero, the environmental impact must be considered in some other form. Today, a prevailing CO<sub>2</sub> emission accounting procedure is to consider worst-case electricity production for a plug-in electric vehicle and to compare that to tail-pipe emissions of a conventional vehicle. Although this method does not provide an accurate comparison, it is still popular. To broaden the perspective, three common principles for CO<sub>2</sub> emission accounting of electricity will be

presented. The first principle is to regard the terms of the specific power supply. The possibility to sign up a green electricity contract and thereby charge *renewable electricity* has been shown to be an attractive combination and argument for purchasing a plug-in electric vehicle (Axsen and Kurani, 2013). Renewable electricity generation implies the usage of renewable sources, i.e. no CO<sub>2</sub> emissions. The second principle is to consider *average electricity*, i.e. to regard the entire power generation portfolio of the electricity market and obtain an average CO<sub>2</sub> emissions value for the electricity mix. Sweden is a part of a Nordic electricity market, whose electricity mix accounts for approximately 85 g. CO<sub>2</sub>/kWh (Swedenergy, 2012). The third principle is *marginal electricity*, i.e. to consider the last dispatched unit used for producing the electricity. This principle implies that using Nordic electricity in Sweden to charge a plug-in electric vehicle reduces the export of electricity to more fossil-heavy electricity markets, and that Swedish plug-in electric vehicles (that is, their owners) should account for that effect. Coal-condense power plants currently have the highest marginal cost and the electricity generation accounts for approximately 900 g. CO<sub>2</sub>/kWh (Connolly et al, 2014). Any of these three CO<sub>2</sub> emission accounting principles works, as long as it is harmonised to comprise all vehicle fuels. However, marginal petrol is never used for any automotive comparisons and therefore not either in this case. On this basis, this thesis will hereby consider electricity as an improvement to the road transport system compared to the petroleum alternative.

## 1.2 Scope of research

By analysing the political and practical prerequisites, this thesis discusses the possibilities offered by electric vehicles in Swedish public transport and public vehicle fleets. The basis for the discussions are findings derived from actual operations and the analysis has been carried out using an interdisciplinary approach in order to understand the surrounding factors that construct the usage of the technology. The results will be discussed according to three research topics. The first topic is the technology procurement scheme *Elbilsupphandlingen* – The Swedish National Procurement of Electric Vehicles and Plug-in Hybrids – an extensive demonstration project, where the material includes technical as well as user perspectives to describe the usage of plug-in electric vehicles in different fleets. The second research topic is a demonstration project of series hybrid ethanol buses, presenting a discussion of the potential for electrification of public transport buses. The last research topic is an analysis of policy practice in Stockholm and a discussion regarding the local political conditions for plug-in electric vehicles. Using an interdisciplinary research design when analysing electric vehicles in action

(whether it is actual vehicles or actual policy practice) has generated non-prescriptive findings that, in addition to traditional findings, also provide greater understanding of the social drivers and new behaviours involved.

### 1.3 Description of definitions

To improve readability of this thesis, the following is a brief clarification of the definitions used in herein. An overview is presented in Table 1. *Battery Electric Vehicle* (BEV) – an all-electric vehicle propelled by an electric motor, which is powered by energy stored in an on-board battery. *Plug-in Hybrid Electric Vehicle* (PHEV) – a vehicle with a high-capacity battery and an electric motor, in addition to the internal combustion engine (ICE). PHEVs are capable of using electricity as its primary propulsion source and ICE assists in recharging the battery or serves as a source of power when the battery is depleted. *Plug-in Electric Vehicle* (PEV) – a general term used to describe vehicles that charge its on-board battery from the electricity grid; the concept includes both BEVs and PHEVs. *Hybrid Electric Vehicles* (HEV) do not charge their battery from the grid, but instead utilise regenerated brake energy.

Table 1. Vehicle definitions used in this thesis

Electric vehicles (EVs)	Vehicle technology		Abbreviation	Brake energy regeneration	Electricity grid charging	Internal combustion engine
		Hybrid electric vehicle		HEV	X	
Plug-in electric vehicles (PEVs)	Battery electric vehicle		BEV	X	X	
	Plug-in hybrid electric vehicle		PHEV	X	X	X

Charging the PEVs from the electricity grid is performed at different conditions with respect to power output. Charging conditions are classified as:

- Normal charging: 10-16A, 230 V, altering current (AC), 2.4-3.8 kW
- Semi-fast charging: 16-32 A, three-phase AC, 12-21 kW
- Fast charging: 32 A, 300-400 V, direct current (DC), 50 kW

Please note that there is a fundamental difference between **vehicle fleet**, which is the total stock of vehicles in Sweden, for example, and the **fleet vehicle** that operates within a public or private company.

## 1.4 Thesis outline

Chapter 1 presents the outline for the research and the structure of the thesis.

Chapter 2 provides a brief background to relevant EU and Swedish energy and transport policy and energy usage in the transport system, as well as introduction to interdisciplinary studies of the energy and transport systems.

Chapter 3 introduces the interdisciplinary research design and the methodology used in this thesis work.

Chapter 4 presents the main findings from the papers and a discussion of these findings according to the three themes:

1. Plug-in electric vehicle deployment in public vehicle fleets
2. Possibilities for introducing electric buses in public transport
3. Political conditions for introducing plug-in electric vehicles

Chapter 5 concludes the work with a final discussion and recommendations for introducing electric vehicles.

## 2 Background

Fossil energy carriers dominate energy use in the road transport system (IEA, 2014a; SEA, 2015a). Local and global implications of the use of fossil fuels include human health issues and greenhouse gas emissions. The transport sector accounts for 20% of global energy usage and road transport constitutes a large share of the final energy usage in transport (IEA, 2014b; Eurostat, 2014). Globally, there are about 1 billion vehicles operating today and projections indicate an increase to 2 billion by 2030 (Sperling and Gordon, 2009). The road transport system is currently, and will probably continue to be, a major energy user.

This thesis focuses on electric vehicles, as electrification is an important energy-efficiency measure (Larminie and Lowry, 2003). The energy efficiency for an electric powertrain is about 80 % compared to a conventional vehicle, which use approximately 25 % of the energy input for propelling the vehicle (Kushnir and Sandén, 2011). For a schematic overview, a Tank-to-Wheel (TTW) analysis can be used to compare different powertrains and the effective power output from the fuel, see Table 1.

Table 1. Energy efficiency for four energy carriers (Kushnir and Sandén, 2011)

Fuel	Energy storage	Conversion efficiency from storage	Powertrain	Powertrain efficiency	Tank-to wheel efficiency
Electricity	Battery	0.81-0.88	Electric	0.8-0.82	0.65-0.72
Hydrogen	Fuel cell	0.41-0.50	Electric	0.8-0.82	0.33-0.41
Gaseous methane	Tank	1	Mechanical	0.20-0.35	0.20-0.35
Liquid fuel	Tank	1	Mechanical	0.18-0.35	0.18-0.35

The electric powertrain is approximately three to four times as energy efficient as a mechanical one. The main energy losses are in the internal combustion engine, which generates large heat losses in the order of 70-75 % (DoE, 2015). The energy efficiency of an electric engine is about 90 % (Kushnir and Sandén, 2011; Larminie and Lowry, 2003). The electric powertrain has neither friction nor transmission losses. The charging and discharging of the energy storage is carried out with an efficiency of approximately 80%. The energy storage could be mechanical (e.g. a fly-wheel) or chemical (e.g. battery, super capacitors or hydrogen). A vehicle powertrain can also be more or less electrified, i.e. with different degrees of hybridisation. Parallel hybrids have both a mechanical and an electric powertrain. In series hybrids, the

converter subsequent the internal combustion engine supplies electricity to the electric powertrain. Hybridisation has the potential to improve the fuel economy of the vehicle, thus parts of operations are carried out in electric mode.

## 2.1 EU energy and transport policies

The current EU policy framework aims to achieve a *cleaner* road transport system, through energy efficiency measures and renewable fuels (EC, 2009b). Renewable fuels include biofuels and renewable electricity. Biofuels may be produced from multiple renewable sources and through multiple conversion routes (Hansson and Grahn, 2013). Renewable electricity is generated by hydro, solar, wind, geothermal and biomass systems. In order to create a cleaner road transport system, introduction of plug-in electric vehicles is identified as an important measure by the Commission's *White Paper on Transport* (COM/2011/0144). The White Paper on Transport describes the future transport system in the EU and includes both technology pathways and possible policy measures. The aim for the EU PEV policy is to introduce 5 million PEVs by 2020 and 15 million by 2025 (Ertrac et al, 2012)

To the Member States, the most prominent EU energy- and transport directives are as follows:

*The Renewable Energy Directive* (2009/28/EC) outlines the energy and climate targets for the EU by 2020, with a main objective to decrease greenhouse gas emissions and increase the use of renewable fuels. But the directive also includes specific goals for the road transport system, which aim for 10 % renewable transport fuels by 2020 (EC, 2009a).

*Clean Vehicles Directive* (Directive 2009/33/EC on the Promotion of Clean and Energy Efficient Road Transport Vehicles) obliges public authorities and private companies operating in public transport to take energy efficiency and environmental impact into account when acquiring road vehicles (EC, 2009b).

*The Energy Efficiency Directive* (2012/27/EU) repeals the Cogeneration Directive (2004/8/EC) and the Energy End-Use Efficiency and Energy Services Directive (2006/32/EC) and describes the measures necessary to reach the 2020 energy efficiency target of -20 % by 2020 (EC, 2012).

*Deployment of Alternative Fuel Infrastructure Directive* (2014/94/EU) is a part of the Clear Power for Transport Package strategy and will facilitate an infrastructure expansion for renewable fuels. (EC, 2014a).



In addition, EU has legislation with the direct aim of exerting pressure on the vehicle manufacturers by defining emission standards. The average carbon dioxide (CO<sub>2</sub>) emission level a passenger car manufacturer can allow in products today is 130 g CO<sub>2</sub>/km and by 2021, this obligatory vehicle emission limit will be adjusted to 95 g CO<sub>2</sub>/km (EC, 2014b). General emission levels (for example carbon monoxide, nitrogen oxides and particular matter) are ruled by the Euro standards, where the prevailing standard is Euro 6/VI (EC, 2007; EC, 2011b).

### **2.1.1 Swedish energy and transport policies**

EU energy, climate and transport policies constitute the regulatory framework for national policymaking in the field; however it constitutes *the floor*. Member States with more progressive policy agendas can decide upon more ambitious or specific goals. For Sweden, the process to decarbonise the road transport system started in 2004. In 2004, the first demand-side policy measure to promote the use of renewable fuels in Sweden was introduced; a regulation stipulating that 85 % of the governmental agencies' vehicle purchases or leasing contract had to be environmentally friendly vehicles (Swedish Parliament, 2004). The regulation did not include regional or local public authorities, but many chose to comply nevertheless. For the public, the vehicle tax became differentiated in 2006, when vehicles with less than 120 g CO<sub>2</sub>/km tailpipe were defined as *green* and where granted tax reliefs (Swedish Parliament, 2006). This green car definition was not updated until 2013, when it became weight differentiated and lowered to 95 g CO<sub>2</sub>/km for average sized fossil-fuel passenger cars. In 2007, another financial support was introduced – a green car rebate (Swedish Parliament, 2007a). The green car rebate subsidised renewable-fuelled vehicles from 2007 to 2009 and totalled 250 million SEK, which granted each applicable vehicle 10.000 SEK (approximately €1.000). Between 2009 and 2011, national, directed financial subsidies to promote the use of renewable fuelled and electric vehicles in Sweden were lacking. Meanwhile, in 2009 the Swedish Government declared that a *fossil fuel-independent* vehicle fleet by 2030 was the primary priority in reaching the overarching goal of a net zero-emission energy system by 2050 (Swedish Government, 2009). The majority of the work in this thesis reflects the conditions and actions from this time period. The absence of national governing and leadership incited local initiatives and collaborations. In 2012, the first national demand-side measure designed specifically to promote plug-in electric vehicles was introduced. A total of 200 million SEK was allocated for super-green car rebates, which granted 40.000 SEK for vehicles emitting less

than 50 g CO<sub>2</sub>/km tailpipe (Swedish Parliament, 2011). In 2014, the super-green car rebate was extended to 2017 (Swedish Parliament, 2014).

## 2.2 Energy use in the Swedish road transport system

The Swedish road transport system uses approximately 85 TWh of fuels, see Figure 1, and constitutes 94 % of the total energy use in transports (SEA, 2015a). In 2013, the share of renewable fuels surpassed 10 %, the EU policy goal for 2020, and the dominating contribution is through low-blends, i.e. biofuels added to fossil fuels. Figure 2 shows the distribution in use of renewable fuels in the road transport system in 2014.

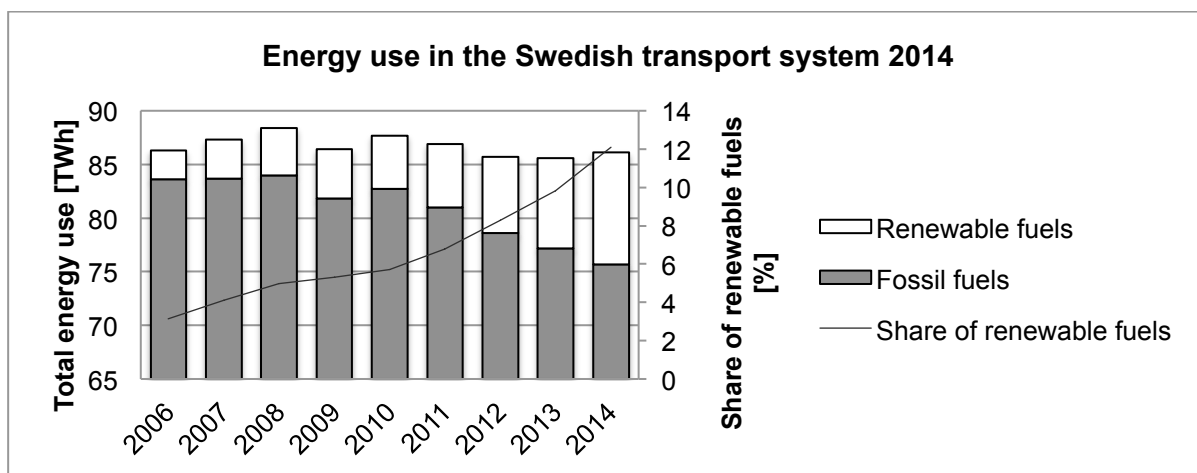


Figure 1. Energy use in the Swedish road transport system and share of renewable fuels (SEA, 2015a)

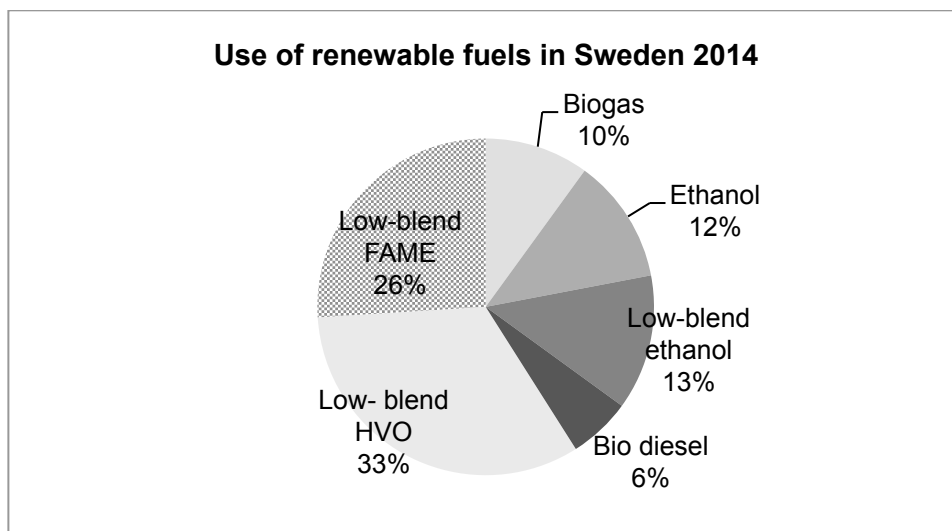


Figure 2. The use of renewable fuels in Sweden (SEA, 2015a). Electricity is not (yet) included in the official statistics

The Swedish road transport system is highly influenced by being just that – Swedish. Ten years ago, in 2004, the most sold passenger car was Volvo V70; in 2014 this was still the most popular passenger car in Sweden (BIL Sweden, 2005; 2015). The Swedish passenger car fleet is heavier than most other European fleets and consequently it has higher CO<sub>2</sub> emission levels (EEA, 2013).

### 2.3 The plug-in electric vehicle market

The sales of third-generation PEVs started around 2010 (see Figure 3) and expanded in 2013-2014 (EVI, 2015). The global market in 2014 included 665,000 plug-in electric vehicles and constituted approximately 0.08 % of all passenger vehicles. Global sales in 2014 amounted to 300,000 plug-in electric vehicles, where 57 % were BEVs and 43 % PHEVs.

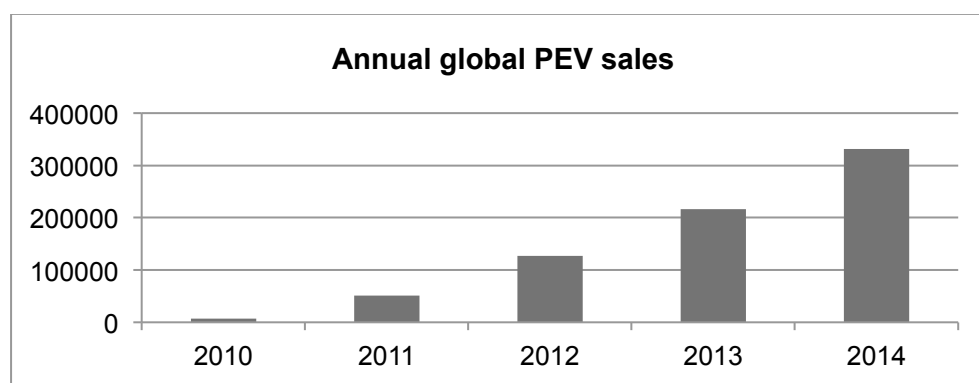


Figure 3. Global sales of plug-in electric vehicles (EVI, 2015)

When regarding market share, Norway stands out with a sales market share of 12.5 % in 2014 (EVI, 2015). Norway provides a substantial incentive framework and the total number of plug-in electric vehicles surpassed 50,000 in April 2015. At that level, the Norwegian Government had initially decided it would repeal several incentive schemes, but that decision has been revised and the schemes extended (Höyre, 2015). The Netherlands has the second largest market share, with 3.9 % in 2014. Dutch incentives became less generous during 2014, reducing the market share from 5.3 % in 2013. The third biggest market share is held by the United States – 1.5 % in 2014 – but given the size of this market, it is estimated that approximately 40 % (about 260,000) of all plug-in electric vehicles are in the US. About 120,000 of these are in California. Over the past decades, California has pushed for progressive policy-making and the development of Zero Emission Vehicles - ZEVs, which also includes fuel cell vehicles (Sperling and Eggert, 2014). The goal for 2025 is to reach 1.5 million ZEVs and the action plan has come to include not only technical, legal and financial measures, but

also consideration of social perspectives and suggested frameworks to specifically promote ZEVs for low-income consumers (Brown et. al, 2013).

The fourth largest market share in 2014 was held by Sweden. The sales of plug-in electric vehicles amounted to 1.4 % and a total of 7,928 of such vehicles were in operation in Sweden (EVI, 201; ELIS, 2015). Sales have continued to increase and in August 2015 were the total number of plug-in electric vehicles was 12,496, see Figure 4. Approximately 80 % of the vehicles are used as fleet vehicles or as company cars, i.e. significantly fewer PEVs are in private ownership. 58 % of the PEVs in August 2015 were PHEVs and the most popular PEVs models are presented in Figure 5.

