

# SUSTAINABLE PERSONAL ROAD TRANSPORT - THE ROLE OF ELECTRIC VEHICLES

Sven Borén

Blekinge Institute of Technology  
Licentiate Dissertation Series No. 2016:02  
Department of Strategic Sustainable Development



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Licentiate Dissertation in  
Strategic Sustainable Development



Department of Strategic Sustainable Development  
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## Acknowledgements

Before I started this journey towards my licentiate degree, I thought that becoming a PhD student at 40 years of age was something one could do only if the addiction to the topic was vast, a pile of savings could be used to keep a good standard of living, and one did not have small kids that would limit the amount of work to 40 hours/week. I am happy to be wrong about the last two assumptions as this fantastic journey, and hopefully a continuation towards a PhD degree, was enabled mainly because of the great support in many ways from my beloved wife Kristina. My kids Sebastian and Stella have been a great driving force for me as I want to find solutions that enable them and future generations a good life, without suffering from unsustainable development. They have, along with all the interesting and inspiring people I have met during this journey, challenged me to describe the research in a way that is understandable and engaging for most people. My parents, parents-in-law, siblings, many friends, PhD student mates and students have also been invaluable in supporting me and have contributed with many fruitful discussions about enabling more sustainable transport solutions.

This work would not have been possible without collaboration with, and financial support from, municipalities, regions, county boards, county councils, and companies participating in the GreenCharge project. Financial support from the Swedish Energy Agency and Blekinge Institute of Technology is also gratefully acknowledged. GreenCharge project partners Andreas Olsson at Region Jönköping County and Jonas Lööf at Miljöfordon Syd have been valuable for the realisation of the practical studies. Stefan Nilsson at Miljöfordon Syd has contributed with discussions about new electric vehicle technology and advice on the dissemination of results outside of the scientific channels.

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*Sven Borén, Karlskrona, Sweden 2016*

## Abstract

Electric vehicles can play an important role in a future sustainable road transport system and many Swedish politicians would like to see them implemented faster. This is likely desirable to reach the target of a fossil independent vehicle fleet in Sweden by 2030 and a greenhouse gas neutral Swedish society no later than 2050. However, to reach both these targets, and certainly to support the full scope of sustainability, it is important to consider the whole life-cycle of the vehicles and also the interaction between the transport sector and other sectors. So far, there are no plans for transitions towards a sustainable transport system applying a sufficiently wide systems perspective, in Sweden or elsewhere. This implies a great risk for sub-optimizations.

The overall aim of this work is to elaborate methodological support for development of sustainable personal road transport systems that is informed by a strategic sustainable development perspective.

The Framework for Strategic Sustainable Development (FSSD) is used as a foundation for the work to ensure a sufficiently wide systems perspective and coordinated collaboration across disciplines and sectors, both in the research and application. Maxwell's Qualitative Research Design and the Design Research Methodology are used as overall guides for the research approach. Specific research methods and techniques include literature studies, action research seminars, interviews, and measurements of energy use, costs, and noise. Moreover, a case study on the conditions for a breakthrough for vehicles in southeast Sweden has been used as a test and development platform.

Specific results include a preliminary vision for electrical vehicles in southeast Sweden, framed by the principled sustainability definition of the FSSD, an assessment of the current reality in relation to that vision, and proposed solutions to bridge the gap, organized into a preliminary roadmap. The studies show that electric vehicles have several sustainability advantages even when their whole life-cycle is considered, provided that they are charged with electricity from new renewable sources. Electrical vehicles also imply a low total cost of ownership and could promote new local 'green jobs' under certain conditions. Particularly promising results are seen for electric buses in public transport. As a general result, partly based on the experiences from the specific case, a generic community planning process model is proposed and its usefulness for sustainable transport system development is discussed.

The strategic sustainable development perspective of this thesis broadens the analysis beyond the more common focus on climate change issues and reduces the risk of sub-optimizations in community and transport system development. The generic support for multi-stakeholder collaboration could potentially also promote a more participatory democratic approach to community development, grounded in a scientific foundation. Future research will explore specific decision support systems for sustainable transport development based on the generic planning process model.