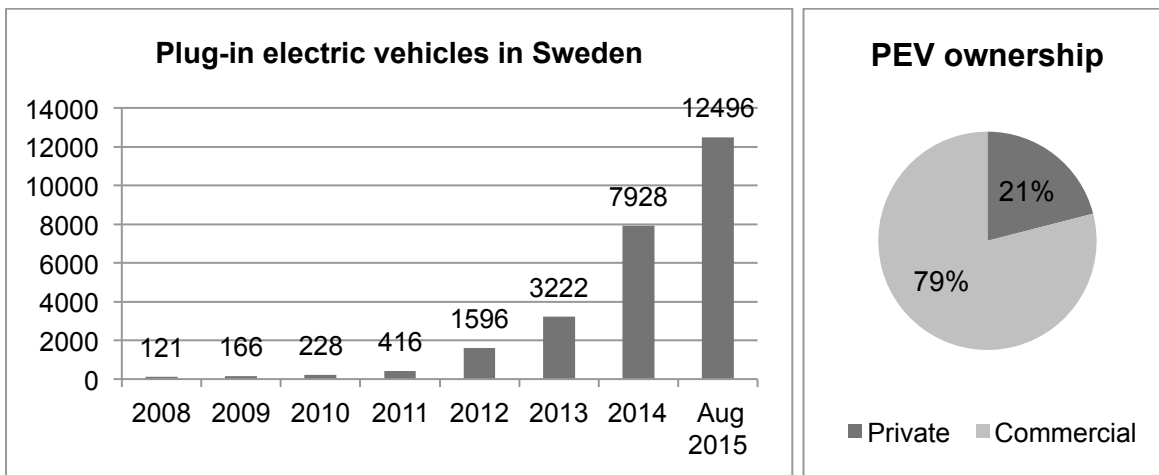


Figure 4. (a) Swedish PEVs 2008 – August 2015 (b) Ownership distribution (ELIS, 2015)

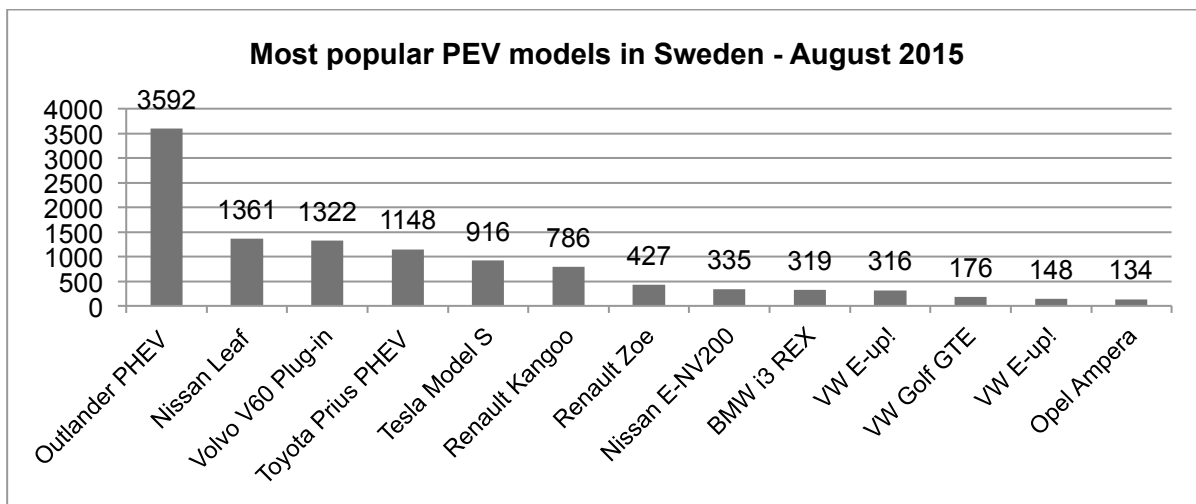


Figure 5. Distribution between the most popular PEV models in Sweden (ELIS, 2015).

## 2.4 Situating the study

This thesis condenses the findings from interdisciplinary studies of the political and practical conditions for introducing plug-in electric vehicles in Swedish energy and transport systems through public vehicle fleets and public transport. This section situates the study in an appropriate context by presenting the Swedish public system, the public vehicle fleet and the public transport bus fleet, and introducing the concepts of the interdisciplinary research approach and systems analysis.

### 2.4.1 Local policy practice

The Swedish public system is divided into three levels – national, county (or regional) and municipal. Only the parliament at national level has legislative power, and this body formulates Swedish national policy goals. At county levels, regional issues are discussed and coordinated. The local public authorities – the municipalities – are the implementers of national policy, but it is the municipalities themselves that choose how they implement policy in order to reach overall national goals, as well as how they will organise the work, internally and externally together with other actors (Bäck and Larsson, 2008). Figure 6 describes the Swedish public system. In order to discuss the conditions for an introduction of plug-in electric vehicles in Sweden, it is therefore important to assess local policy practice and the political conditions for such introduction; actions on the local level reveal the actual commitment.

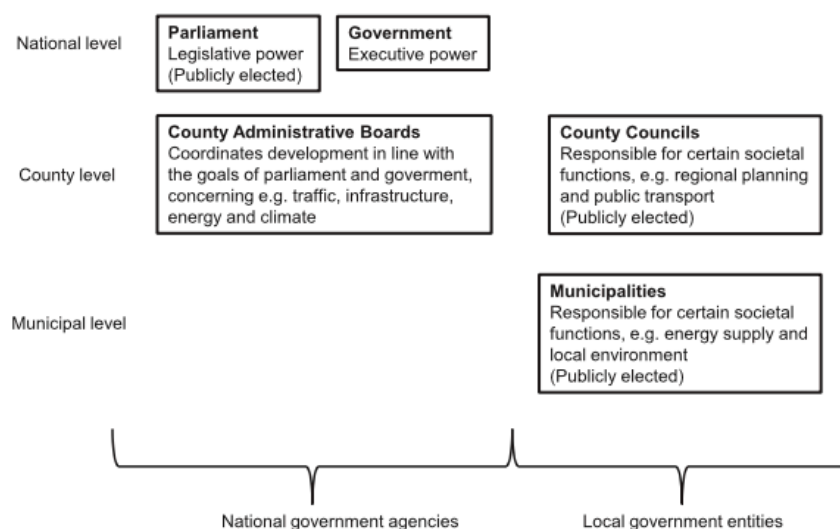


Figure 6. The Swedish public system, picture from Paper I

Local and regional public actors develop strategic documents to present their visionary picture of the future. Even though this work focus foremost on the role of the local public authority,

it is also important to consider the entire institutional structure. New technologies imply new working processes and, if left unidentified, such processes could lead to shortcomings in infrastructure provision, transition failures and lock-in effects (Foxon and Pearson, 2008). Local public authorities are given the responsibility to lead the transition to a more sustainable society (EC, 2011a), therefore it is vital to study on-going policy processes.

#### **2.4.2 Public fleets**

This study focused on the operations of plug-in electric vehicles in fleets and in particular in public fleets. Among studies with an end-user focus, it is more common to target PEV operated by private owners. In Sweden, fleets are the primary recipients of vehicles in the new-car sales market (Transport Analysis, 2015a). Fleets therefore constitute a favourable physical entry for new vehicle technologies and this study will complement studies that describe conditions for the private owner of PEVs.

An introduction of PEVs in fleets has other advantages over introduction in the private market. New vehicle technologies are initially more expensive than conventional ones, and the infrastructure for refuelling is not yet developed; these are two prominent factors that have been identified to inhibit the adoption of PEVs (Gnann and Plötz, 2015; Dumortier et al, 2015). Fleet vehicles are used more than the average privately owned vehicle (Nesbitt and Sperling, 1998), which means that fleet vehicles can maximise the benefit with low operational costs and motivate a higher purchase price. Fleets also benefits from being precisely fleets, i.e. consisting of multiple vehicles. A composition of different vehicles integrates flexibility and allows battery electric vehicles to be used for tasks suitable for the technical specifications.

Even though PEVs are commercially available products, powertrain components and materials are still continuously being improved. Since the battery constitutes a significant part of the total lifecycle cost (Delucchi and Lipman, 2001) and there are still uncertainties regarding the aging of the batteries (Klett et al, 2014), fleets have better possibilities to account for that risk compared to a private consumer. Furthermore, the mobility need for (most) fleets is considered to be more predictable compared than for a private household (Schmidt et al, 2014).

The Swedish public fleet comprises approximately 32,000 vehicles (passenger cars and vans) and public fleets represent a significant purchaser group (Miljöfordon Syd, 2015). The share of bio-fuelled and plug-in electric vehicles varies among the regions/municipalities. Today, the

public fleets in the City of Stockholm and the municipality Botkyrka, just south of Stockholm, include over 90 % renewable fuelled passenger cars (Miljöfordon Syd, 2015). However, even though the CO<sub>2</sub> emissions from the entire public fleet are decreasing, in an international perspective the average emission level is still high – 140 g CO<sub>2</sub>/km. A local progressive initiative is on-going in the city of Växjö, which decided in 2010 to become a fossil-free municipality by 2020 (10 years prior to the national goal). Since 2010, the municipality will only consider public procurement tenders claiming the maximum level of 110 g CO<sub>2</sub>/km – a measure that consider only those vehicles with far better standards than the then-prevailing national standard for green cars.

Public procurement is the formal procedure where contracts are awarded to providers of goods and services. Public procurement is a demand-side policy measure and in the EU, public procurement accounts for more than € 2 trillion annually, or 19 % of EU GDP (EC, 2015d). Today, Swedish procurement law comprises the Public Procurement Act (Swedish Parliament, 2007b) and Utilities Procurement Act (Swedish Parliament, 2007c). A special case of tender process is technology procurement, where the objective is to promote the development of more energy-efficient products, systems or processes and the purchaser group thereby places an order requesting technically pioneering, i.e. innovative, tenders (Edquist et al, 1999; Swedish Parliament, 2003).

The current European Green Public Procurement Criteria specifies that passenger cars shall emit less than 130 g CO<sub>2</sub>/km and vans vehicles less than 170 g CO<sub>2</sub>/km. (EC, 2015a). An example of a national initiative is Germany, where 10 % of the new federal fleet vehicles are required to emit less than 50 g CO<sub>2</sub>/km. (EC, 2015b).

Directive 2009/33/EC on the Promotion of Clean and Energy Efficient Road Transport Vehicles or simply the Clean Vehicle Directive govern all public transport services and road transport vehicle acquisitions and require all EU public bodies to consider environmental and fuel consumption when purchasing, leasing or procuring vehicles or services.

To formulate progressive technical specifications in public procurement processes has been recognised by a public inquiry as an underutilised measure to push for change (Swedish Government, 2013). This implies that one responsible approach to achieve the ambitious targets of a fossil-independent vehicle fleet is through an initial introduction of PEVs in public fleets. Plug-in electric vehicles still imply certain economical risks and an initial introduction in

fleets would reduce the liability for vulnerable private economies. To introduce PEVs in public-vehicle fleets gives the public body an excellent opportunity to fortify the requirements for vehicle acquisitions and to be a leader in the transition to an energy-efficient transport system.

### 2.4.3 Public transport

Buses account for 50-60 % of the public transport service provided in Europe and 95 % of the buses use diesel (UITP, 2011a; Clean fleets, 2014). In Sweden, buses constitute 52 % of all public transport journeys and today, 70 % of the buses use diesel (Swedish Bus and Coach Federation, 2014). Buses are also included in the Swedish national policy goal to achieve a fossil-independent vehicle fleet by 2030. Globally, buses with various degrees of electrification are already available to numerous markets and have the most rapid development in the heavy segment (Clean fleet, 2014). There are different ways to electrify buses and this thesis discusses the usage of non-connected buses; trolley buses and buses using other on-road electric systems are not included.

Just as for the public vehicle fleet, the Clean Vehicle Directive (Directive 2009/33/EC) governs the public transport services. Authoritative instruments, such as those for public procurement regulate public transport purchases, but public transport is also subject to other rules and regulations. The adoption of ultra-low emissions zones is one measure implemented in for example London, Paris and Hamburg. From July 2015, no diesel buses or vans manufactured before 2001 are allowed in the city centre of Paris (Le Monde, 2015). The regulations will be reinforced in 2020, when no diesel vehicles at all manufactured before 2011 (buses, vans, passenger vehicles) will be allowed to operate on the streets of Paris. This is an example of where the policy instrument initially affects commercial transport and then, in a later step, also comes to include private owners. Sweden has two bus manufactures with numerous upstream suppliers; these manufacturers have therefore focused resources to develop different technical solutions. Since 2009, the Swedish Government has allocated approximately 1 billion SEK annually to a strategic research initiative called *Fordonsstrategisk Forskning och Innovation* (Vinnova, 2015) – a name that could be translated to Strategic Research and Innovation for Vehicle Technologies.



#### 2.4.4 Interdisciplinary research and a systems approach

Energy studies are traditionally based on a technical perspective, where a component artefact or a physical system is studied, quantified and optimised (D'Agostino et al, 2011). However, to understand and manage the deployment of electric vehicles, it is important to analyse the political and practical conditions without separating the technology from its societal context. An interdisciplinary research approach allows use of both quantitative and qualitative methods, which complement each other and generate a greater understanding of the subject than when used on their own. Interdisciplinary research has succeeded in explaining implementation failures of cost-effective energy efficiency measures (Palm and Thollander, 2010), as well as the classification of energy end-users as a way to describe and ultimately offer the possibility to influence behaviours (Stephenson et al, 2010). An interdisciplinary approach has been identified as essential to successful decarbonisation of the transport system (Schwanen et al, 2011). As social or cultural values and political interests of potential PEV owners have proven to be as influential as the perceptions of the technical limitations (Sovacool and Hirsh, 2009), it is clear that studying the introduction of electric vehicles implies considerations other than strictly technical ones. An interdisciplinary approach can provide new insights about a subject, but Persson (2014) argues that the process of combining sciences may come at the expense of depth. However, neglecting the influence of public acceptance for plug-in electric vehicles entails a risk of stalling PEV introduction (Ralston and Nigro, 2011; Davis, 1993). An interdisciplinary research approach will be practised in this thesis through combining technical methods with methods from social science. This approach enables study of the technical perspective while the societal context is also considered.

Traditional technical research focuses on a specific artefact, but a systems approach allows a broader perspective. A systems approach can be applied to a technical system, for optimising the energy efficiency of an entire process rather than a single process step (Wetterlund et al, 2011), but can also consider actors, e.g. technology-end users, decision-makers and public and private institutions. The systems approach enables study of areas such of the decision-making process for public transport (Falde, 2011). A system can be defined as a collection of *components*, which are separated from the surroundings by a *system boundary*, and the *interrelations* between the components (Ingelstam, 2002). The system boundary is a theoretical concept to define what is inside and outside the system, i.e. the components and interactions that are included in the systems analysis. Figure 7 is an illustration of a defined system.

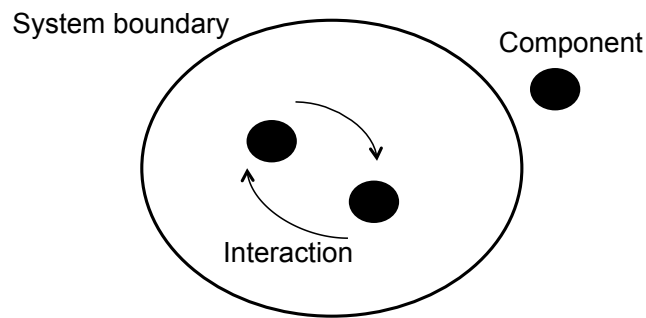


Figure 7. Adopted visual description of a systems approach (Ingelstam, 2002)

Churchman (1968) accentuates the anthropogenic influence of every defined system, in terms of the system's creation for a certain purpose. Data can be included or excluded, or never even sought out. This thesis will consider the energy and transport systems and its subsystems as socio-technical systems, a definition developed by Hughes (1983); a definition that rejects a separation between the technology and its social context, i.e., the individual actors, organisations, institutions and their political framework. According to Hughes (1983), this is a context that creates the system's meanings and functions. A significant part of this thesis will discuss the user perspective of operating plug-in electric vehicles. This interaction – between technology and end-user – is considered to be one of the most complex to study (Boulding, 1956), however it is highly relevant because it determines whether the user accepts or rejects the technology (Davis, 1993).

## 3 Method

Data can be collected and structured according to different methods, depending on the desired research outcome and research discipline. This thesis is based on research carried out using an interdisciplinary research approach with the aim of attaining greater understanding by combining technical methods with methods used in social science.

### 3.1 Conducting interdisciplinary research

This PhD project was carried out within the interdisciplinary graduate school Energy Systems Programme (*Program Energisystem*), which provided practical knowledge about different methods that are applicable to different energy topics as well as the prerequisites to collaborate with other doctoral students from different backgrounds. This thesis contributes with insights from the process of practising interdisciplinary research – in preparations, collecting material and analysing the material, and explains why this approach generated non-prescriptive findings.

The common characteristic for the studies that constitute the foundation for this thesis is the combination of methods, which aided in flipping the perspectives and changing the narrative point of view. By acknowledging the seamless web between the technology and the social context, this approach resulted in new findings with respects to the he conditions for introducing electric vehicles in Sweden. This section will continue with an introduction to the research design for the papers. The presentation gives a general understanding of how the each combination of methods has significance in this context. The following sections will explain the individual methods in more detail. There are of course strengths and weaknesses with each method, but in this context it is more important to consider the impact of the combination of methods on the research design. Thus, in Chapter 4 this thesis will discuss how the combinations of methods can contribute to new insights, and the shortcomings experienced, in parallel with presentation of the results.

#### 3.1.1 Introduction to the papers and the combination of methods

This thesis is based on seven scientific papers. Table 2 presents the methods and combination of method for each paper, together with a brief description of the objective of the paper. The aim was to combine technical methods with methods from social science, to achieve an interdisciplinary socio-technical approach.

Table 2. Methods used for each paper

Paper	Methods	Origin of method	Objective with paper
Paper I	Document study	Social science	Analyse the public energy and transport policies for sustainable transports
	Interview study	Social science	
	Backcasting	Technical science (mostly)	
Paper II and III	Real-life operating conditions	Technical science	Study the usage of ethanol series hybrid buses
	Standardised duty cycle tests	Technical science	
Paper IV	Questionnaire	Social science	Study the usage of BEVs in fleets with a technical and a user perspective.
	Interview	Social science	
	Logbook	Technical and social science	
Paper V	Focus group	Social science	Discuss the findings in paper IV and attain greater understanding of fleet operations with BEVs
	Logbook	Technical and social science	
Paper VI	Questionnaire	Social science	Study the usage of BEVs in fleets with a large and more detailed data set than for paper IV.
	Interview	Social science	
	Logbook	Technical and social science	
Paper VII	Interview	Social science	Identify the actions policy entrepreneurs undertake to consolidate the use of PEVs

In paper I, the local public policy practice in Stockholm is studied by combining policy analysis and backcasting to identify opportunities for and barriers to an increased use of renewable fuels and plug-in electric vehicles. The research design in paper I was the joint effort of all four authors - Linda Olsson, Linnea Eriksson (née Hjalmarsson), Mårten Larsson and me.

Papers II and III assess the potential of series hybrid buses in public transport based on data collected from both standardised duty cycle tests and real-life operating conditions. This work is not truly interdisciplinary – it only includes technical methods – but the combination of technical methods enables a discussion based on both the theoretical and the actual improvement potential. Based on an evaluation programme developed by Stockholm Public Transport and bus manufacture Scania, my contribution to the research design for paper II and III was mainly to combine results from the different methods in an innovative way.

Papers IV, V and VI study the use of plug-in electric vehicles in public fleets, and I developed and continuously improved the research design throughout the project. Experiences from the research design process were presented at EVS27 in Barcelona (Wikström et al, 2013). Paper IV studies the usage of plug-in electric vehicles in commercial fleets during one year and in addition to the traditional functionality perspective of the vehicles; questionnaires and interviews present a user perspective. Through use of focus groups, paper V provides an additional user perspective to the findings from Paper IV. Focus-group discussions resulted in a deeper understanding of the experienced operating conditions and the existing operational barriers for battery electric vehicles in fleets. Paper VI studies the usage of plug-in electric vehicles in commercial fleet during a three-year period, with an increased level of detail compared to paper IV.

Paper VII examines the actions of policy entrepreneurs when introducing plug-in electric vehicles to a local public authority. The theory of outcome indicators provides a framework to discuss how the policy entrepreneurs facilitate and accelerate the introduction of plug-in electric vehicles in public authorities. The research design in paper VII was a joint effort by Linnea Eriksson and me and was based on findings on a larger interview study carried out by Eriksson (Hjalmarsson, 2014). In the following section the different methods used are presented.

### **3.2 Methods for policy analysis**

Policy analysis was used to study the public policy practise in Stockholm. Public policy is the process that includes goals, decisions, action and inactions, which are imperative when governing a system (Hill, 2005; Jenkins, 1978; Smith, 1976) and policy continuously unfolds over time as the process proceeds (Hill, 2005; Smith, 1976). Paper I studies two policy sectors, energy and transport, and within each policy sector different policy processes are constantly on going. According to Falde (2011), energy and transport policy processes are often parallel, i.e. processes occur simultaneously and independent of each other, even when they treat the same issue. Parallel policy processes pose a risk of developing contradictory policies but this can be avoided by coordination between sectors, which policy analysis literature refers to as policy integration. When analysing policy integration, certain parts of the policy process can be selected as study objects (Howlett, 2009). Paper I focuses on three characteristics of the policy process – problem definitions, policy goals and policy measures (Rouillard et al., 2013). In

paper I, two methods are used to analyse the public policy process: an interview study and a document analysis.

### **3.2.1 Document analysis**

Document analysis is a secondary source method where a specific topic is chosen for study and the researcher selects documents that describe the topic. The thematic approach enables, for example, study of the topic from different perspectives or to follow trends. Document analysis is an efficient and reliable method, and also highly appropriate in qualitative case studies (Bowen, 2009).

### **3.2.2 Interview study**

An interview study is a series of interviews on a specific topic. Interviews are more or less structured conversations between the researcher and the respondent. Interviews can provide deeper understanding of certain topics, such as motives, norms and values, because the respondent has the possibility to provide richer explanations (Kvale, 1996).

### **3.2.3 Backcasting**

Backcasting, in contrast to traditional forecasting, starts by formulating desired future scenarios and is used to develop the strategies required to achieve the desired future (Dreborg, 1996; Hughes and Strachan, 2010; Quist and Vergragt, 2006). Forecasting on the other hand assesses the current situation and extrapolates that state into the future. Interest in backcasting has increased however, mainly because it can identify necessary measures which are far more progressive than those for the business-as-usual case, in order to reach environmental, energy or climate goals (Höjer and Mattson, 2000). The scenarios are polarised to each other, and this shows different possible options to reach the desired future (Dreborg, 1996). Backcasting is also considered a suitable method for communicating with both decision-makers and the public; it presents the goal alongside with the actions necessary to get there.

## **3.3 Methods for studying the technical perspective**

The functionality perspective of a vehicle focuses on the technical execution on a task, by assessing the technical data of the operations. The scope of the data collection can be at a macro level, i.e. by generating data sets for the movement of the vehicle. Data collection can also be at a micro level, for example the energy flows through the powertrain during operations. For the research design, the level of detail depends on the formulated research question and accessibility to powertrain and project budgets.

### 3.3.1 CAN bus logs

In the demonstration project of the series hybrid buses, Scania was a partner and provided component level-based data from the buses' CAN bus<sup>1</sup> logs. CAN (controller area network) is a protocol and the CAN bus is a low-speed serial vehicle bus for interconnecting automotive components and transmitting data to the logs. The CAN bus logs include, for example, detailed data for each component in the powertrain and the position of the throttle.

### 3.3.2 GPS data

GPS (Global Positioning System) is a system developed and managed by the United States' Department of Defence and is uses 27 satellites to determine the position (longitude, latitude and altitude) of a certain GPS receiver. Using GPS, it is possible to study the movements of a vehicle and obtain information about position, velocity, acceleration and retardation.

### 3.3.3 Vehicle logbooks

A cost-effective way to monitor the movements of the vehicle is for the user to keep a vehicle logbook. In Sweden, the Swedish Tax Agency expects all commercial vehicles to keep vehicle logbooks to monitor their movements (Swedish Tax Agency, 2015). This logbook template requires information about date, driving distance (meter reading), location, refuelling volumes, and the purpose of the vehicle's journey. For monitoring plug-in electric vehicles, the official template was used and was extended to request information regarding charging conditions, but users were also encouraged to provide personal comments for a certain journey and/or share her/his general thoughts on operating a plug-in electric vehicle. Information on charging conditions included type of charging equipment and location for charging. Users could include their contact details, which enabled further information exchange. No automatic collection of vehicle logbook data was allowed and the users had to fill out the information themselves. This measure was enforced in order to increase the possibility that users would register personal comments in the logbooks, i.e. an additional user perspective on operations. An example of a logbook is found in Appendix 1. The logbook was improved during the project and this process is described in more detail in Section 3.5.

### 3.3.4 Duty cycle tests

Real-life operations are interesting since they provide information about a particular application, but the obtained data is situation-specific and driving conditions can vary. A

---

<sup>1</sup> The bus in CAN bus is, in contrary to the study object, not an automotive bus but a device.

method to generate reproducible and, thus comparable experimental data is to use standardised duty cycle tests. Duty cycles represent different vehicle running patterns and are often coupled to a certain traffic scenario, for example urban or motorway operations. The characteristics of duty cycles vary with respect to, for example, average speed, top speed, aggressiveness of acceleration/retardation and number of stops per kilometre (see Table 3). Depending on the complexity of the cycle, the duty cycles are carried out in practice or performed in a virtual environment at a test-bench. Duty cycle tests are primarily used to determine fuel economy and for measuring exhaust emissions such as carbon monoxide, volatile organic compounds, nitrogen oxides and particulate matter. The duty cycle used to type approve light-duty vehicles (passenger cars and vans) in Europe is the New European Driving Cycle (NEDC), which is an stylised cycle that repeats the low-speed urban cycle (ECE-15) four times and then finishes with a motorway driving section (EUDC). The ECE-15 cycle is designed to represent city driving conditions, e.g in Paris or Rome. The International Association of Public Transport, UITP, has developed a simple duty-cycle series for actual on-road tests with buses – the SORT (Standardised On-Road Test) cycles. The SORT cycles hold three velocity trapezoids with increasing end-speed.

Table 3. Duty cycle characteristics (Dieselnet, 2015a; 2015b; UITP, 2011b)

Duty cycle	Average speed [km/h]	Maximum speed [km]	Time idling [%]	Cycle type
NEDC	33.6	120	22.6	Mixed
Braunschweig	22.9	58.2	22.0	Urban
SORT 1	12.6	40	39.7	Urban
SORT 2	18.6	50	33.4	Mixed
SORT 3	26.3	60	20.1	Suburban

### 3.4 Methods for studying the user perspective

To complement a technical description of the vehicles' functionalities, the users of the technology were included in the analysis. To render the perceptions of the technology and the experiences, four different qualitative methods were used. Questionnaires were used to study the general attitudes towards the vehicles. The user comments retrieved from the logbooks mainly provided additional information regarding a specific journey. Interviews helped with the interpretations of user comments but also provided information about the operating conditions for the plug-in electric vehicles. Together, findings from the questionnaires,



logbooks and interviews constituted the foundation for the material discussed during focus groups, see figure 8.

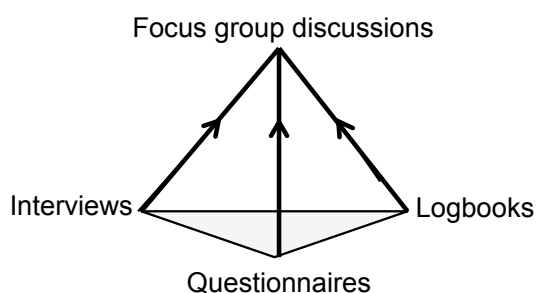


Figure 8. Research design exemplified. Findings from interviews, questionnaires and logbooks provided input to focus group discussions.

### 3.4.1 Questionnaires

Questionnaires are a simple and popular method to gather and compile data from a large number of respondents (Brace, 2004). Questionnaires have a defined structure and the outcome can be studied either statistically or quantitatively. In this case, the data has been analysed quantitatively. Recurring questionnaires with the sample group can monitor general attitudes towards, for example, plug-in electric vehicles.

### 3.4.2 Single interviews and focus group discussions

Interviews, just as interview study presented in 3.2.2, is a series of more or less structured conversions between a respondent and the researcher, but differ in that the purpose of each individual interview can vary; therefore they are detached from each other. The interviews enabled more in-depth information to be gathered about a user's particular experiences and contributed to greater understanding about electric vehicle operation in commercial vehicle fleets.

To discuss the research findings with users, in-depth group interviews or focus groups were carried out. Focus group is a method used to enhance the understanding of peoples' actions, attitudes, beliefs and motives. The method does not aim to measure attitudes, compared to quantitative methods, but instead aims to develop greater understanding of the factors underlying the attitudes. In practice, a group of individuals are brought together discuss a specific issue under the guidance of a moderator. The groups are preferably small, approximately six users, and in contrast to individual interviews the benefit of using focus groups is that the users are able to interact and elaborate on the topic (Morgan, 1998). The focus group participants, when listening to others, may argue and challenge each other's views

and thus persuade the others reflect on their own perspective. Hence, by using focus groups it is possible to obtain more varied views in relation to a particular issue (Bryman, 2008).

### 3.5 Designing interdisciplinary research

Research in action involves the study of on-going events and processes while they actually happen; this requires robust data collection because information must be captured during a continuously changing situation. Without an appropriate data collection method, vital data can be lost and results will not be accurate. The research design for the different studies has been an important element of this PhD work, the papers and this thesis. This section will describe more specifically the method development for papers IV-VI, i.e. the socio-technical data collection from the PEV technology procurement scheme/*Elbilsupphandlingen*. Validity and reliability are important to the overall robustness of the data sets, hence developments to increase the volume of reliable data. Right from the start, the ambition was to include both a technical perspective and the perspective of the users. Driving and charging behaviours can be monitored by several means but a cost-effective way to monitor a large group of vehicles is the vehicle logbook. The project was financed by the Swedish Energy Agency, which provided a standardised questionnaire designed for users of plug-in electric vehicles in projects funded by the agency.

The development of vehicle logbook was the primarily task when the project started. As mentioned, the template from the Swedish Tax Agency was used as a basis and the aspects of a plug-in electric vehicle were then incorporated. As the project went on, shortcomings in the logbook were soon identified. Unlike automatic technical devices, logbooks require user interaction. To increase the robustness and richness of the data collection, several measures were implemented with the direct aim of avoiding unnecessary misunderstandings. To improve the correctness of the submitted data, measures to increase user engagement were implemented. A strong user engagement has a proven positive effect on the dissemination of sustainable energy technologies (Ornetzeder and Rohracher, 2006).

Initially, the submission rate of charging data was low. The requested charging information was been too detailed, as the logbook requested information about both voltage and current. The users in this case had no specific training and the information was not always accessible, which resulted in lost or unclear logbooks. To attain relevant and robust charging data from the users, the logbook eventually focused on collecting information about charging location and

whether a simple Schuko plug had been used or particular electric vehicle supply equipment (EVSE) had been used. EVSE refers to equipment (and protocols) developed for manage more sophisticated charging than compared to that for a normal plug. This simplification improved the submission rate and robustness of the charging data.

Prior to the introduction to any real users, plug-in electric vehicles were an isolated technical matter. As a result, the terminology is somewhat rigid and complicated and made communication difficult in the beginning of the research project – for users and among project partners. Therefore, concepts came to mean different things to different people and were not even consistent among the partners of the research project. Addressing the problem meant first of all a realisation of the problem. Then, the project partners agreed on a common use of terminology. For the research, this meant that the users and others, e.g. fleet managers and decision-makers for example, got one set of concepts from all the project partners. A common use of terminology was also important for the project partners so that in their external communications they could present scientifically valid findings.

Misunderstandings due to conceptual confusions could be avoided by a uniform use of concepts and terminology. However, misunderstandings are by nature unpredictable, and one early example is how the users interpreted the word *Fast*, which was listed among the charging alternatives. Due to the limited space in the physical logbook, *Fast* – an abbreviation of fast-charging, the collective term referring to high-voltage DC charging – was specified. However, many users interpreted *Fast* as referring to the unit of time and subsequently referred to the charging as *Fast* when they had charged the vehicle for a short period of time. For considering power transfer, a less well-known concept than the familiar one of time, the space allocation in the vehicle logbook was reprioritised and *Fast-charging* was printed in full. The project developed an interest in which geographical locations were suitable for developing fast-charging infrastructure. This work is not included in this thesis but it meant that those using fast-charging were asked to specify this one.

Simultaneously to the developments to clarify the logbook, a user guidance material describing the project and the charging alternatives was also developed and distributed to all vehicles involved. Figure 9 presents the page spread from the user guidance material. Information about charging alternatives is shown at on the right-hand side of the spread.

**Vad kul att du kör elbil!**

Här kommer lite information om projektet Elbilsupphandlingen och om den utvärdering som genomförs.

**Elbilsupphandlingen**  
är ett samarbete mellan Vattenfall och Skövde kommun, som tillsammans med SVE, Konnerhus Induscentral AB har genomfört en samordnad upphandling av elbilar och laddhybrider. Samarbetet har varit mellan organisationer och företag från hela landet samtidigt intresse att vara med och köpa elbilar. Energimyndigheten stöder Elbilsupphandlingen genom en marknadenssättning till alla fordon.

**Ditt deltagande är viktigt!**  
Loggboken ger ett kundansvarande uttryck om användandet av elbilar.  
Tack!  
/Matsen, KTH och Peter (TSS)

Flera typer av data samlas in från elfordonen som ingår i Elbilsupphandlingen, så som loggbok du fyller i efter att ha använt elbilen, information om din körning, men även dina erfarenheter och synpunkter är väldigt för att förstå hur elbilarna används och fungerar i samhället. Materialet samlas hos Test Site Sweden (TSS) och sammanställs av KTH.

Du kan läsa mer om projektet på [www.elbilsupphandling.se](http://www.elbilsupphandling.se)

**Att ladda elbilen**  
Det finns flera typer av laddning. Olika elfordon har olika tekniska förutsättningar så samtliga tekniker inte är möjliga just för ditt fordon.

**Snabbbladdning**  
Avtar laddning vid en specifik snabbbladdningsstation. Denna infrastruktur är under utveckling och därför ber vi dig att ange vilken snabbbladdningsplats du använder.

Det är viktigt i det fortsatta arbetet att förstå behovet av snabbbladdning.

**Behöver du hjälp att hitta en laddplats, använd gärna:**

- [www.uppladdning.se](http://www.uppladdning.se)
- Smartphone-applikationer:
  - Charge and Drive
  - Ladda elbilen (under utveckling)

1-fas  
1-fas  
3-fas

Figure 9. Developed guidance material

Studies have emphasised the need to involve the users in technical demonstration projects (Ornetzeder and Rohrer, 2006). Involved users provide more correct data and have a desire to contribute to the research project, these theories were incorporated in the process of constructing the user guidance material. The guidance material therefore also includes an engaging presentation of the project and the associated researcher and database personnel; see the left-hand side of the spread in Figure 9. The impact of these measures was never properly quantified, but the amount of useful logbook data increased.

The questionnaire provided by the Swedish Energy Agency was mainly developed for those who use a plug-in electric vehicle as their private vehicle. All questions were not relevant for fleet users and questions were added to attain a better understanding of the attitudes towards plug-in electric vehicles as fleet vehicles and their associated operating conditions. The questionnaires provided a quantitative picture of the process of incorporating the vehicles in the fleets, but to attain a better understanding of the findings from the questionnaires, interviews were carried out. The interviews provided additional, mostly non-technical, information regarding the introduction and deployment of the vehicles. The interviews could describe and explain the quantitative findings from the questionnaire.

The data obtained from the logbooks provided the technical description of driving and charging behaviours. This material encouraged a hypothesis about how the users progressed from being novices to more experienced users. To validate this interpretation, single and group interviews were carried out. It soon became obvious that external factors influenced the

progress of the users, factors that were not found in the technical data. The project had an expressed socio-technical research approach from the beginning but as the research design was developed organically it became clear that the really important questions could not be fully answered and understood by using only logbooks and questionnaires.

## 4 Results

Based on the main findings in the papers, this section will discuss the conditions for electric vehicles in the Swedish road transport system. This will be done according to three themes, where the possibilities for public fleets are discussed first, followed by a discussion of the opportunities for electric vehicles in public transport. Lastly, the chapter presents a discussion regarding the local political conditions for increasing use of electric vehicles. All discussions are based on the main findings from the interdisciplinary studies, whose goal was to obtain information about different aspects that shape use of electric vehicles.

### 4.1 Possibilities for plug-in electric vehicles in public fleets

This section discusses the findings in paper IV-VI. The transition to a more fossil independent road transport system is a great challenge and public fleets could take on the responsibility of being pioneers. Public actions can indeed guide and set the expectations of the citizens.

Approximately 75 % of EU's total transport emissions come from passenger cars and vans (EC, 2015c). This work aim to increase the chances that technically feasible applications and activities, using electricity as fuel, can be identified and further developed.

#### 4.1.1 Introduction to the study case – *Elbilsupphandlingen*

The empirical material was collected from a technology procurement scheme called the Swedish National Procurement of Electric Vehicles and Plug-in Hybrids, *Elbilsupphandlingen*, hereafter referred to as the *PEV technology procurement scheme*. The PEV technology procurement scheme was a public-private procurement scheme carried out between 2011-2014 and coordinated by the City of Stockholm and the utility company Vattenfall. The tender included passenger cars and vans. The objective was to gather public and private organisations interested in introducing PEVs, so-called lead adopters (Nesbitt and Sperling, 1998), and thereby jointly request a larger volume of vehicles to attract PEV manufacturers to the Swedish market.

In 2011, framework agreements were established with four manufactures – Chevrolet, Citroën, Mitsubishi and Renault – which delivered nine vehicle models to the participating organisations: Volt, iOn, iMiEV, Outlander PHEV, Kangoo ZE (in three different versions) and Zoe. Prior the expansion of the vehicle fleet derived from the framework agreement

(herein called the procurement fleet), a fleet of 50 vehicles (the demonstration fleet) was operating during September and December 2011 in order to establish the data collection process. Figure 10 presents the expansion of the procurement vehicle fleet and the composition of the fleet in October 2014.

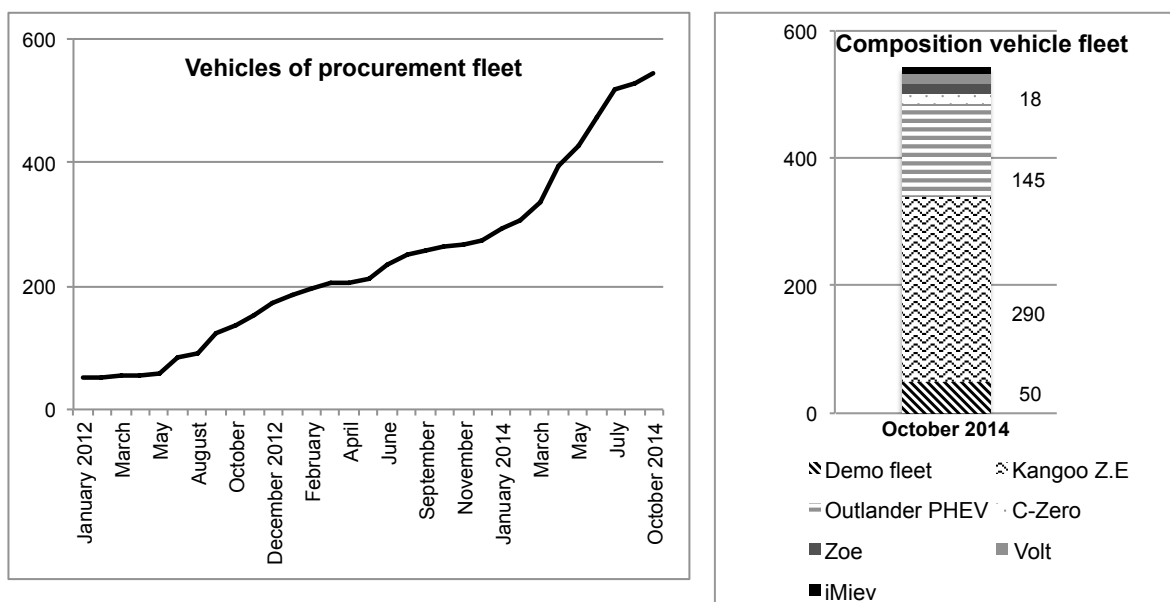


Figure 10. Expansion of procurement fleet and fleet composition in October 2014

Even though the data collection comprises both BEVs and PHEVs, PHEVs have deliberately been excluded from the discussion regarding the PEV possibilities in public fleets. Findings show that the flexibility of a PHEV is a fundamental difference compared to the operations of a BEV. Beyond the PHEV's battery, an ICE provides longer driving distances, and we have become used to this flexibility. Although PHEVs and their users have contributed with a lot of important experiences (one of the best examples is the experienced condition of *performance anxiety* rather than the term *range anxiety*, as discussed among BEV users) an introduction of PHEVs does not require any genuine behavioural changes. Therefore, this work will primarily discuss the possibilities for implementing BEVs in public fleets.