**Keywords:** Strategic Sustainable Development, Transport Planning, Electric Vehicles, Testing, LCA

## Thesis disposition

This thesis includes an introductory part and the following papers, which have been slightly reformatted from their original publication in order to fit the format of the thesis. The content of the papers, though, is unchanged.

### Paper 1:

Robèrt, K.-H., Borén, S., Ny, H., Broman, G., 2016. A strategic approach to sustainable transport system development - Part 1: Attempting a generic community planning process model. *Journal of Cleaner Production*. In press.

### Paper 2:

Borén, S., Robèrt, K.-H., Ny, H., Nurhadi, L., Broman, G., Trygg, L., 2016. A strategic approach to sustainable transport system development - Part 2: The case of a vision for electric vehicle systems in Southeast Sweden. *Journal of Cleaner Production*. In press.

### Paper 3:

Borén, S., Ny, H., 2016. A Strategic Sustainability and Life Cycle Analysis of Electric Vehicles in EU Today and by 2050. *Proceedings of the 18th International Conference on Sustainable Urban Transport and Environment (ICSUTE)*, Madrid, Spain, March 24-25, 2016. In press.

### Paper 4:

Nurhadi, L., Borén, S., Ny, H., 2014. Advancing from Efficiency to Sustainability in Swedish Medium-Sized Cities: An Approach for Recommending Powertrains and Energy Carriers for Public Bus Transport Systems. *Procedia - Social and Behavioral Sciences*. pp. 586–595.

### Paper 5:

Borén, S., Nurhadi, L., Ny, H., 2016. Preference of Electric Buses in Public Transport: Conclusions from Real Life Testing in Eight Swedish Municipalities. *Proceedings of the 18th International Conference on Sustainable Urban Transport and Environment (ICSUTE)*, Madrid, Spain, March 24-25, 2016. In press.

## Other Publications

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*. pp. 818–827.

Nurhadi, L., Borén, S., Ny, H., Larsson, T., n.d. Competitiveness and Sustainability Effects of Cars and their Business Models. *Journal of Cleaner Production*. In review.

Borén, S., Nurhadi, L., Ny, H., 2013. How can fossil fuel based public bus transport systems become a sustainable solution for Swedish medium-sized cities? *Poster at the 6th International Conference on Life Cycle Management (LCM)*, Gothenburg, Sweden, August 25-28, 2013.

## **Acronyms**

BEV	Battery Electric Vehicles
EV	Electric Vehicles
FSSD	Framework for Strategic Sustainable Development
ICEV	Internal Combustion Engine Vehicle
HFCEV	Hydrogen Fuel Cell Electric Vehicle
LCA	Life Cycle Assessment
SLCA	Strategic Life Cycle Assessment
SP	Sustainability Principle
TCO	Total Cost of Ownership

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# 1 Introduction

*This section introduces the reader to the subject of the thesis and informs about the embedded strategic sustainability approach and about the aim and scope.*

## 1.1 Background

Today's vehicles and the supporting infrastructure contribute greatly to society's sustainability challenges. Many stakeholders have become aware of this and have taken several initiatives for transforming the transport system. Many of the initiatives are focused on reducing the use of fossil fuels and emissions of greenhouse gases. For example, the Swedish parliament has decided on the target of a fossil independent vehicle fleet in Sweden by 2030 and a greenhouse gas neutral Swedish society by 2050 (Ministry of the Environment, 2011). Also the European Union has set some long-term targets, like reducing greenhouse gas (GHG) emissions with at least 40 % by 2030 and 80 % by 2050 (The European Commission, 2014). Several studies have suggested Electric Vehicles (EVs) as a long-term solution, mainly because of their high efficiency, very low emissions during drive, low noise levels, and the possibility to use renewable sources for their electricity (T. B. Johansson et al., 2013; Nurhadi et al., 2014). Existing goals and roadmaps see short-term solutions in biofuels and more efficient combustion engines, accompanied by increased use of public transport and less car travel (H. Johansson, 2012; T. B. Johansson et al., 2013; Sköldbberg et al., 2013; Ståhl et al., 2013; The European Commission, 2011). However, these goals and roadmaps are not ambitious enough in relation to the magnitude of the challenges and the urgency for actions. We are rapidly approaching biophysical tipping points beyond which self-reinforcing degradation of our global habitat will likely set off (Steffen et al., 2015). The existing goals and roadmaps mentioned above lack a sufficiently wide systems perspective. They focus mainly on the transport system in itself and often only on climate issues, or in some cases even only on carbon dioxide emissions. To reach the target of a greenhouse gas neutral Swedish society, and certainly to support the full scope of sustainability, it is important to consider the whole life-cycle of the vehicles and also the interaction between the transport sector and other sectors. There is otherwise a great risk for sub-optimizations and loss of pace in the transition. Development of transport systems is complicated also since there are many different stakeholders involved with different interests and perspectives. Methodological support for development of sustainable transport systems should therefore be based on scientific grounds and allow for differences in values to become clear, so that the values can be weighed against each other and discussed in relation to the scientific grounds.