#### 4.1.2 Fleet vehicles in action

During the process, as vehicles continuously joined the data collection, it was important to distinguish between changes caused by a growing data sample, i.e. the total number of journeys, accumulated driving distance or charging occasions for example, and the changes resulting from altered user behaviours. Relative metrics were applied to study the usage over time. Initial results, based on data between from 2011 and 2012 and published in paper IV, were interpreted to reveal four main findings:

1. Usage increased over time
2. Longer journeys as a result of increased user experience
3. Decreased usage of other/public charging outlets
4. Learning process demonstrated by findings 1-3

However, discussing these findings with actual users in focus groups contributed to a much greater understanding of the operative conditions for fleets. The user perspectives acquired during focus groups (paper V) and from more detailed technical data (paper VI) contributed to a revision of the findings as follows:

1. Usage increase with time as new users join
2. Driving behaviour determined by other factors, such as behavioural and organisational factors, rather than technical factors.
3. Public fleets BEVs do not use public charging
4. The initial operating conditions given the BEV will support or delay the adoption process for the users

At fleet level, the initial data indicated a decreasing share of relatively short journeys; see Figure 11. Figure 11 illustrates the share of journeys carried out which was shorter than 40 km. A decreasing share of short journeys was interpreted in paper IV as increased confidence among the users and the “courage” to operate longer journeys. However, reviewing data from a longer time period revealed that the trend changed to show a more consistent driving behaviour.

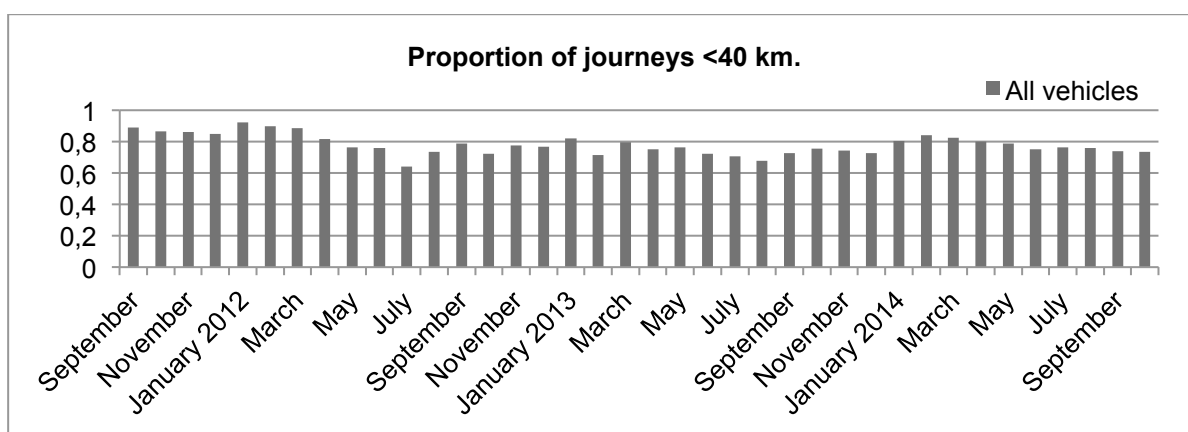


Figure 11. Proportion of journeys shorter than 40 km between September 2011 and October 2014 for the entire studied fleet



The initial data collection was highly influenced by the operations carried out by the demonstration fleet. The demonstration fleet differed in several aspects from the procurement fleet. A significant share of the demonstration vehicle fleet consisted of conventional vehicles that had been retrofitted with an electric powertrain, which resulted in some reliability issues. Uncertainties in general regarding a new technology had a negative effect on usage, and this will be addressed later during the discussion of influential factors. The distribution between the two vehicle categories, i.e. passenger cars and vans, also differed between the demonstration and the procurement fleet.

Improvements in database tools allowed the data from the vehicles to be categorised from 2013 and this enabled a higher level of detail in the analysis. Data could be compiled according to vehicle model or categorised per vehicle category. This enabled new comparisons, to expand the analysis shown in Figure 12, and illustrated the respective share for each vehicle category. Figure 12 shows that for relatively longer journeys, vans were more often used more often than passenger cars.

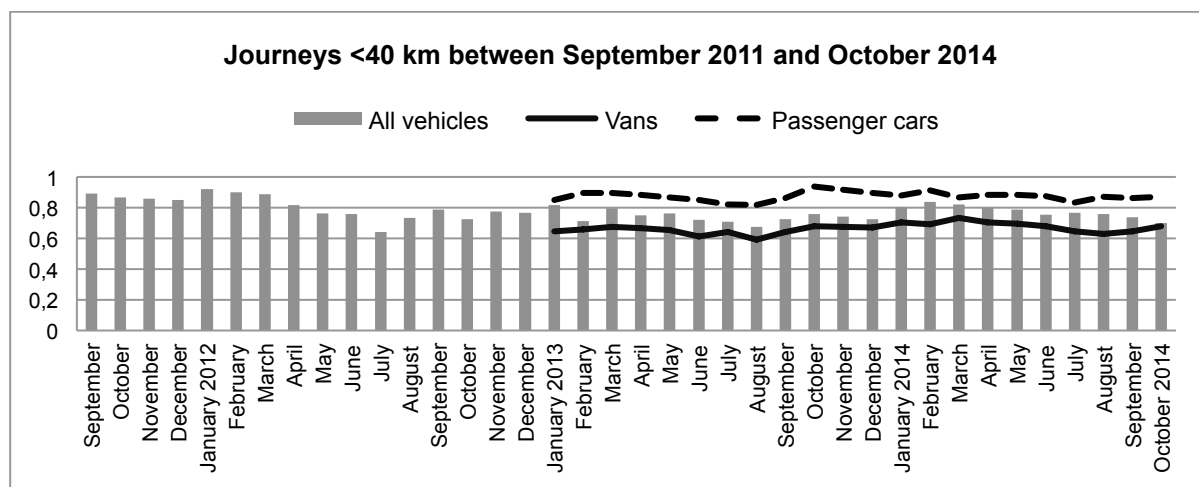


Figure 12. Proportion of journeys shorter than 40 km presented for each vehicle category

Regardless of vehicle category, the extent of the usage in terms of frequency is similar. In Figure 13 the dashed line indicates the average number of trips carried out per month. In this work, a *journey* has been defined as the total distance between charging occasions, and a *trip* is when the vehicle is used but not charged upon arrival at the destination. According to this definition, a journey can comprise several trips. The bold lines in Figure 13 represent the average number of journeys carried out. However, the different relationship between trips and journeys indicates that both driving and charging behaviours differ between the vehicle categories, where passenger vehicles charge more frequently than vans

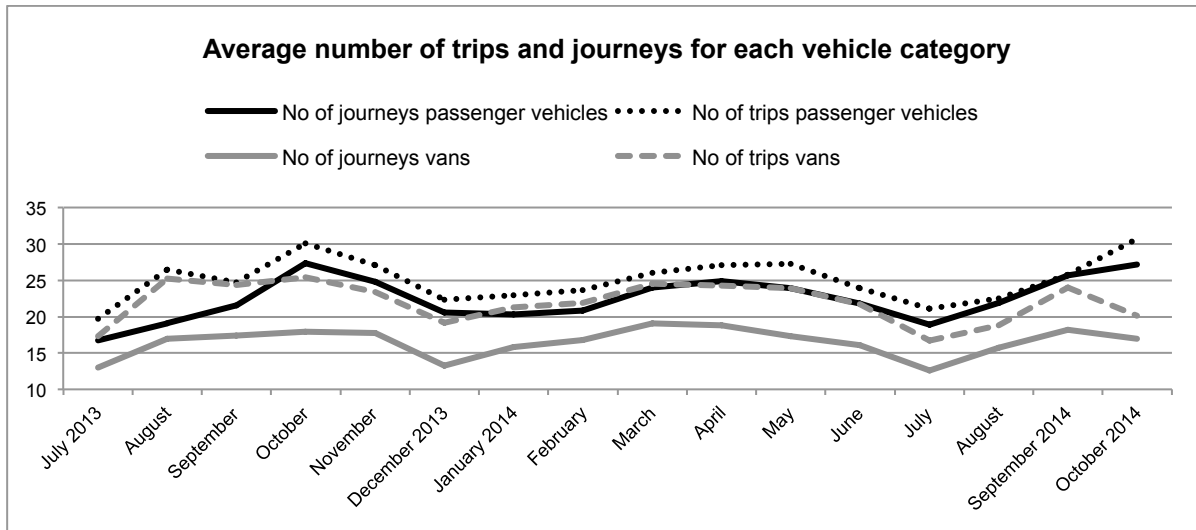


Figure 13. Average number of trips (dashed) and journeys (bold) between July 2013 and October 2014, presented for each vehicle category.

The overall usage depends on frequency and duration (or driving distance). Findings show that vans are used more than passenger vehicles. The two vehicle categories have similar technical prerequisites, which indicate that the driving patterns are determined by factors other than strictly technical factors.

Designated vehicles (assigned to a certain user or specific task) are used for longer journeys and aggregated on time; this behaviour implies a higher degree of usage compared to pool vehicle use.

#### 4.1.2.1 Factors that influence the driving behaviour

Battery capacity defines the upper limit for technical viability of BEVs but the findings in paper VI show that actual operations were nowhere near this upper limit. This implies that there are factors other than the battery capacity that ultimately influence driving behaviour. In this thesis, four non-technical findings that influence the usage will be presented.

##### *Deployment strategy*

During the data synthesis process, the influence of deployment strategy became more and more prominent. Even though paper IV identified different driving patterns and included a comparison between different applications (designed in the paper as *operational categories*) the analysis failed to deliver a rich discussion regarding the category-specific measures mentioned in the paper.

Different organisations have used different deployment strategies. All deployment strategies serve different purposes, and all have the potential to substitute fossil fuel use, but these different strategies need different levels of support. The two main deployment strategies are as pool vehicles, with high visibility and many potential users, and that the vehicle is dedicated to a certain user or task, which implies high usage since the vehicle's operation can be optimised in accordance with the technical specification of the battery. Both deployment strategies have potentially significantly positive effects, but there are also drawbacks. Making BEVs available in car-pools gives users have the possibility to choose the BEV, but there is a prevailing risk that the user will choose another (and quite possibly a conventional) vehicle. Dedicated vehicles have the potential to operate a large total number of electric kilometres but findings show that average monthly usage is still low.

#### *Initial introduction/ information/ communication*

Since BEVs are a new technology, so it should be considered as necessary to introduce the vehicle to potential users. Paper V shows this has not been the case in all organisations, but merely making information available to potential users is not always enough. The technical characteristics have to be explained, and users prefer this not just as information but also as communication, with tangible examples and clear explanations of the differences between a BEV and a conventional vehicle. For many users, there is no major difference, but it is nevertheless important to inform the users about it. During the interviews and focus groups, it came evident that the driving behaviour of the vehicle was determined early in the introduction process and, in the absence of interventions, remained static. Intervention measures can change driving behaviour. Practical examples of interventions that have increased usage are:

- Communicating the range. Many users found it difficult to relate to driving distance and range as useful units when not travelling directly between two well-known destinations, between two cities for example. By communicating range in terms other than the technical specifications, users found it easier to operate the vehicles within their range limit. For example, the municipality boundaries have been used successfully as a way for users to envision a geographical area suitable for the BEV.
- Relocating the BEV to an attractive parking space. Allocating the most accessible parking spaces – for example in a cramped garage – increases the legitimacy for the BEV and boosts acceptance.

The usage of BEVs is initially moderate if not assisted in one way or another. User acceptance can falter at first and fleet users have a low tolerance for operational failures; it is easy to go for a proven technology and chose a conventional vehicle.

Since the beginning of this project, the description of the users' facing and embracing the new technology has changed from a learning process to an adoption process. During the focus groups, the majority of users never referred to *learning* ("I could drive before") but consistently talked about an initial and spontaneous aspiration to master the technology.

Common for the users that expressed experiencing a learning process were that they all had little or no introduction to the technology. A certain group also lacked the option to choose another vehicle. Owing this complete lack of knowledge, some users were unsure and tentative during initial operations. If this initial experience is negative, users may refrain from using the vehicle again, thus inhibits the deployment. If usage was mandatory, users eventually learnt about the vehicles' technical operational characteristics, but continued to lack knowledge of technical features. This meant that this user group, compared to the users in general, were dissatisfied with certain aspects of the vehicle, such as heating (simply because they were unaware of several functions that complement the main heating system).

The users require *sufficient* information and communication. The definition of "sufficient" is individual, which makes the term applicable for describing what the users expect and need before undertaking a positive initial experience. The project used both Experimental Learning Theory (ELT) and the Technology Acceptance Model (TAM). ELT was a chosen as a theoretical framework to describe the cyclical process of improving an action through increased practical experience. In retrospect, it was clear that this theory described only some of the users – those who had not been given sufficient information prior to the introduction. The general users were better described by TAM, since the initial operations determined subsequent willingness to continue using the vehicle. Some aspects of the non-users could also be included in TAM. For example, not knowing or understanding the system design creates acceptance issues that obstruct widespread deployment. Whereas the process of gaining acceptance is linear, the process of learning is circular, and perhaps not all fleet users are patient enough to iterate this process. The influence of sufficient information therefore determined the usage of the vehicles.

### *Policy documents*

Usage of fleet vehicles is governed by the organisation's vehicle policy. Common rules and routines for using the vehicles can be more or less detailed but findings show that users generally follow rules expressed in the policy. Initial findings on charging behaviour came to show, through focus groups, to actually have nothing to do with the users and their ability or confidence in operating the vehicle, but were the result of the prevailing charging routines. Findings in papers V and VI show that charging behaviour is primarily determined by the common routines. Three main charging behaviours have been identified within the scope of this work: after every use, in the end of the day and when "necessary".

The formulations in the policy documents have been identified as very important for the management and usage of fleet vehicles. This implies the possibility to revise the policy documents and thereby achieve the desired behaviours. Umeå, a participating municipality, took the opportunity during its BEV introduction process and evaluated the effectiveness of its entire fleet. Based on this inventory and together with findings from the project, Umeå revised its policy documents to reduce the total number of automotive vehicles and promote the use of BEVs.

### *An restrictive approach*

Almost all journeys studied here were shorter than 70 km. The average range for the vehicles used were approximately 120 km. Relating this to terms of battery state-of-charge (SOC), this experimental data indicates the batteries are operating in the upper half of capacity. All vehicles included in this project have lithium-ion batteries, and these batteries have not cycling restrictions; therefore, the main issue is to achieve efficient use of the produced battery capacity.

The focus group discussions confirm that users aim to return with approximately 50 % range remaining. One problem mentioned by the users is the poor accuracy of the displayed remaining range. The main issue with winter conditions was the reduced sense of reliance on an already unpredictable source of information. In other studies, users refer to this situation as operating by a guess-o-meter (Lundström, 2014). Nissan Leaf users have for example developed their own range matrix to help users develop a sensibility for the relationship of the displayed remaining range, the personal driving behaviour and prevailing weather conditions, and how this affected the SOC. Fleet users are not the ordinarily enthusiasts who can overlook

these initial issues. Instead, there is a risk that fleet users reject BEVs the use and continue to use the fleet's conventional vehicles.

Findings show that during winter, i.e. in sub zero temperatures and snow, vehicle usage decreases. The operating conditions change and the electricity consumption subsequently increases, which means reduced range for the users. Studies show that in winter conditions, with heaters running for example, the electricity consumption is approximately 50 % higher than the consumption in ordinary conditions (Norden Energy and Transport, 2014). The users stated that winter conditions increased uncertainty regarding operations, because the calculated range could drop unpredictably and users were unfamiliar with external heating systems. However, even though winter conditions influence the range, users stated that the individual driving behaviour had an even bigger impact on the range. Driving behaviour is known to influence the overall energy management of the vehicle (Knowles et al, 2012). Many users state that their instantaneous reaction was to alter their driving behaviour in order to maximise the range.

#### *4.1.2.2 The use of public charging*

The initial data showed a decreased use of public charging. This charging behaviour was interpreted as meaning that users had stopped seeking every opportunity to charge, as a result of increased confidence. However, as the data sample grew the vehicle usage declined and when discussing the matter in focus groups, it was revealed that the initial use of public charging was due to curiosity about its function. There was never a genuine need for the electricity.

The empirical findings show that fleet vehicles do not use public charging and qualitative studies explain that users are reluctant to rely on external factors for vehicle operations. Thus, in the beginning of a deployment of PEVs, prior the expansion of the charging infrastructure, fleets appear to be particularly suitable for the initial introduction prior to charging infrastructure expansion.

Angawa (2010) has shown that the availability of fast-chargers has a positive influence on the usage of fleet vehicles, as users return with a lower SOC and have operated in a larger geographical area. This change in driving behaviour occurs without any significant use of the fast-chargers, i.e. the users more or less perceive the fast-chargers as a back-up option. This is not an ideal business case for developers of fast-charging infrastructure but could have an

impact of the usage on fleet vehicles. During the project, fast-chargers have been available in some Swedish cities, mainly in southern Sweden. In the questionnaires, the users state that the most important factor for the enlargement of the PEV market is the development of the charging infrastructure and the availability of fast-chargers.

Even though the demand for fast-charging is low among the vehicle fleet studied here, other fleet applications such as taxis can have great benefits from this functionality. Throughout this project, public-fleets interest for fast-charging has been low. On the second-hand market, the condition of the battery can affect the vehicle's value, which implies that a vehicle with low or no usage of fast-chargers could be more attractive.

#### *4.1.2.3 Creating acceptance*

As mentioned, many non-technical factors determine the usage levels and ultimately the deployment rate of the new technology. Obsolete perceptions or the lack of knowledge can contribute to acceptance issues, which inhibits users from joining the initiative. Confidence had never been an issue for the users who had been provided with sufficient information and communication. Acceptance issues were a problem among non-users. Hillman and Sandén (2008) suggest that new technologies fail to succeed due to the lack of advocates. Paper VII identified the policy entrepreneur as an actor who consolidates the new technology in policy actions, in practices and even in the society. Actions undertaken by the policy entrepreneur influence non-technical aspects of operations but also affect *technical change*, i.e. the change in development and dissemination of new technologies. Outcome indicators therefore constituted a useful framework for studying the impact of the policy entrepreneur; the objective of the theory is to complement traditional public policy evaluation theories, which do not include the process of technical change. A policy entrepreneur is not completely crucial for successful deployment of plug-in electric vehicles, but the findings show that the policy entrepreneur influenced the rate at which the vehicles were introduced. Perhaps even more importantly, the (more or less) systematic but consistent work has had an impact of the overall awareness and knowledge in many levels of the organisations and this lead to positive effects for technology acceptance.

Expressing the contribution of the policy entrepreneur in terms of an indicator was an attempt to reach a greater audience, beyond the new public-management researchers. Indicators appeal to many people because they provide a theoretical framework that (at least historically) is intended to monitor and display measurable parameters of development. Descriptive

indicators are used to illustrate the current state of a system and performance indicators relate to a set target, but indicators are increasingly being used with an explicit systems approach. Socio-ecological indicators, sustainability indicators or environmental indicators are different methods for assessing the impact of, for example, a certain public policy measure or scheme (Cooper, 2013; Gudmundsson and Hedegaard Sørensen, 2013). In paper VII, outcome indicators were used to explain new emerging behaviours in policy practice, among users of the technology and in how the local business network organised its work.

#### **4.1.3 What are the possibilities for public fleets?**

Papers IV-VI contributed to greater understanding of the introduction, deployment and implementation of plug-in electric vehicles in public fleets. The work goes beyond a mere technical assessment and includes perspectives of people who together determine the prerequisites for a large-scale introduction of PEVs. Of all the details of this work, nothing is as important as the most fundamental finding: Only using technical methods when analysing the use of PEVs overlooks the influence of users, organisational structures and the operating conditions. This finding should be of principal interest for automotive and battery system industries. These industries have the possibility to ensure the batteries are not oversized; this can decrease the material consumption, increase resource efficiency and ultimately lower the cost (hopefully for the end-consumer as well).

Governments can use public fleets as *agents of change* (Nesbitt and Sperling, 2001) and this work can confirm that an initial electrification of public fleets is favourable. Both driving and charging behaviours of the studied fleets indicate favourable conditions for BEVs. The users of studied fleets use other vehicles for journeys that exceed BEV technical specifications. Fleet operations in this study do not depend or rely on public charging. During a period where the charging infrastructure is developed, fleets are favourable to electrify. However, the travelled average driving distance per month is still quite low. The benefit of low operational costs is not evident. The study has included different interventions to increase usage of the vehicles, but these succeed mainly in attracting more users and not in increasing the average driving distance. The organisational structures surrounding fleet vehicles provide excellent conditions to undertake a brave transition to BEVs. In case of an operational failure, there is organisational support and an action plan; hence the measure is equally important for conventional vehicles. Most private households have to rely on road assistance companies and/or on friends and family in case of an operational failure.



Findings from paper V show that most fleet users have no emotional or other attachment or agenda when operating the vehicles; they just want to carry out their tasks. They therefore represents a greater market segment more than present private PEV owners, which Diffusion of Innovation Theory refers to as *early adopters* (Rogers, 2003). In most cases, early adopters are well-educated, middle-aged men, and PEVs seem to be no different (Elforsk, 2009; Plötz et al, 2014; Figenbaum et al, 2014). Luckily, there are also studies that have identified early adopters of PEVs with other socio-demographical backgrounds (Tal et al, 2013). Early adopters have certain characteristics that make them interesting to study. However, in this context fleet users appear to be much more important to study, because they have relevance as a large consumer group. The studies have revealed underlying acceptance issues, where employees theoretically have a positive attitude towards the technology but refuse to operate the vehicles. This situation could be similar to that found in Sweden in general. A recent study shows that 60 % of the Swedes are positive or very positive towards plug-in electric vehicles and only 7 % have an explicit negative attitude towards PEVs (SEA, 2015b). In addition, 65 % believe that PEVs will constitute an important and substantial part of the road transport system. However, the market share is still only 0.5 % (BILSweden, 2015). For example, environmental studies often account for social desirability bias, a tendency of respondents to exaggerate their environmental concerns (Bryman, 2008). The average individual recognise plug-in electric vehicles as a measure to address certain energy and climate issues (SEA, 2015b; Thiel et al, 2012) but is hesitant to purchase or lease a PEV right now. In this situation, the knowledge attained from fleet users could be used to increase understanding about a future, broader, market. Studies of the fleet users show an adoption process in which they progress from novices to more experienced users. The findings show that fleet users appreciated the added value of operating a silent vehicle, which was perceived as environmentally friendly. The users felt that operating a silent vehicle made them calm(er) and made them less aggressive drivers, which ultimately benefitted range management. Other road users do not as easily notice a silent vehicle and the PEV users foremost expressed a concern for pedestrians and cyclists; this in turn made the PEV users more observant. New EU legislation, which makes it compulsory for PEVs to have a warning sound (EC, 2014c), could be considered unfortunate for PEV introduction when users find silent operation a great benefit compared from to a conventional vehicle. It is unusual for legislation to specify such requirement, in this case to specify sensory input. The more common way is to specify the desired outcome of the legislation – in this case, the avoidance of collisions. The warning sound inevitably places the responsibility to

avoid a collision on the pedestrian or the cyclist, not the PEV driver. The PEV users in this study express a willingness to take that responsibility – at least until all vehicles, and not just the high-end models, are autonomous enough to brake upon the risk of collision.

During operations in both public and private fleets for over three years, BEVs have proven their technical functionality and have succeeded in gaining the acceptance among fleet users. Given the flexibility of PHEVs, users find that operating a PHEV is different from driving a conventional vehicle. Without any real behavioural changes, this indicates that PHEV is the technically feasible alternative to fossil-fuelled vehicles. However, for many fleet applications the ambition could be higher and given favourable conditions and a genuine engagement, BEVs could certainly constitute a significant share of the public vehicle fleets.

## 4.2 Opportunities for public transport

This section will discuss opportunities for improving energy efficiency by electrifying the public transport buses. The discussion will be based on findings from papers II and III but other perspectives will also be considered and discussed.

### 4.2.1 Ethanol series hybrid buses

A series hybrid bus has the potential to improve fuel economy and contribute to CO<sub>2</sub> savings in the order of 30% in a well-to-wheel perspective (Weston, 2010; Clean fleets, 2014). Further, this thesis includes studies of ethanol series hybrid buses that decrease the fossil CO<sub>2</sub> emissions even more. Papers II and III analyse the use of ethanol series hybrid buses and is based on material collected during a demonstration project, which included six ethanol series hybrid buses (and one reference ethanol bus) between 2009 and 2010. As seen in Figure 14, a series hybrid has no mechanical link between the internal combustion engine and the drive axle. This improves the energy efficiency of the powertrain. In addition, the bus was equipped with on-board energy storage, in this case a super-capacitor, for brake energy recovery. Figure 14 shows the series hybrid powertrain. A more detailed technical description of the series hybrid bus is found in the paper II and III.

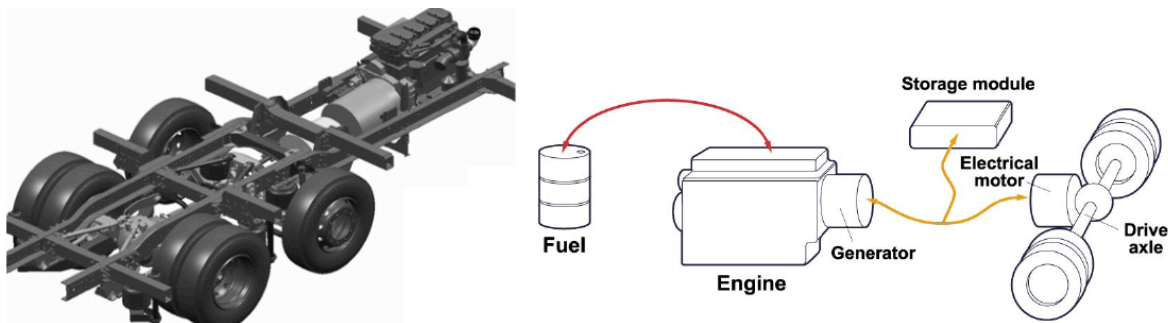


Figure 14. Hybrid system used in the project illustrated, the authentic layout and a schematic design.

Pictures used by the courtesy of Scania

By combining actual, real-life operations data with standardised duty cycles, papers II and III could identify a large gap between the theoretical and practical fuel consumption reduction potential. For this project, SORT (Standardised On-road Test) cycle tests were carried out. The SORT cycles include three cycles; SORT1 represent urban driving conditions, SORT2 represents semi urban or mixed conditions and SORT3 that corresponds to suburban driving conditions, which in this context implies the highest average speed and the lowest numbers of stops/km and time spent idling. Figure 15 presents empirical data from paper III.

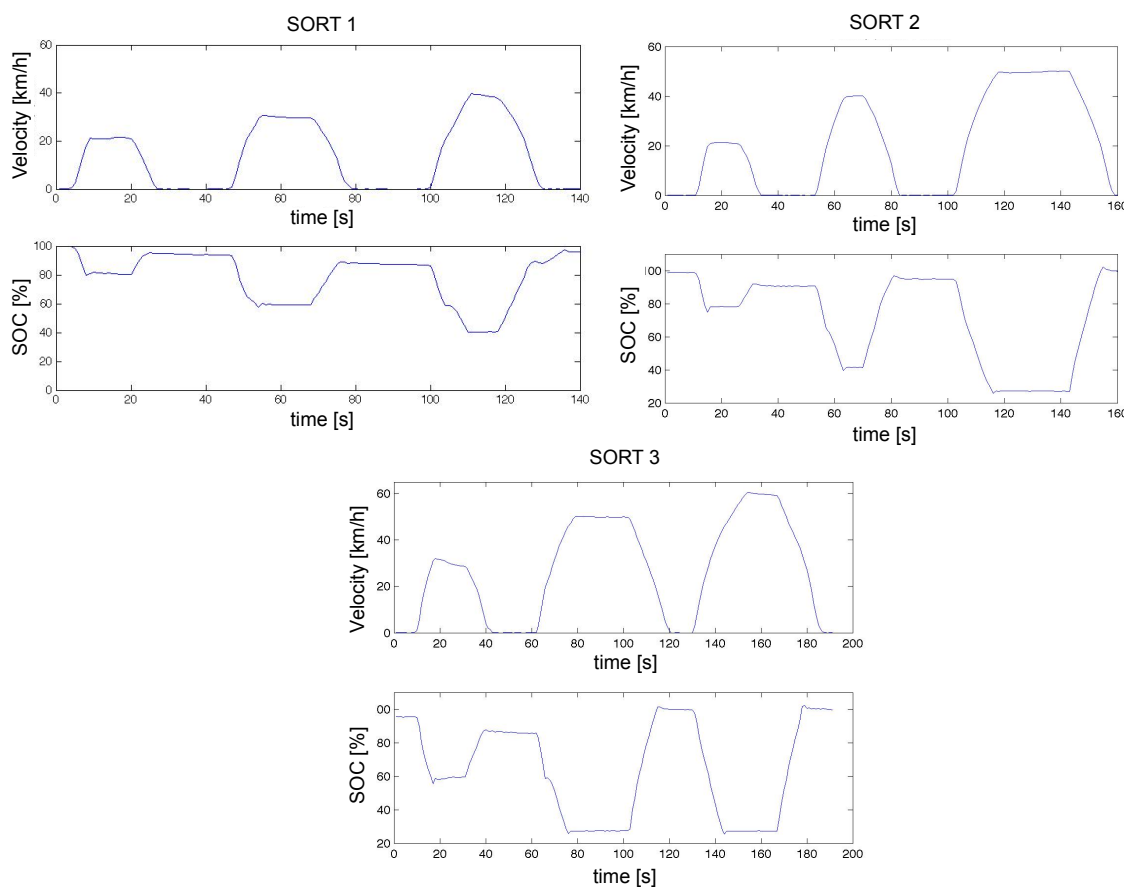


Figure 15. Experimental velocity (top) and State-of-Charge profiles (bottom) for SORT 1-3 test cycles

The SORT cycle test showed that hybridisation had a significant fuel reduction potential, depending on operating conditions in the order of 10-20 %. With additional start/stop functionality, i.e. shutting down the ICE while idling, the reduction potential became even greater in comparison to that of the reference bus (approximately another 10 %).

Two tests of real traffic situations were carried out within the demonstration project. An extensive field-test was conducted, where the six series hybrid buses operated on the regular bus lines for one year in the southern suburbs of Stockholm (see Figure 16) and a one-day inner-city test was run in Stockholm where two central bus lines were simulated, i.e. a series hybrid bus and the reference bus operated on the routes and stopped at the designated bus stops but without passengers. The main purposes of the field test were to evaluate the robustness of the system and to get reactions from the public. The one-day inner city test was carried out in to experimentally investigate the fuel reduction potential in more urban conditions where, according to the SORT cycle tests, the theoretical contribution of the hybridisation would be **the greatest**.

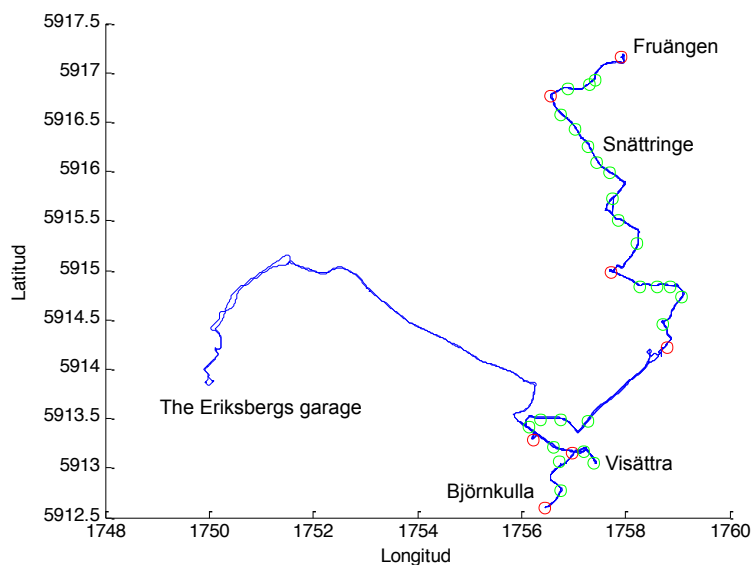


Figure 16. GPS movement data from route 704.

Paper III investigates different possible measures to further reduce fuel consumption and suggests technical measures to increase energy efficiency. This paper is not particularly interdisciplinary – in fact it is not at all interdisciplinary – but the combination of measures demonstrate the inherent weakness of making decisions based on only one source of information.

Carrying out field tests in regular traffic is challenging. Operating regular bus lines with demonstration buses is not allowed to interrupt normal traffic. Suburban bus routes were designated to the project, because the tolerance for technical failures and blocking inner-city streets was low. Using inner-city bus lines were possible for one day only after negotiations. Given the empirical findings, operating other routes would have provided other results, because the impact of operating conditions is significant. The contribution of the hybrid system varies not only with duty cycle but also topography, congestion and driver efficiency. Right now, an extensive demonstration project with seven plug-in hybrid buses is operating a (kind of) central bus line in Stockholm, bus line 73. It will be interesting to learn about the experiences from this project.

The SORT cycle tests were chosen since they are relatively easy to carry out in practice. Other duty cycles, which in some ways better represent an actual driving pattern, are generally carried out in virtual test environments. These duty cycle tests were carried out at an airfield with both the series hybrid and reference buses. The SORT gave very favourable results. Duty cycles that are more similar to real operating conditions would perhaps generate more realistic fuel consumption data, but these cycles are more likely to be performed in a bench test and not in action at an airfield.

By combining duty cycle tests with actual operations, the large gap between the theoretical and actual energy-saving potential become evident. The theoretical contribution of the hybrid system, regenerating brake energy when the bus decelerates for bus stops or traffic lights, is promising; however real inner-city operations are far from optimal and do not allow the bus to reach the velocities necessary for optimal energy storage management. As a result the series hybrid bus simply became a heavier version of the reference bus and occasionally reported higher fuel consumption. However, whereas real operations depend heavy on traffic conditions, the functionality of the start/stop feature is more detached from external factors and showed a potential for significantly reduction of fuel consumption. Reducing the fuel consumption while idling is beneficial to all buses, and vehicles in general, equipped with an ICE. To be able to shut down the engine will also reduce noise at the bus stops.

#### **4.2.2 Opportunities for electrification of public transport buses**

There are many reasons to electrify public transport buses; the benefits go far beyond decreased fuel consumption. Noise and particular pollutants contribute to reduced quality of life and have health implications in metropolitan areas. One bus corresponds to the same

number of passengers as approximately 35 passenger cars (Swedish Bus and Coach Federation, 2014). An increasing use of buses could alleviate traffic congestion in urban areas and also reduce the environmental impact per passenger-kilometre. Buses are flexible and scalable solutions, which could easily adapt to changes in mobility demand. In general, public transport is an exceptionally good option for mobility in urban areas and is often given a lot of attention when planning for future transport systems (Office of Regional Planning, 2010; Swedish Government 2013b). The opportunities offered by public transport buses should be difficult for any decision-maker to overlook. However, buses constitute only a small share of the Swedish road transport system – 6.2% in fact (Swedish Bus and Coach Federation, 2014) – and buses' share of public transport has consistently been just under 20 % for the past 15 years (Transport Analysis, 2014). Figure 17 illustrates the development of passenger kilometres travelled by buses and passenger cars. In 1950, the two transport modes were at similar levels, but since then the use of passenger car has markedly increased in Sweden. The development of passenger car use did not happen by itself but was the consequence of policy-making and investments in infrastructure (Falkemark, 2006).

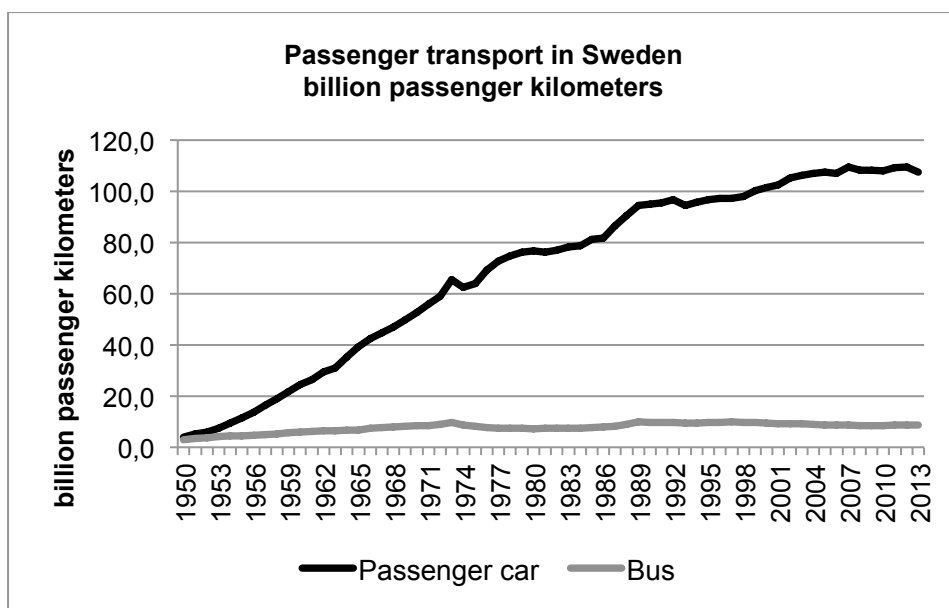


Figure 17. Passenger kilometers carried out by bus and passenger car (Transport Analysis, 2014).

Even though public transport in general and buses in particular are expected to transport a significant number of passengers, after these persons have abandoned their passenger cars, records show no evidence of genuine efforts to increase the attractiveness of public transport. The intention of this section in the thesis is to discuss the opportunities for electrifying public transport buses, but first it is important to acknowledge that despite the political attention

gained during the recent years, public transport has not yet started to increase its market share of the transport system.

The operating cost is a significant share of the Total Cost of Ownership (TCO) of a bus. Several studies suggest it would be financially favourable to replace conventional diesel buses with all- electric and plug-in hybrid alternatives (Nylund and Koponen, 2012; Lajunen 2014). Most TCO studies are based on simulations. The demonstration project of series hybrid buses has shown that fuel economy is sensitive to driving conditions and that real driving conditions differ from optimal, standardised or simplified driving conditions. The method is suitable for developing estimates and identifying suitable vehicle concepts, but it needs to be complemented with real-life studies. However, developing the charging infrastructure for the bus – implicitly the charging behaviour – is also an element that can be approached in different ways. Today, there are a number of all-electric and plug-in hybrid buses in Sweden that fast-charge at end-stations (Stockholm County Council, 2015; ElectriCity, 2015). Nurhadi et al. (2014) have studied electric buses in local public transport in the Swedish city of Karlskrona, and findings show that the TCO for an all-electric and a plug-in hybrid bus is approximately 20 % lower than the TCO for the diesel reference bus. Another approach is to use the bus stops for charging. For this type of charging pattern, super-capacitors have often been used instead of batteries because the power output is higher than for fast chargers and would damage a battery. In 2010, the joint venture of Sunwin (SAIC and Volvo Buses) carried out trails in Shanghai with 40 super capacitor buses and seven bus stops for charging. The trail was perhaps not very successful (Sunwin, 2010) but it is an interesting approach for using the buses' existing stationary occasions for charging.