## 1.2 A strategic sustainability perspective

All of the above motivates the use of the Framework for Strategic Sustainable development – FSSD (Broman and Robèrt, 2015) as a foundation for this thesis work, as it ensures a sufficiently wide and strategic systems perspective. It includes, for example, a unifying and operational definition of sustainability,

which is needed to facilitate coordinated collaboration across disciplines and sectors. The FSSD also provides guidelines for how any actor can create economically viable strategies that support society's fulfillment of the principled sustainability definition. Moreover, the FSSD has proven useful for analyzing and coordinating the use of various methods, tools and other support for sustainable development (Broman and Robèrt, 2015), and it has been used for sustainable transport system development (Alvemo et al., 2010; Borén, 2011; Cars et al., 2012). The first phase of a project called GreenCharge (2012) was a prominent example of when different local transport stakeholders got together and used the FSSD with the ambition to develop the transport system towards sustainability. This project therefore constituted a suitable case for this research (see below).

### 1.3 Aim and scope

To address the above-mentioned challenges and gaps, the overall aim of this thesis was to elaborate methodological support for development of sustainable personal road transport systems that is informed by a strategic sustainable development perspective. Most of the research was done within the above-mentioned GreenCharge project, which focused on conditions for a market breakthrough for electric road vehicles in the southeast region of Sweden. Because of its involvement of more than 20 companies, more than 25 municipalities, several county boards, county councils, and other stakeholders, the project represented a great test and development platform in relation to the overall aim of this thesis. Secondary aims, while pursuing the overall aim by means of this case, were to develop a vision of sustainable personal road transport in southeast Sweden and an initial development plan towards that vision, and specifically to explore the role of EVs in this context.

To guide the studies further, the aims were supplemented by the following research questions:

1. What methodological support can be elaborated for development of sustainable personal road transport systems based on a strategic sustainability perspective?
2. What might a vision for sustainable personal road transport in southeast Sweden look like, with a focus on EVs, and what might an initial development plan towards that vision look like?
3. What are the major sustainability effects of EV-based personal road transport systems, and what are the major barriers and enablers for development of such systems?

Because of the focus of the GreenCharge project, the test and application case of this research was limited to personal road transport with a focus on EV systems. The implications of this are discussed in section 4.

## 2 Research approach

*This section presents the frameworks that informed the research design and informs about the research methods,*

### 2.1 Research design and methods

The initial research design for this thesis followed the Maxwell Research Design guidelines (Maxwell, 2008), which covers goals, conceptual framework, methods, validity, and guiding questions that inform research questions (Figure 1).