Public transport is an arena in which it is politically and technically is favourable to be pioneering. There are many different opportunities, which are economical feasible for electrifying public transport buses. Demonstration projects of buses, such as the one on which papers II and III are based, establish a close cooperation between the project partners – in this case the bus manufacture Scania, the public transport operator Stockholm Public Transport (SL) and the bus operator Nobina. Collaborating with other parties and sharing experiences enabled the partners to better understand the different objectives and each other's perspectives. The feasibility of implementing plug-in electric buses varies and an understanding of partners' perspective is important when assessing which type of plug-in electric bus is suitable for a particular city or municipality. Electrification of buses could also be an option for

increasing the attractiveness of buses prior to any substantial efforts to improve the general conditions for public transport operations in urban areas. Measures and efforts to expand public transport are not only desirable from a local environmental point of view but could also benefit two specific groups in particular: those who actively choose not to own a passenger vehicle and those who can not afford a passenger vehicle.

### 4.3 Political conditions for an electric vehicle introduction

The structure of the Swedish public system makes it important to study the local political conditions in the perspective of the introduction of electric vehicles. This section will analyse the conditions for both public fleets and public transport. For passenger vehicles, the commitment of a local public authority that is considering an introduction of plug-in electric vehicles will have to go beyond the acquisition of the vehicles. A political vision to introduce plug-in electric vehicles implicitly includes actions to promote the emergence of a new technical system, for example through expansions of the public charging infrastructure. Electrifying public transport implies centralised charging facilities, but perhaps the greater challenge is to ensure the appropriate prerequisites for introducing technologies in an extremely route-optimised service system.

This section will discuss the political conditions in the perspective of plug-in electric vehicles, based on a study of the policy practice in Stockholm, but will also highlight the influence of policy entrepreneurs for political agenda-setting.

#### 4.3.1 Local energy and transport policy conditions

This section primarily discusses the findings in paper I, but with special regard to the implications for plug-in electric vehicles. The study on which paper I is based was carried out approximately one year after the local politician and traffic commissioner Ulla Hamilton launched the political vision of Stockholm as *City of Electric Vehicles 2030* (Hamilton, 2009). At that time, plug-in electric vehicles had not been on the Swedish (or any) political agenda for a long time, but technical, mainly electro-chemical, improvements (Nykvist and Nilsson, 2015) had enabled development of a new generation of plug-in electric vehicles.

The aim of this study was to assess whether the current policy practice reinforces transport and energy policy goals. By analysing local and regional policy practice, it was found that the superordinate goal was to reach a resilient road transport system and the measures mentioned in energy policy were biofuels and plug-in electric vehicles.



Findings in paper I show a lack of policy integration, which could ultimately influence the deployment of plug-in electric vehicles. Policy integration failures are not unique to Stockholm; nor are they a concern unique to energy and transport policy. Public transport, however, was shown to be integrated in both energy- and transport policy. Public transport succeeded in fulfilling separate policy goals, without an integrated approach; thus the service provided mobility while simultaneously being able to reduce the environmental impact. This indicates favourable conditions for achieving an energy-efficient and renewable public transport system. Other cities have already adopted far-reaching targets for electrifying its public transport buses. In Amsterdam, for example, all buses shall be all-electric by 2025 (Municipal Council of Amsterdam, 2015). Helsinki aims for 40 % of the buses to be electric by the same year (Yle, 2015).

The studied documents in paper I included both visionary documents, with weak scientific basis, and governing documents. The policy documents included different forecast scenarios regarding the developments of energy and transport systems. In transport policy, it is common to rely on forecast models. However, forecasting policy has a tendency to overestimate impact due to the optimistic bias of the forecaster (Tal and Cohen-Blankshtain, 2011). Based on the information given in the policy documents, certain fuel and technology pathways were identified and illustrated through a backcasting study. Backcasting is used to envision the desired future and has gained interest because measures to mitigate climate change, for example, are radically different to the current policy practice. Paper I visualised the discrepancy between the on going policy processes and the desired future. To complement optimistic forecasting studies, backcasting serves to challenge the perceptions and assumptions on which the forecasts are based. Banister and Hickman (2013) argue that backcasting research is seldom implemented; hence its main purpose is to suggest radical changes, and backcasting research could benefit from *more realistic* scenarios. This implies that there is a significant potential to complement the current policy practice, based primarily on forecasts, along with backcasting scenarios. Simultaneously, considering current policy practice in backcasting could improve the chances that backcasting findings will be implemented and contribute to more resilient policy developments.

Paper I confirms the picture of political decision-makers as suffering from *fuel-du-jour syndrome*, and capable of paying attention to only one fuel at a time (Gordon and Sperling, 2009). The political discourse therefore makes different renewable transport fuels compete with each

other rather than competing with the fossil option. In Sweden, the fuel-du-jour by the mid-2000's was ethanol. The current Swedish policy framework promoted the use of biofuels for road transports. Regardless of the technology-neutral intention of the support, ethanol became the dominant fuel. Figure 18 illustrates the monthly ethanol vehicle sales in Sweden between 2005 and 2015. Figure 18 shows insignificant sales prior to 2006, when ethanol gained in popularity, and a return to small sales shares after 2010.

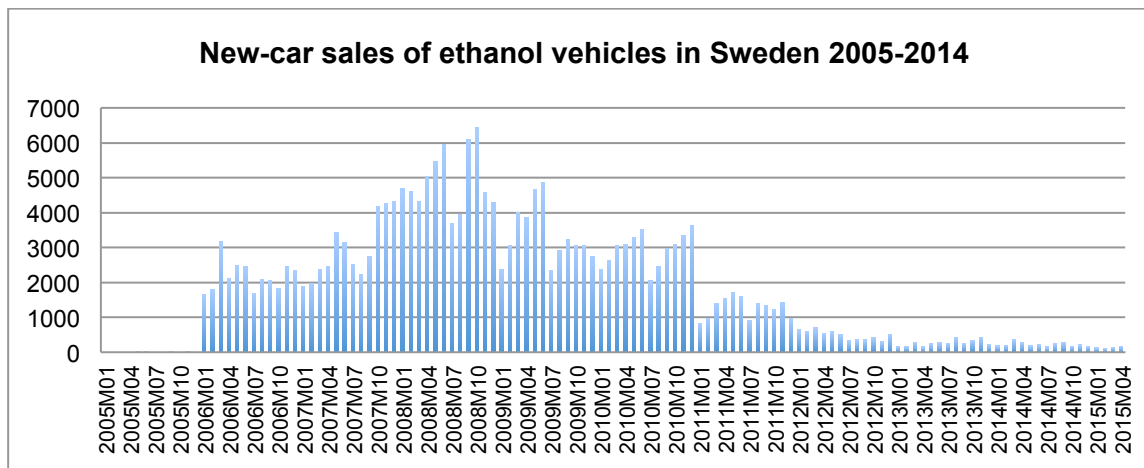


Figure 18. Ethanol vehicle sales in Sweden (Transport Analysis, 2015b)

In 2010, the public debate in Sweden became critical to ethanol and questioned how sustainable the imported ethanol really was. Sadly enough, the discussions never involved the sustainability index of petroleum fuels and ethanol came to be considered a policy failure in Sweden by the general public (Eklöf, 2011). It was a progressive measure to promote renewable-fuelled (i.e. ethanol) vehicles, especially in public fleets, and the subsequent criticism still today influences the public debate. The political interest today concerns primarily biogas or/and plug-in electric vehicles. Civil servants have an understanding of the need for multiple fuels but politically the options are limited to the two fuel options investigated in paper I. The interview study, carried out in 2011 when there were less than 1,000 PEVs in Sweden (ELIS, 2015), showed that some respondents anticipated a similar situation to that of ethanol for plug-in electric vehicles.

### 4.3.2 Political agenda-setting

Paper VII shows that an important individual with agenda-setting abilities is the policy entrepreneur. Kingdon (1984) describes the policy entrepreneur as an individual, inside or outside the public institution, with the ability to influence the political agenda in public-policy processes. The findings in paper VI show how the policy entrepreneur influences the

introduction of plug-in electric vehicles in public authorities, for example by informing/persuading political decision-makers and consolidating the technology in governing policy documents. The policy entrepreneurs in paper VII have taken actions beyond the decision-makers and have been involved in the deployment process, which has influenced the acceptance of the plug-in electric vehicles.

A policy entrepreneur waits for the right moment to push for a policy proposal. Kingdon (1984) defines this moment as a *policy window*. A policy window could be explained as the moment when the political agenda is reviewed and issues are prioritised. A policy window could be predicted to open up after an election, for example, or this could happen unpredictably due to a crisis or another specific event. The policy entrepreneurs have used the PEV technology procurement scheme as a window of opportunity for promoting plug-in electric vehicles. Capitalising on arisen opportunities is one way of overcoming institutional failures in the system (Foxon and Pearson, 2008). EU mandate that the public authorities to go first (EC, 2011a) but without national incentives, the local authorities become tentative. Paper VII show that policy entrepreneurs have an important role as initiators to political actions as the decision-makers seek for local opportunities to implement national policy. During the deployment process, the policy entrepreneurs' actions have inspired use and educated the users.

In this early part of the global process of introducing plug-in electric vehicles, the political conditions for plug-in electric vehicles are influenced by actions undertaken by an individual; the policy entrepreneur. The policy entrepreneurs advocate the new technology and repeatedly ensure the prerequisites for deployment.

### **4.3.3 Local public authorities as forerunners**

Understanding the society surrounding the technology is fundamental because it can be argued that it is the society that constructs the technology (Latour, 1987). In the process of understanding the role of local public authorities in introducing electric vehicles in Sweden, encounters with employees of different public companies and municipalities, public officials and politicians were specifically important since they provided information beyond policy documents, vehicle data and political party manifestos. Local public authorities gather a lot of competences, and a lasting impression gained from the interview study with the public officials were their commitment to provide their politicians with the best possible material. However, they are not given particularly favourable conditions, as the system boundaries are often

defined too narrow and without any opportunities to work in cross-disciplinary teams, which make it difficult to consider the areas of energy and transport simultaneously.

The political conditions for an introduction of plug-in electric vehicles were considered uncertain in paper I, but it is interesting to reflect over the developments since the study was carried out. The coordination of the PEV technology procurement scheme (*Elbilsupphandlingen*) was a major contribution to the implementation of the policy goals; thus a recognised barrier was the lack of plug-in electric vehicles on the Swedish market. The City of Stockholm increased its own fleet of plug-in electric vehicles, from 0.7 % in 2010 to 12.6 % in 2014 (City of Stockholm, 2015). The NGO and motor enthusiasts group Miljöfordon Syd regard the City of Stockholm as working progressively with both plug-in electric vehicles and biogas (Miljöfordon Syd, 2015).

In 2014, the City of Stockholm budgeted for an expansion of 100 additional, public normal charging outlets and 10 fast-chargers. In April 2015, 13 fast-chargers were available in the City of Stockholm and another eight in the county. The public parking company *Stockholm Parkering* provides normal charging from over 800 charging outlets. Almost 5,700 plug-in electric vehicles are registered in the county of Stockholm (ELIS, 2015), which constitutes almost half the entire Swedish market; and this makes this area the premier geographical recipient of PEVs in Sweden. There are of course a variety of factors, beyond of the scope of this thesis, which influence this dominance of PEVs in Stockholm, but it could also be an indicator of a local policy process that has consolidated the technology in the society.

When Miljöfordon Syd analysed the ten most progressive municipalities in Sweden, they could conclude that these would reach the national goal of a fossil-independent vehicle fleet by 2024, six years prior the target of 2030. The City of Stockholm is one of these ten municipalities, and given that their current share of renewable fuelled vehicles is 97 % (Miljöbarometern, 2015), the national goal of a fossil-independent vehicle fleet by 2030 is not out of reach. The deployment rate of biofuelled vehicles shows that the local public authorities have been forerunners and demonstrated the technology. The rest of the society may follow the pioneering local authorities, but at more moderate speed. Prior to 2013, and the constraint of the Swedish green car definition, almost 45 % of private Stockholm household purchased a *green vehicle*.

In Sweden and globally, it is cities and municipalities who are the forerunners when states act passively. In cooperation between cities, affinities beyond regions or nations are created and experiences are exchanged.

#### 4.4 The future is interdisciplinary or not at all

This section's title, borrowed from the Canadian quartet Frog Eyes, accurately sums up the findings of this work regarding the creation of favourable conditions for plug-in electric vehicles. An interdisciplinary approach recognises the interactions between the vehicles and the surroundings, and this approach enabled a scope of analysis beyond the technical specifications.

There are numerous technical studies that evaluate the functionality of a new technology, but often the operator/user is ignored or excluded from the evaluation. This work complements research of a more technical nature, by increasing knowledge of operating conditions, organisational context and conditions for BEVs in public fleets. By including non-technical perspectives, both from users and by individuals described as policy entrepreneurs, the findings contribute to greater understanding regarding the work involved in the implementation process of a new technology. The research design enabled a relevant discussion regarding operational barriers, a topic that is often restricted to discussions of range, charging times and purchase costs.

Different policy areas overlap and each area formulates different conditions, defines problems and implements its own measures to deal with the same issue. An interdisciplinary approach can identify conflicts regarding policy goals or measures, but an even greater benefit is that it can transcend the theoretical limitations a policy area might have in terms of lack of knowledge, power or systems awareness.

Endorsing the interdisciplinary approach is important because the vast majority of energy research have a single-discipline approach. However, interdisciplinary research relies to some extent on the supply of detailed disciplinary studies, and more importantly the technology itself. Interdisciplinary research requires system-oriented experts with the ability to assess and select the relevant information in a broader context. The interdisciplinary researcher has the ability to compile, assess and consider different perspectives, and can thereby contribute with new insights. This thesis, for example, has demonstrated how interdisciplinary research can

identify organisational barriers for plug-in electric vehicles and reveal the lack of policy integration between energy and transport policies.

The interdisciplinary research carried out in this thesis succeeded in capturing policy entrepreneurial actions, which were shown to be decisive for the deployment of PEVs in public fleets, and offer greater understanding of users' situation in PEV operations. An interdisciplinary approach is a complement to disciplinary studies. The interdisciplinary researcher can complement traditional research approaches with a broader systems perspective, thus offering vital contribution in understanding a more complex future.

## 5 Conclusions and recommendations

This work has captured the process in recent years, as electric vehicles have emerged on the scene and earned a place on the political agenda. The work has mainly focused on actions taken to introduce electric vehicles in public vehicle fleets and public transport services and the political and practical conditions for introducing plug-in electric vehicles in Swedish energy and transport systems. The interdisciplinary approach used in the work generated findings regarding the usage of plug-in electric vehicles that go beyond a traditional technical description of empirical data and changed the narrative point of view.

The Swedish national goal of fossil independence for the road transport system is very ambitious; if it is implemented it will be a momentous achievement. However, given current (national) policy instruments, the Swedish Energy Agency's long-term scenario report<sup>2</sup> expects the usage of electricity in the road transport sector to be 0.4 TWh by 2030. If a significant share of the 4,5 million passenger vehicles in Sweden, say that 50 %, would be plug-in electric vehicles, this would correspond to approximately 7 TWh<sup>3</sup>. Using the same assumptions, 0.4 TWh comprises a Swedish market of approximately 135,000 PEVs. The average lifetime of a passenger car in Sweden is approximately 17 years (BILSweden, 2013), so vehicles sold today will quite possibly operate to some extent in 2030. It could be argued that only the really ambitious local public authorities, which already have a large share of renewable-fuelled vehicles and that have already implemented the appropriate vehicle policies, can reach the national goal. The current national guidelines are tentative and it is not realistic to expect the private vehicle fleet in Sweden to surpass the expectations of local public authorities – at least not without enormous financial support. And to heavily subsidise personal transports would diminish effects of any actions to promote use of public transport. Public transport has been identified as a functioning policy area in which to implement new technologies. The challenge is to provide attractive public transport and simultaneously make sure that biofuelled or plug-in electric vehicles are chosen when a new-car sales opportunity arises. If a significant electrification of the road transport system is needed in order to reach the national goals,

---

<sup>2</sup> The report is also called *Knuff-rapporten* (the Nudge report) after an incident between two party leaders at a televised debate during the 2014 Swedish National election.

<sup>3</sup> Given a vehicle use 0.2 kWh/km and drive 15,000 km annually.

public fleets can be used as agents of change. This thesis has identified especially favourable conditions for electrifying the public fleets prior to the electrification of the private fleet.

Findings from this thesis show that fleet vehicles do not rely on public charging, and during expansion of the public charging infrastructure, fleet operations can continue normally. For tasks and applications beyond the technical specifications of battery capacity, fleets consists of several vehicle options and an alternative can be used. For a private vehicle the relationship is more digital; all the journeys are within the technical capability, or not. Nevertheless, when assessing the potential to electrify private vehicles, datasets like national travel surveys are predominantly used. These extensive data samples show general traveling behaviours. For the Swedish case, 85 % of all journeys carried out are shorter than 50 km (Transport Analysis, 2007), and thereby it is concluded that the potential for use of battery electric vehicles is 85 %. This approach neglects considerations regarding how these 85 % of the vehicles are allocated. To understand the real substitution potential, the absolute number of vehicles that never exceed a certain range must be identified. A JRC project, monitoring 16,000 private vehicles during one month, states that the real substitution potential for BEVs is between 10 and 25 % of privately owned vehicles (De Gennaro et al, 2014). New business models are emerging, which innovatively compensate for events beyond the technical capability of the BEV.

However, in the near future BEVs will probably serve as a complement to a conventional vehicle. The household will expand its car ownership, which will make it a *hybrid household*. In this context, this term refers to a household with both a BEV and (a) conventional vehicle(s). In Norway, 15 % of the BEV households are one-vehicle households (Haugneland and Kvisle, 2013). The other 85 % of the households own two cars *or more*. A consumer behaviour where BEVs are only added to existing more or less conventional vehicles is not a resilient approach for electrifying the road transport system. PHEVs, in contrast to BEVs, could be considered as a flexible option that technically<sup>4</sup> could replace any conventional vehicle. However, the environmental benefit depends on charging behaviour. PHEVs can vary between being vehicles predominantly operating in electric mode to conventional vehicles with oversized energy storage for regenerative brake energy. This situation makes PHEVs analogous to ethanol vehicles. Most ethanol vehicles have a technical configuration that allows these vehicles to operate on petrol in addition to the biofuel. In this case, there the environmental benefit is determined mainly by the price sensitivity of the end-consumer (Pacini and Silveira,

---

<sup>4</sup> More and more vehicle models are entering the market but the total model range is not yet available as PHEVs.



2011). The environmental benefits of BEVs, in a local emission perspective, can never be doubted. Electrification is an excellent energy-efficiency measure but the overall aim is also to constrain the absolute numbers of vehicles operating this planet.

This thesis shows that it is difficult to implement energy and transport policies without contradicting policy goals. Considering excessively narrow system boundaries could affect the actual environmental impact of a policy measure (Olsson, 2015). Backcasting could be used in the policy process, to identify and articulate different drivers and goals for the different policy areas. However, there is a critical point where the complexity no longer provides a decision-maker with any new information.

Both scientific and practical needs motivated this study. Paper I visualised the need for using multiple fuels in order to achieve the adopted policy goal but the development does not look promising. Plug-in electric vehicle constituted 1.5 % of the sales in 2014, which is almost double the sales share for ethanol passenger vehicles (0.8 %) (BIL Sweden, 2015).

Unfortunately, the findings show that biofuels and plug-in electric vehicles are competing with each other over the political agenda. With this political discourse, it is easy to forge the main goal – that of reducing the anthropogenic contribution of greenhouse gas emissions to the atmosphere, i.e. by reducing the use of fossil fuels. It is of course desirable for this transition to be energy-efficient, but the suboptimisation has perhaps gone too far. Not only shall biofuels reduce the use of fossil fuels; they are also expected to erase social injustices. And when electricity is used as a vehicle fuel, it has to relate to its worst-case production. Household electricity loads are exempted from this theoretical imperative.

Findings from this research have been put into action and will have long-term impact. The studies have put plug-in electric vehicles on the political agenda and have contributed to the formation of new policies. As a result of the findings and the municipality's own experiences from participating in the PEV technology procurement scheme, Umeå has revised its vehicle policy. Umeå's vehicle policy now expresses explicitly that PEVs should be used primarily for all journeys that require a car or van. In addition, the policy documents now include guidelines for bicycle use to decrease the overall vehicle demand. Uppsala is another example of a local public authority, which gained initial experiences of PEV through the PEV technology procurement scheme. Based on the findings regarding driving and charging behaviours and after having operated the vehicles for some time, Uppsala developed its own technical specifications and carried out its own procurement process. In order to understand the

conditions for fleet vehicles, the discussions with fleet managers have been valuable. Many fleet managers within the PEV technology procurement scheme have a systematic approach for optimisation of the fleet usage. The fleet managers are used to evaluating the energy and cost efficiency of different vehicle choices; hence this group can easily comprehend the benefits, despite a higher initial investment cost. However, without practical experience, fleet managers found it difficult to argue for plug-in electric vehicles in decision-making setting. The scheme enabled the authorities to test different vehicle models and learn about their different attributes, which increased knowledge and allowed additional purchases (Hjalmarsson, 2014). Practical experience is a process known to have positive effects on the diffusion of new energy technologies (Raven, 2007).

To understand and assist in a bringing about the transition to a resilient road transport system, this work has analysed the experiences of real policy practice, actual users and authentic operating conditions. Some knowledge can be obtained only from actual practice. This thesis complements previous findings and aim to explore the conditions for electric vehicles, beyond the technical aspects. Even though the work is situated in Sweden, findings regarding the usage of electric vehicles in fleets are applicable to other geographical areas. The findings are useful in any introduction of electric vehicles because they elaborate on favourable conditions for deployment.

This thesis also aims to be a methodological contribution and to present concrete examples of interdisciplinary research processes and research designs in addition to the findings generated by the project. Sharing methods from other disciplines challenge the normative problem definition. Addressing non-technical barriers of a technology enriches the discourse around the conditions for the technology. Just multiple methods alone are no guarantee for new findings; a genuine shift in perspective is required. It is hoped that this thesis has demonstrated the importance of an interdisciplinary research approach and that this approach will be more common in the future - not only to implement more research findings in policy, but also as a basis for research to discover and reveal different interactions in the context in which the technology is used. However, traditional studies of energy and transport systems tend to consider only measurable technical parameters, and their outcome is foremost recommendations regarding the new and/or improved technology. One prominent example of an interdisciplinary failure is the biggest EU FP7 project – Green eMotion – an initiative with 43 partners in eight European countries which spent € 42 million but which failed to include a

study of the user perspective and how they perceived the vehicle operations. With this in mind, this chapter, and entire thesis, will conclude with some recommendations.

### 5.1 Recommendations for future research

There are many interesting perspectives to study when it comes to energy in transports. The interdisciplinary research in this case has mainly been carried out using a socio-technical approach but there are many other interesting interdisciplinary crosscuts that could provide new knowledge, in particular regarding the conditions for introducing BEVs. As seen in this work, a significant share of the battery pack is not utilised and it would be interesting to study how to influence the underlying behavioural factors causing this behaviour. Cognitive methods and theories could complement technical studies.

In addition to the research completed in this project, a comparison between the movements of a conventional vehicle and a battery electric vehicle was planned within the PEV technology procurement scheme, using five fleet vehicles from each technology, with similar work specifications. The idea was to use GPS to compare driving behaviours and individual interviews to discuss the operations with the users to understand more about the motives and factors that influenced the operations. The research hypothesis was that both vehicle types operate within the technical limitations of a typical BEV, but that the geographical operation area would be larger for the conventional vehicles. Similar results have been presented before, but this study intended to investigate a Swedish case and contribute with reflections from the users' perspective. Unfortunately, there were problems with the GPS logs and the study was never conducted. It would have been very interesting to investigate how different user groups would have planned their work and what strategies they would have applied.

An interesting but more long-term type of research would be to follow policy entrepreneurs for several years, studying the path and how this entrepreneurial ability has shaped the surroundings. Many have pointed out the policy entrepreneur as an enabler or to someone who can increase the pace; it would be very interesting to assess, over more or less an entire career, the impact of those individuals. It could be suggested that they are far more influential than expected. This could be especially interesting to follow in a country like Sweden, where the power is decentralised and therefore accessible to others than those with the political power.

Lastly, the role of spatial planning and an intermodal society have been given increased attention; this attention is well-deserved. However, the majority of work focuses on planning new cities and not the situation in existing urban areas. Backcasting could contribute to this field by abandoning old, inherited perceptions and by focusing on the reallocation of public space. Exploring different desired future scenarios and investigating the implications, both positive and negative, could contribute to drastic changes in formulated policy goal. Previously, most people did not mind the cigarette smoke in restaurants, public buildings and other shared spaces, but now that smoking is prohibited, would be difficult to revert to the old situation. Something similar could be the case with vehicles in urban areas.

## 5.2 Policy recommendations

Sweden has adopted a very ambitious target for its road transport system – a fossil-independent vehicle fleet by 2030. Given this is the main policy goal for the road transport system, a good start would be to design a policy framework that specifically targets two groups: The first group includes the public fleets that this work has demonstrated are suitable as agents of change. The second group is the company cars. It is fair to have higher expectations on these two groups than on private car owners.

Fleets have proven to only utilise the power outlets provided by their own organisations but for promoting the use of PEVs more generally, the support of public normal charging would have a positive effect. Not everyone lives in a detached house with an own garage where they can charge their vehicle at night. Access to public charging should also increase the number of electric kilometres travelled by PHEVs and is therefore desirable from both a local and a global emission perspective.

Financial incentives and PEV adoption have displayed a positive and significant relationship (Sierzchula et. al 2014), but financial incentives have also been shown to disproportionately benefit high-income consumers (Diamond, 2009). How crucial the amount of granted money actually is for executing a purchase could perhaps be questioned but it is most definitely an important message to consumers. However, temporary measures, like the green car rebates, are schemes that have included limitations to a certain number of vehicles and will therefore always be considered a burden on public finances. It is therefore vital to introduce continuous schemes that could become more ambitious in the future.

General knowledge about plug-in electric vehicles is very low (SEA, 2015b). An important policy measure could be to create a market demand merely by raising awareness about the technology. Information campaigns could of course increase the awareness to some extent but more radical measures could also be implemented. For example, why not introduce sustainable transport in the curriculum for all fourth graders? Waste management is already integrated in the education. Why not do the same with transport? Introduce the subject of sustainable transports and PEVs to the students at driving schools. Raising awareness could be done on a broad basis, systematically and preferably in a tangible way.

This work has concluded findings from some early efforts to promote the use of plug-in electric vehicles in Sweden. The general recommendation to everyone is to try one! Not only this study has shown that the attitude towards the technology improves after having actually experienced driving a plug-in electric vehicle (Fjendbo et al, 2013; Lawton et al, 2008). So far, 15 % of Swedes have had this first PEV experience (SEA, 2015b). The remaining 85 % should take every opportunity they get to try one. Public (and private) fleets are an excellent opportunity to facilitate that first experience of operating a plug-in electric vehicle.



## 6 Acknowledgements


My academic research journey has been perfectly managed by my supervisor Professor Per Alvfors, who has with great enthusiasm supported (most of) my ideas and with unique insights have taught me how to behave at conferences. To my co-supervisor and social-science superstar Lisa Hansson: It's been a treat – You have helped me develop my softer sides, providing me with excellent knowledge about qualitative methods and life in general.

These past years have been full of exciting and inspiring people and personalities. Of course, past and present colleagues at Energy Processes and particularly the Sub Zero Heroes: Martin, Mårten, Mimmi, Johannes, Farzad, Raimund and Kjell Höglund – our time in the basement offices will always be dear to me. To all the intelligent and sometimes crazy people associated with the Energy Systems Programme – you made my days truly interdisciplinary and much more interesting. I have also been privileged to have some excellent colleagues at the Swedish Energy Agency and especially the Transport Unit; your encouragements have meant the world to me. Speaking of personalities; Mårten Larsson – you are not only pretty smart, you are also extremely funny. You made me laugh every single day, regardless of our mode of transportation – camels, trains or taxis. Linnéa Eriksson and Linda Olsson – thanks for great cooperation and fun times around Sweden and Europe! Worth mentioning is also Dick Magnusson – you are a truly talented researcher but also a chillwave whiz kid. Eva Sunnerstedt, you are a force of nature! Working with you has been really inspiring and fun. Not working with you, but instead competing in Oresund Electric Car Rally or hanging out in Brussels, has also been most enjoyable. Anders Folkesson – you introduced me to the scientific process and I'm still thankful that you took time for a phone call instead of going to the toilet before your San Paulo flight. I would also like to mention Per Lundgren - nothing stops you (unless it is a really good bottle of Ripasso)! For an academic on the way to becoming a bureaucrat, you Per is a friendly reminder of that change can happen fast.


Last but not at all least: my super-considerate (and incredibly loud) friends and family! I'm impressed by your interest and desire to understand my (research) interests. Klas – you are the love and soundtrack of my life! Klara och Otto – ni är underbara! Jag är så otroligt stolt över att vara just er mamma. Och min egen lilla Mamma – you are the light and absolutely fabulous!

Martina Wikström  
Stockholm, September 2015


## 7 Appendix 1



**Loggbok för Elbilsupphandlingens Testflotta**



**VATTENFALL**



Månad: \_\_\_\_\_ Elbilens registreringsnummer: \_\_\_\_\_

Datum		Mätarställning		Laddning			Kommentarer	Förare
Resans start	Resans slut	Typ	Plats	Erfarenheter – positiva och negativa samt oförutsedda händelser			Namn och telefon	
		<input type="checkbox"/> Snabb <input type="checkbox"/> Normal 10 A <input type="checkbox"/> Normal 16 A	<input type="checkbox"/> Ordinarie <input type="checkbox"/> Annan <input type="checkbox"/> Ej laddat					
		<input type="checkbox"/> Snabb <input type="checkbox"/> Normal 10 A <input type="checkbox"/> Normal 16 A	<input type="checkbox"/> Ordinarie <input type="checkbox"/> Annan <input type="checkbox"/> Ej laddat					
		<input type="checkbox"/> Snabb <input type="checkbox"/> Normal 10 A <input type="checkbox"/> Normal 16 A	<input type="checkbox"/> Ordinarie <input type="checkbox"/> Annan <input type="checkbox"/> Ej laddat					
		<input type="checkbox"/> Snabb <input type="checkbox"/> Normal 10 A <input type="checkbox"/> Normal 16 A	<input type="checkbox"/> Ordinarie <input type="checkbox"/> Annan <input type="checkbox"/> Ej laddat					
		<input type="checkbox"/> Snabb <input type="checkbox"/> Normal 10 A <input type="checkbox"/> Normal 16 A	<input type="checkbox"/> Ordinarie <input type="checkbox"/> Annan <input type="checkbox"/> Ej laddat					
		<input type="checkbox"/> Snabb <input type="checkbox"/> Normal 10 A <input type="checkbox"/> Normal 16 A	<input type="checkbox"/> Ordinarie <input type="checkbox"/> Annan <input type="checkbox"/> Ej laddat					
		<input type="checkbox"/> Snabb <input type="checkbox"/> Normal 10 A <input type="checkbox"/> Normal 16 A	<input type="checkbox"/> Ordinarie <input type="checkbox"/> Annan <input type="checkbox"/> Ej laddat					
		<input type="checkbox"/> Snabb <input type="checkbox"/> Normal 10 A <input type="checkbox"/> Normal 16 A	<input type="checkbox"/> Ordinarie <input type="checkbox"/> Annan <input type="checkbox"/> Ej laddat					
		<input type="checkbox"/> Snabb <input type="checkbox"/> Normal 10 A <input type="checkbox"/> Normal 16 A	<input type="checkbox"/> Ordinarie <input type="checkbox"/> Annan <input type="checkbox"/> Ej laddat					
		<input type="checkbox"/> Snabb <input type="checkbox"/> Normal 10 A <input type="checkbox"/> Normal 16 A	<input type="checkbox"/> Ordinarie <input type="checkbox"/> Annan <input type="checkbox"/> Ej laddat					
		<input type="checkbox"/> Snabb <input type="checkbox"/> Normal 10 A <input type="checkbox"/> Normal 16 A	<input type="checkbox"/> Ordinarie <input type="checkbox"/> Annan <input type="checkbox"/> Ej laddat					
		<input type="checkbox"/> Snabb <input type="checkbox"/> Normal 10 A <input type="checkbox"/> Normal 16 A	<input type="checkbox"/> Ordinarie <input type="checkbox"/> Annan <input type="checkbox"/> Ej laddat					
		<input type="checkbox"/> Snabb <input type="checkbox"/> Normal 10 A <input type="checkbox"/> Normal 16 A	<input type="checkbox"/> Ordinarie <input type="checkbox"/> Annan <input type="checkbox"/> Ej laddat					
		<input type="checkbox"/> Snabb <input type="checkbox"/> Normal 10 A <input type="checkbox"/> Normal 16 A	<input type="checkbox"/> Ordinarie <input type="checkbox"/> Annan <input type="checkbox"/> Ej laddat					
		<input type="checkbox"/> Snabb <input type="checkbox"/> Normal 10 A <input type="checkbox"/> Normal 16 A	<input type="checkbox"/> Ordinarie <input type="checkbox"/> Annan <input type="checkbox"/> Ej laddat					
		<input type="checkbox"/> Snabb <input type="checkbox"/> Normal 10 A <input type="checkbox"/> Normal 16 A	<input type="checkbox"/> Ordinarie <input type="checkbox"/> Annan <input type="checkbox"/> Ej laddat					

**Instruktioner**  
 Förare: Fyll i bladet för varje resa – namn och telefonnummer räcker med en gång per förare och sedan en signatur för övriga resor.  
 Fordransvarig: Byt bladet i bilen varje månad. Senast den 10:e i varje månad ska förra månads uppgifter vara inregistrerade på [www.testsitesweden.com/logg](http://www.testsitesweden.com/logg)  
 Det här bladet kan laddas ner på [www.elbilsupphandling.se/loggtestflotta](http://www.elbilsupphandling.se/loggtestflotta)



## 8 References

- Anegawa, T., 2010. Development of quick charging system for electric vehicle in the Proceedings of 21st World Energy Congress, Montreal, Canada.
- Axsen, J., Kurani, K.S., 2013. Connecting plug-in vehicles with green electricity through consumer demand. *Environmental Research Letters*. 8, 1-8.
- Banister, D., Hickman, R., 2013. Transport futures: Thinking the unthinkable, *Transport Policy*, 29; 283-293.
- BIL Sweden, 2005. Statistics – New registrations 2004. Statistik – Definitiva *nyregistreringar 2004*. Stockholm, Sweden.
- BILSweden, 2013.  
[http://www.bilsweden.se/MediaBinaryLoader.axd?MediaArchive\\_FileID=f2ebfaff-36fc-4564-bd33-613f4ff5d770&FileName=11\\_manader\\_kvar\\_till-valet\\_BIL\\_Sweden.pdf](http://www.bilsweden.se/MediaBinaryLoader.axd?MediaArchive_FileID=f2ebfaff-36fc-4564-bd33-613f4ff5d770&FileName=11_manader_kvar_till-valet_BIL_Sweden.pdf) Accessed: 2015-06-28
- BIL Sweden, 2015. Statistics – New registrations 2014. Statistik – Definitiva *nyregistreringar 2014*. Stockholm, Sweden.
- Boulding, K. E., 1956. General systems theory - the skeleton of science. *Management Science*, 2: 197-208.
- Brace, I., 2004. Questionnaire design: how to plan, structure and write survey material for effective market research. Kogan Page, Ltd, London, UK.
- Brown, E.G. Jr., Governor's Interagency Working Group on Zero-Emission Vehicles, 2013. 2013 ZEV Action Plan - A roadmap toward 1.5 million zero-emission vehicles on California roadways by 2025. Sacramento, US.
- Bryman, A., 2008. *Social Research Methods* 3rd ed. Oxford University Press, Oxford, UK.
- City of Stockholm, 2015. Environmental indicators. Share of green vehicles in the City's fleet. *Andel miljöbilar i stadens bilflotta*  
<http://miljobarometern.stockholm.se/key.asp?mp=MP15&mo=1&dm=2&nt=1>
- Connolly, D., Lund, H., Mathiesen, B.V., Werner, S., Möller B., Persson, U., Boermans, T., Trier, D., Østergaard, P.A., Nielsen, S. 2014. Heat Roadmap Europe: Combining district heating with heat savings to decarbonise the EU energy system. *Energy Policy*, 65;475-489
- Cooper, P., 2013. Socio-ecological accounting: DPSWR, a modified DPSIR framework, and its application to marine ecosystems. *Ecological Economics*. 94, 106–115.
- Churchman, C. W., 1968. *The Systems Approach*, Delacorte Press, New York
- Clean Fleets, 2014. Clean Buses - Experiences with Fuel and Technology Options. Available at [www.clean-fleets.eu](http://www.clean-fleets.eu) Accessed 2015-05-29

D'Agostino A.L., Sovacool B.K., Trott K., Ramos C.R., Saleem S., Ong Y., 2011. What's the state of energy studies research? A content analysis of three leading journals from 1999–2008. *Energy*, 36;508–519

Davis, F. D., 1993. User acceptance of computer technology: system characteristics, user perceptions. *International Journal of Man-Machine Studies*. 38:457-87.

De Gennaro M., Paffumi, E., Scholz, H., 2014. A pilot study to address the travel behaviour and the usability of electric vehicles in two Italian provinces. *Case Studies on Transport Policy*, 2; 116-141.

Delucchi, M.A., Lipman T.E., 2001. An analysis of the retail and lifecycle cost of battery-powered electric vehicles. *Transportation Research Part D: Transport and Environment*, 6; 371-404.

Dieselnet, 2015a. [https://www.dieselnet.com/standards/cycles/ece\\_eudc.php](https://www.dieselnet.com/standards/cycles/ece_eudc.php) 2015-08-31

Dieselnet, 2015b. <https://www.dieselnet.com/standards/cycles/braunschweig.php> 2015-08-31

DoE (US Department of Energy), 2015. <https://www.fueleconomy.gov/feg/atv.shtml> 2015-05-27

Dreborg, K.H., 1996. Essence of backcasting. *Futures*, 28; 813–828.

Dumortier, J., Siddiki, S., Carley, S., Cisney, J., Krause, R. M., Lane, B. W., Rupp, J. A., Graham, J.D. 2015. Effects of providing total cost of ownership information on consumers' intent to purchase a hybrid or plug-in electric vehicle. *Transportation Research Part A: Policy and Practice*, 72; 71-86.

EC, 2007. Regulation (EC) No 715/2007 of the European Parliament and of the Council of 20 June 2007 on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information.

EC, 2009a. Directive 2009/28/EC of the European Parliament and of the Council of April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

EC, 2009b. Directive 2009/33/EC on the Promotion of Clean and Energy Efficient Road Transport Vehicles

EC, 2011a. White Paper Roadmap to a Single European Transport Area—Towards a Competitive and Resource Efficient Transport System. COM/2011/0144 final. Brussels.