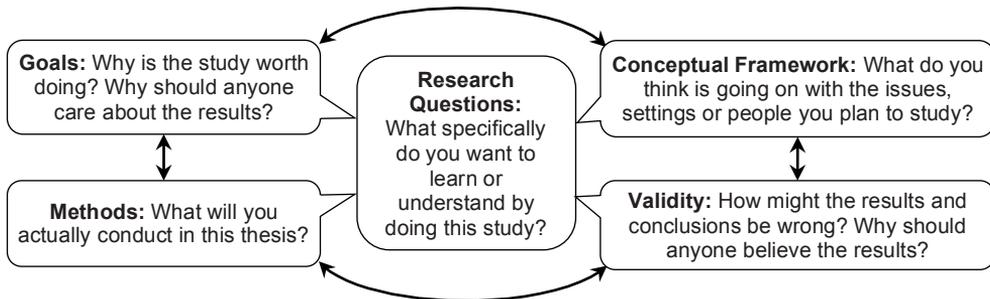


Figure 1: Topics in Maxwell's research design methodology. Developed from (Maxwell, 2008).

The topics and the guiding questions have been included in the research plan that framed the thesis and its research questions. As the GreenCharge project has framed most studies in this thesis, the goals have been directed by the GreenCharge research aim to develop a roadmap for fossil free transport by 2030 in southeast Sweden. Within that frame, the thesis has had a particular focus on vision design, on sustainability effects of EV-based personal road transport systems, and on finding barriers and enablers for development of such systems. Other goals that have affected the research design are; the author's personal desire to contribute to sustainable development of energy and transport systems, society's ambitions for sustainable development in all sectors, and the focus of Blekinge Institute of Technology on applied IT and innovation for sustainable growth (Ahlström, 2014). Mapping the conceptual framework was useful. Studies about what is going on in society regarding energy and vehicles in the context of sustainable transport development provided an important knowledge base. The FSSD is also a conceptual framework that informed the research. This is described in section 2.2. Methods used in this thesis are described later in this section, and validity is discussed in section 4.

Within the research design, the Design Research Methodology - DRM (Blessing and Chakrabarti, 2009) was used as an 'umbrella' to influence the design of the individual studies and thesis papers to quite evenly cover the DRM study phases 'Research Clarification', 'Descriptive 1', and 'Prescriptive 1' (Figure 2). As paper 4 was created first, it helped to refine the goal and focus of the research by literature studies. Previous studies on sustainable transport solutions (Alvemo et al., 2010; Borén, 2011) formed a knowledge base that was helpful throughout the thesis. A better understanding of the research topics was achieved during the

descriptive phase 1, where empirical data was analysed via Strategic Life Cycle Assessment (SLCA) and Life Cycle Assessment (LCA). During the prescriptive study phase, assumptions, experiences, and syntheses from each study contributed to finding the proposed solutions.

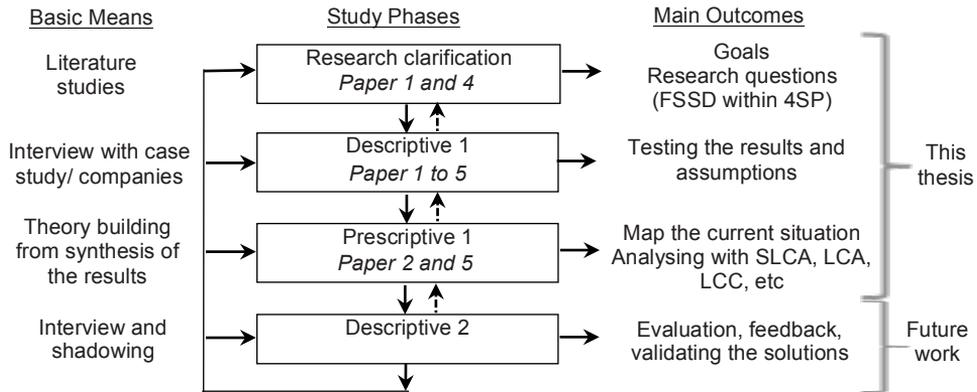


Figure 2: Mapping of thesis papers in DRM. Developed from (Blessing and Chakrabarti, 2009).