EC, 2011b. Commission regulation (EU) No 582/2011 of 25 May 2011 implementing and amending Regulation (EC) No 595/2009 of the European Parliament and of the Council with respect to emissions from heavy duty vehicles (Euro VI) and amending Annexes I and III to Directive 2007/46/EC of the European Parliament and of the Council

EC, 2012. Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC

- EC, 2014a. Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure
- EC, 2014b. Regulation (EU) No 333/2014 of the European Parliament and of the Council of 11 March 2014 amending Regulation (EC) No 443/2009 to define the modalities for reaching the 2020 target to reduce CO<sub>2</sub> emissions from new passenger cars
- EC, 2014c. Commission regulation (EU) No 540/2014 of the European Parliament and of the Council of 16.4.2014 on the sound level of motor vehicles and of replacement silencing systems, and amending Directive 2007/46/EC and repealing Directive 70/157/EEC (OJ L 158, 27.5.2014, p. 131).
- EC, 2015a. [http://ec.europa.eu/environment/gpp/eu\\_gpp\\_criteria\\_en.htm](http://ec.europa.eu/environment/gpp/eu_gpp_criteria_en.htm) Accessed: 2015-05-29.
- EC, 2015b. [http://ec.europa.eu/environment/gpp/pdf/news\\_alert/Issue27\\_Case\\_Study58\\_Berlin\\_clean%20vehicles.pdf](http://ec.europa.eu/environment/gpp/pdf/news_alert/Issue27_Case_Study58_Berlin_clean%20vehicles.pdf) Accessed: 2015-05-29.
- EC, 2015c. [http://ec.europa.eu/clima/policies/transport/vehicles/index\\_en.htm](http://ec.europa.eu/clima/policies/transport/vehicles/index_en.htm) Accessed: 2015-05-29.
- EC, 2015d [http://ec.europa.eu/environment/gpp/what\\_en.htm](http://ec.europa.eu/environment/gpp/what_en.htm)
- Edquist, C., Hommen, L. & Tsipouri, L.J. (Eds.), 1999. Public technology procurement and innovation. Klumer Academic Publishers, Boston.
- EEA (European Energy Agency), 2013. Monitoring CO<sub>2</sub> emissions from new passenger cars in the EU. Copenhagen, Denmark.
- Eklöf, J., 2011. Success story or cautionary tale? Swedish ethanol in co-existing science–policy frameworks. *Science and Public Policy* 38; 795-806.
- ElectriCity, 2015. <http://www.goteborgelectricity.se/en> Accessed: 2015-06-25
- Elforsk, 2009. Plug in road 2020. Report based on consumer surveys, interviews and seminars. *Plug in road 2020. Rapport baserad på konsumentundersökning, intervjuer och seminarium*. Elforsk report 09:40.
- ELIS, 2015. Electric Vehicles in Sweden *ELbilar I Sverige*. Statistics available at <http://elbilsstatistik.se>
- Ertrac, EPoSS and Smartgrid, 2012. European Roadmap: Electrification of Road Transport. Brussels, Belgium.
- EVI (Clean Energy Ministerial's Electric Vehicles Initiative, the International Energy Agency's Hybrid & Electric Vehicle Implementing Agreement (IA-HEV) and Urban Foresight), 2015. Global EV Outlook 2015. Newcastle upon Tyne. United Kingdom.
- Falkemark, G., 2006. Politics, mobility and environment: the historical emergence of an unsustainable transport system, *Politik, mobilitet och miljö: om den historiska framväxten av ett ohållbart transportsystem*, Gidlunds Förlag, Möklinta, Sweden.

- Falldé, M., 2011. Miljö i tanken? Policyprocesser vid övergången till alternativa drivmedel i kollektivtrafiken i Linköping och Helsingborg 1976-2005 [Environment in mind? Policy processes with the transition to alternative fuels in public transportation in Linköping and Helsingborg 1976-2005]. PhD Dissertation. Linköping University, Sweden
- Figenbaum, E., Kolbenstvedt, M., Elvebakk, B., 2014. Electric vehicles - environmental, economic and practical aspects. As seen by current and potential users. TØI report 1329/2014.
- Fjendbo Jensen, A., Cherchi, E., Lindhard Mabit, S., 2013. On the stability of preferences and attitudes before and after experiencing an electric vehicle. *Transportation Research Part D: Transport and Environment*, 25; 24-32
- Foxon, T., Pearson, P. 2008. Overcoming barriers to innovation and diffusion of cleaner technologies: some features of a sustainable innovation policy regime. *Journal of Cleaner Production*, 16; 148-S161
- Gnann, T., Plötz, P. 2015. A review of combined models for market diffusion of alternative fuel vehicles and their refueling infrastructure. *Renewable and Sustainable Energy Reviews*, 47; 783-793.
- Gudmundsson, H., Hedegaard Sørensen, C., 2013. Some use—Little influence? On the roles of indicators in European sustainable transport policy. *Ecological Indicators*. 35; 43–51.
- Hansson, J., Grahn, M., 2013 Outlook for renewable fuels in Sweden (Utsikt för förnybara drivmedel i Sverige). IVL Report No B2083.
- Haugneland, P., Kvisle, H.H., 2013. Norwegian electric car user experiences. *Proceedings of the 27<sup>th</sup> Electric Vehicle Symposium*. Barcelona, Spain.
- Hill, M.J., 2005. *The Public Policy Process*. Pearson Longman, Harlow.
- Hillman K. M., Sandén B. A., 2008. Exploring technology paths: The development of alternative transport fuels in Sweden 2007–2020. *Technological Forecasting and Social Change*, 75; 1279-1302.
- Hjalmarsson L., 2014. Decision-makers' thoughts on electric vehicles – Experiences from the Swedish National Procurement of Electric Vehicles and Plug-in Hybrids. *Så resonerar beslutsfattare om elbilar i den egna organisationen – erfarenheter från Elbilsupphandlingen*, National Conference on Transportation Research, January 8-9 2014, Linköping, Sweden.
- Howlett, M., 2009. Governance modes, policy regimes and operational plans: a multi-level nest model of policy instrument choice and policy design. *Policy Sciences*, 42; 73–89.
- Hughes, T. P., 1983. *Networks of Power: Electrification in Western Society, 1880-1930*. Johns Hopkins University Press, Baltimore.
- Hughes, N., Strachan, N., 2010. Methodological review of UK and international low carbon scenarios. *Energy Policy* 38, 6056–6065.
- Höjer, M., Mattson, L.G., 2000. Determinism and backcasting in future studies. *Futures*, 32; 613–634.

- Høyre, 2015.  
<http://www.hoyre.no/filestore/Filer/Politikkdokumenter/Finans/BilavgiftsgjennomgangENIGHET.pdf> Accessed: 2015-06-10
- IEA (International Energy Agency), 2012. EV City Casebook. Paris, France.
- IEA, 2014a. Key World Energy Statistics, Paris, France.
- IEA, 2014b. World Energy Outlook 2013. Paris, France.
- Ingelstam, L., 2002. Systems: to consider society and technology. *System: att tänka över samhälle och teknik*. Swedish Energy Agency. ISBN: 9189184246.
- Jenkins, W.I., 1978. Policy Analysis. Martin Robertson, London.
- Klett, M., Georgios Zavalis, T., Kjell, M. H., Wreland Lindström, R., Behm, M., Lindbergh, G., 2014. Altered electrode degradation with temperature in LiFePO<sub>4</sub>/mesocarbon microbead graphite cells diagnosed with impedance spectroscopy. *Electrochimica Acta*, 141; 173-181.
- Knowles, M., Scott, H., Baglee, D., 2012. The effect of driving style on electric vehicle performance, economy and perception. *International Journal of Electric and Hybrid Vehicles*. Volume 4, Issue 3. DOI: 10.1504/IJEHV.2012.050492
- Kushnir, D., Sandén, B.A., 2011. Multi-level energy analysis of emerging technologies: a case study in new materials for lithium ion batteries. *Journal of Cleaner Production*, 19; 1405-1416.
- Kvale, S., 1996. *InterViews: An Introduction to Qualitative Research Interviewing*. Sage Publications, Thousand Oaks, California.
- Lajunen, A., 2014. Energy consumption and cost-benefit analysis of hybrid and electric city buses. *Transportation Research Part C: Emerging Technologies*. 38; 1–15.
- Larminie, J., Lowry, J., 2003. *Electric Vehicle Technology Explained*. John Wiley & Sons, Ltd. Hoboken, United States
- Larsson, T., Bäck, H., 2008. *Governing and Governance in Sweden*, Studentlitteratur, Lund.
- Latour, B., 1987. *Science in Action*. Harvard University Press, Cambridge Massachusetts, United States.
- Lawton, T.K., Frank, L., Bradley, M., Kavage, S., Chapman, J. (2008) Urban form, travel time, and cost relationships with tour complexity and mode choice. *Transportation* 35: 37–54.
- Le Monde, 2015. Interview with Mayor Hidalgo, 28th of January 2015.  
[http://www.lemonde.fr/pollution/article/2015/01/27/anne-hidalgo-en-2020-plus-aucun-vehicule-diesel-ne-roulera-dans-paris\\_4564657\\_1652666.html](http://www.lemonde.fr/pollution/article/2015/01/27/anne-hidalgo-en-2020-plus-aucun-vehicule-diesel-ne-roulera-dans-paris_4564657_1652666.html) Accessed: 2015-05-29
- Lundström, A., 2014. Differentiated driving range: Exploring a solution to the problems with the "guess-o-meter" in electric cars. In proceedings of the 6<sup>th</sup> International Conference on Automotive User Interfaces and Interactive Vehicular Applications. Seattle, US.
- Miljöfordon Syd, 2015. The green vehicle diagnosis 2014. *Miljöfordonsdiagnosen 2014*. Available at <http://www.miljofordonsdiagnos.se/HTML/start.aspx> Accessed at 2015-05-29

Morgan, D., 1998. Focus groups as qualitative research. *Qualitative research methods*, Vol. 16. Sage Publications, Thousand Oaks, California.

Municipal Council of Amsterdam, 2015. Sustainable Amsterdam – Agenda for renewable energy, clear air, a circular economy and a climate-resilient city. Amsterdam, the Netherlands.

Nesbitt, K., Sperling D., 1998. Myths regarding alternative fuel vehicle demand by light-duty vehicle fleets. *Transportation Research Part D: Transport and Environment*, 3; 259-269.

Nesbitt, K., Sperling, D., 2001. Fleet purchase behavior: decision processes and implications for new vehicle technologies and fuels. *Transportation Research Part C: Emerging Technologies*. 9; 297–318.

Norden Energy and Transport, 2014. RekkEVIDde – Assessing range and performance of electric vehicles in Nordic driving conditions –Project Final Report.  
<http://www.energiogtransport.net/content/wp-content/uploads/2011/03/1.-RekkEVIDde.pdf>

Nurhadi, L., Borén, S., Ny, H., 2014. A Sensitivity Analysis of Total Cost of Ownership for Electric Public Bus Transport Systems in Swedish Medium Sized Cities. *Transportation Research Procedia* 3; 818 – 827.

Nylund, N.O., Koponen, K., 2010. Fuel and Technology Alternatives for Buses. Overall Energy Efficiency and Emission Performance.  
<http://www.vtt.fi/inf/pdf/technology/2012/T46.pdf> accessed: 2015-06-25

Nykvist, B., Nilsson, M., 2015. Rapidly falling costs of battery packs for electric vehicles. *Nature Climate Change* 5; 329–332.

Office of Regional Planning, 2010. Regional development plan for the Stockholm region – RUFs 2010. *Regional Utvecklingsplan För Stockholmsregionen, RUFs 2010 – så blir vi Europas mest attraktiva storstadsregion*. Stockholm, Sweden.

Olsson, L., 2015. Sociotechnical system studies of the reduction of greenhouse gas emissions from energy and transport systems. PhD dissertation. Linköping University, Linköping, Sweden.

Ornetzeder, M., Rohracher, H., 2006. User-led innovations and participation processes: lessons from sustainable energy technologies, *Energy Policy*, 34;138-150.

Pacini, H., Silveira, S., 2011. Consumer choice between ethanol and gasoline: Lessons from Brazil and Sweden. *Energy Policy*, 39; 6936-6942.

Plötz, P., Schneider, U., Globisch, J., Dütschke, E., 2014. Who will buy electric vehicles? Identifying early adopters in Germany. *Transportation Research Part A: Policy and Practice*, 67; 96-109.

Quist, J., Vergragt, P., 2006. Past and future of backcasting: the shift to stakeholder participation and a proposal for a methodological framework. *Futures*, 38; 1027–1045.

Ralston, M., Nigro, N., 2011. Plug-in Electric Vehicles: Literature Review. Available at <http://www.ourenergypolicy.org/plug-in-electric-vehicles-literature-review/> Accessed: 2015-05-29

- Raven, R. 2007. Niche accumulation and hybridisation strategies in transition processes towards a sustainable energy system: An assessment of differences and pitfalls. *Energy Policy*, 35;2390-2400.
- Rouillard, J.J., Heal, K.V., Ball, T., Reeves, A.D., 2013. Policy integration for adaptive water governance: learning from Scotland's experience. *Environmental Science Policy*, 33; 378–387.
- Rogers, E. M., 2003. *Diffusion of Innovations*, 5th ed. Simon and Schuster. New York City. United States.
- Schmidt, J., Eisel, M., Kolbe L.M., 2014. Assessing the potential of different charging strategies for electric vehicle fleets in closed transport systems. *Energy Policy*, 74; 179-189
- Schwanen T. Banister D. Anable J., 2011. Scientific research about climate change mitigation in transport: A critical review, *Transportation Research Part A: Policy and Practice*. 45:993-1006.
- SEA (Swedish Energy Agency) 2015a. Transportsektorns energianvändning 2014 (Energy use in the transport system 2014). ER 2015:01
- SEA, 2015b. Attitudes towards and knowledge about plug-in electric vehicles 2015. *Inställningen till och kunskaper om laddfordon 2015*. Eskilstuna, Sweden.
- Smith, B.C., 1976. *Policy Making in British Government*. Martin Robertson, London.
- Sovacool B.K., Hirsh R.F., 2009. Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition. *Energy Policy*, 37; 1095-1103.
- Sovacool, Benjamin K. 2014. What are we doing here? Analyzing fifteen years of energy scholarship and proposing a social science research agenda. *Energy Research & Social Science*, 1;1-29.
- Sperling, D., Gordon, D., 2009. *Two Billion Cars – Driving Towards Sustainability*. Oxford University Press, United Kingdom.
- Sperling D., Eggert A., 2014. California's climate and energy policy for transportation. *Energy Strategy Reviews*, 5; 88-94.
- Stockholm County Council, 2015. <http://www.sll.se/verksamhet/kollektivtrafik/aktuella-projekt/Laddhybridbuss/> Accessed: 2015-06-25
- Sunwin, 2015. <http://www.slideshare.net/ResearchIndia/super-capacitor-buses-in-shanghai-5156990> Accessed: 2015-05-26
- Swedenergy (Svensk Energi), 2012. Guidance on the origin of electricity. *Vägledning angående ursprungsmärkning av el*. Stockholm, Sweden.
- Swedish Bus and Coach Federation, 2014. Statistics on the bus industry. *Statistik om bussbranschen*. Stockholm, Sweden.
- Swedish Government, 2009. Bill 2008/09:162. A joint climate and energy policy – climate. *Proposition 2008/09:162. En sammanhållen klimat- och energipolitik – klimat*, Stockholm, Sweden.

Swedish Government, 2013a. Public Inquiry 2013:12. Good business – a strategy for sustainable public procurement. *Statens Offentliga Utredningar 2013:12 Goda affärer - en strategi för hållbar offentlig upphandling*. Stockholm, Sweden.

Swedish Government, 2013b. Public Inquiry 2013:84 On fossil-free road. *SOU 2013:84 Fossilfrihet på väg*. Stockholm, Sweden.

Swedish Tax Agency, 2015.

<http://www.skatteverket.se/privat/skatter/arbeteinkomst/formaner/bilarmm/korjournal.4.18e1b10334ebe8bc8000695.html> Accessed: 2015-05-29

Swedish Parliament, 2003. Act 2003:564. *Förordning (2003:564) om bidrag till åtgärder för en effektiv och miljönpassad energiförsörjning*. Stockholm, Sweden.

Swedish Parliament, 2004. Act on governmental bodies' purchases and leasing of green cars 2004:1364. *Förordning (2004:1364) om myndigheters inköp och leasing av miljöbilar*. Stockholm, Sweden.

Swedish Parliament, 2006. Act on Road Taxation 2006:227. (*Vägtrafikskattelag (2006:227)*). Stockholm, Sweden.

Swedish Parliament, 2011. Act on Green Super Car Rebate 2011:1590. *Förordning (2011:1590) om supermiljöbilspremie*. Stockholm, Sweden.

Swedish Parliament, 2007a. Act on Green Car Rebate 2007:380. *Förordning (2007:380) om miljöbilspremie*. Stockholm, Sweden.

Swedish Parliament, 2007b. Act on Public Procurement 2007:1091. *Lagen om offentlig upphandling*, Stockholm, Sweden.

Swedish Parliament, 2007c. Utilities Procurement Act 2007:1092. *Lag om upphandling inom områdena vatten, energi, transporter och posttjänster*, Stockholm, Sweden.

Swedish Parliament, 2014.

<http://www.regeringen.se/pressmeddelanden/2014/12/supermiljobilspremien-forlangts-/> 2015-05-28

Tal, G., Cohen-Blankshtain, G., 2011. Understanding the role of the forecast-maker in overestimation forecasts of policy impacts: The case of Travel Demand Management policies, *Transportation Research Part A: Policy and Practice*, 45; 389-400.

Tal, G., Nicholas, M. A., Woodjack, J., Scrivano, D., 2013. Who Is Buying Electric Cars in California? Exploring Household and Vehicle Fleet Characteristics of New Plug- In Vehicle Owners . Research Report – UCD-ITS-RR-13-02. Institute of Transportation Studies University of California, Davis, US.

Thiel, C., Alemanno, A., Scarcella, G., Zubaryeva, A., Pasaoglu, G., 2012. Attitude of European car drivers towards electric vehicles: a survey. JRC Scientific and Policy Report no. JRC76867, Petten, the Netherlands.

Transport Analysis, 2007. National Travel Survey 2005-2006. SIKI Statistics Report 2007:19. Stockholm, Sweden.



- Transport Analysis, 2014. Transport revenue passenger kilometers 1950-2013, *Transportarbete 1950-2013*, Stockholm, Sweden.
- Transport Analysis, 2015a. Statistics Swedish Vehicle fleet 2014. *Fordon 2014*. Östersund. Sweden.
- Transport Analysis, 2015b. New vehicle registrations, *Nyregistreringar*, Stockholm, Sweden.
- UITP (International Association of Public Transport), 2011a. <http://www.uitp.org/sites/default/files/cck-focus-papers-files/FPNov2011.pdf> 2015-05-29.
- UITP, 2011. SORT – Standardised on-road test cycles, 2004. Available for purchase at [www.uitp.com](http://www.uitp.com) 2011-03-01
- Vinnova, 2015. <http://www.vinnova.se/sv/ffi/Om-FFI/> Accessed: 2015-05-29
- Weston, M. 2010. London Hybrid Bus Trials, Proceedings of Low Carbon Vehicle Partnership (LowCVP) Conference, Twickenham, United Kingdom.
- Wetterlund, E., Pettersson, K., Harvey, S., 2011. Systems analysis of integrating biomass gasification with pulp and paper production – Effects on economic performance, CO2 emissions and energy use. *Energy*, 36; 932-941.
- Wikström M, Sunnerstedt E, Alvfors P., 2013. Obstacle 1: Capture experience generation of Swedish electric vehicle users, Proceedings of the 27th Electric Vehicle Symposium, Barcelona, Spain.
- Palm J., Thollander, P., 2010. An interdisciplinary perspective on industrial energy efficiency. *Applied Energy*, 87; 3255-3261.
- Persson, J., 2014. Low-energy buildings: energy use, indoor climate and market diffusion. PhD Dissertation. KTH – Royal Institute of Technology. Stockholm, Sweden
- Yle, 2015. [http://yle.fi/uutiset/helsinki\\_transport\\_invests\\_in\\_electric\\_buses/7899188](http://yle.fi/uutiset/helsinki_transport_invests_in_electric_buses/7899188) Accessed 2015-06-28