Another method for obtaining results in this thesis work was literature reviews via databases (e.g. Science Direct, Engineering Village, Web of Science, Elsevier, and Taylor Francis Online) and Internet search engines (e.g. Scopus, Summon, and Google Scholar). Literature has also been retrieved from authorities and institutional websites (e.g. Swedish Environmental Protection Agency, Swedish Transport Administration, European Commission, Universities, Swedish Environmental Institute, and Thomas D. Larson Pennsylvania Transport Institute). The research has included multi-stakeholder interviews and seminars with experts, decision-makers and other key stakeholders in transport planning in southeast Sweden. This has to a high extent informed the results in paper 1, 2, and 5 and to some extent the results in the other papers. Energy use data for electric buses was collected via measurement of charged electricity and elapsed distance, and noise was measured according to the UN standard ECE 51-02. Interviews of bus operators were used to estimate costs, and surveys were used to reveal passenger and driver opinions. Static calculations of environmental effects and costs were used in papers 3 and 4, and initial system dynamic simulations informed the results in paper 2. Logical argumentation was used especially in paper 1 and to some extent in the other papers.

## 2.2 Framework for strategic sustainable development

As mentioned in section 1.1, the FSSD (Broman and Robèrt, 2015) is designed to support planning towards a sustainable future. It is applicable in any area, including the transport area. It has been chosen as a foundation for this work for the reasons explained in the introduction (section 1.2). As shown in Figure 3, the FSSD includes a five-level model. The vision of success belongs to level 2 and is framed by sustainability principles (SPs).

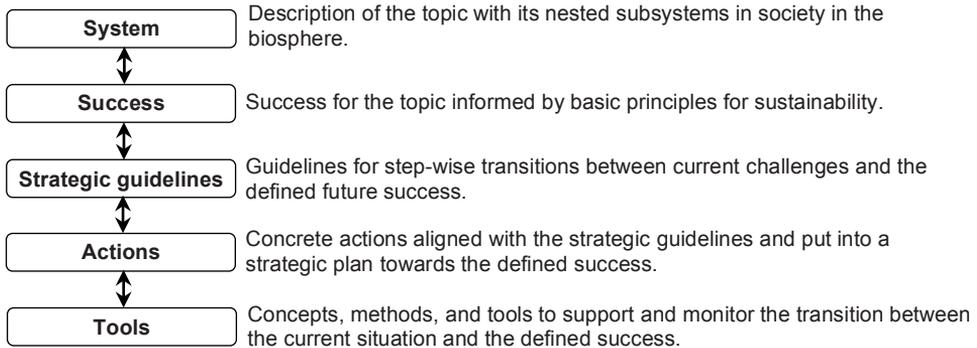


Figure 3: Levels of the FSSD (Broman and Robèrt, 2015), and descriptions (Lindah, 2013).

The social part of the sustainability definition (principle IV below) is currently being further elaborated (Missimer, 2015), but the following version of the SPs was used in this thesis (Ny et al., 2006):

“In a sustainable society, nature is not subject to systematically increasing . . .  
 I ... concentrations of substances extracted from the Earth’s crust,  
 II ... concentrations of substances produced by society,  
 III ... degradation by physical means, and in that society . . .  
 IV ... people are not subject to conditions that systematically undermine their capacity to meet their needs.”

The FSSD also includes an operational procedure – ABCD (Ny et al., 2006; Broman and Robèrt, 2015), illustrated in Figure 4.

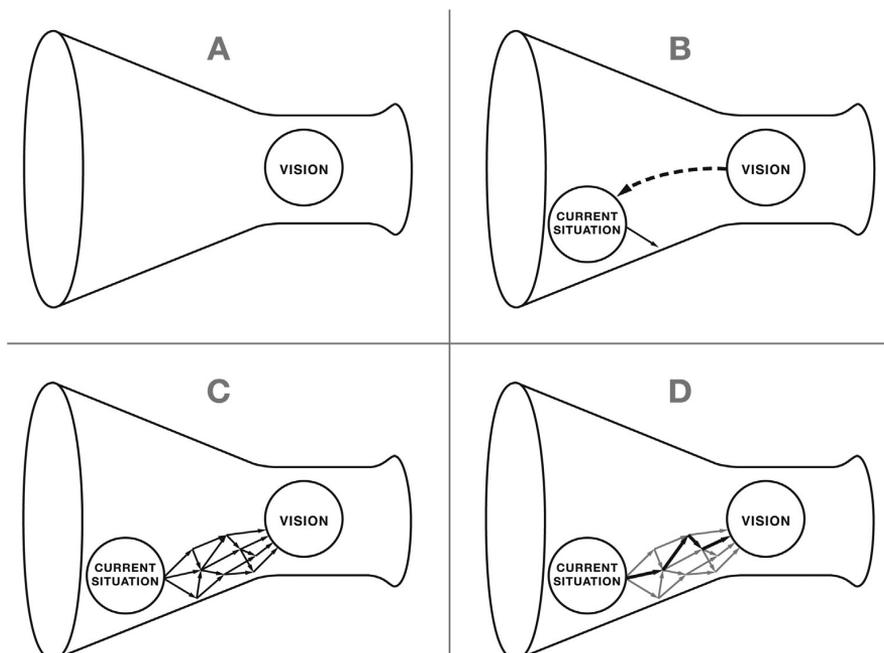


Figure 4: The funnel metaphor and the ABCD-procedure of the FSSD. Reprinted from Broman and Robèrt (2015), page 5, with permission from Elsevier.

The FSSD supports organizations in creative co-creation of strategic transitions through backcasting planning and redesign for sustainability. It has informed the structure and the flow of this thesis work and was used in particular in papers 1 and 2. As described by Broman and Robèrt (2015), the inclined funnel wall in Figure 4 clarifies the systematic character of the challenge as well as the self-benefit of having and working towards a sustainable vision (avoiding hitting the wall of the funnel while moving to the vision in the opening of the funnel). A sustainable vision is captured in (A). The current challenges and assets in relation to the vision are captured in (B). Possible steps towards the vision are captured in (C), and these are prioritized into a strategic plan in (D).

The methods used for sustainability analysis when comparing different vehicles in papers 3 and 4 enhance the baseline analysis (B) in the ABCD procedure. The SLCA (Ny et al., 2006; Gunnarsson, 2010) used in papers 3 and 4 is an overarching method to assess social and ecological sustainability aspects. It allows for a quick identification of the most important high-level sustainability challenges, which can guide necessary decisions and activities and, if needed, additional analyses. The SLCA displays the ‘hot-spot’ issues that are particularly important for sustainable development. Based on the SLCA results, further studies in papers 3 and 4 were done via LCA (ISO, 2006) to quantify environmental impacts, and the use of energy, materials and land. This goes beyond the limits of a traditional Well-to-Wheel analysis that is otherwise commonly used in the transport sector. Total cost of ownership based on Life Cycle Costing (LCC) (ISO, 2008) was used in paper 4 to include costs caused by different vehicles, and externalities (partly covered by emission costs). The integration of the methods mentioned above is explained in Figure 5. The use of these methods is further described in each paper.

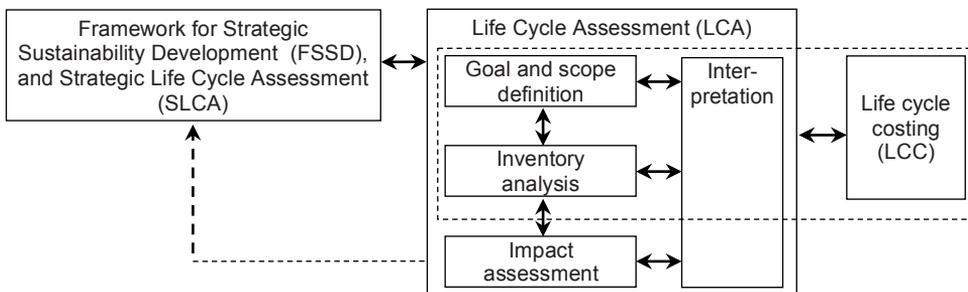


Figure 5: How an iterative approach uses SLCA to scope LCA and LCC analysis (Paper 4).

### 3 Summary of appended papers

*This section presents summaries of the appended papers, a short description of the relation of the respective paper to the thesis, and the present author's contribution to each paper.*

#### 3.1 Paper 1 and 2

*A strategic approach to sustainable transport system development*

*- Part 1: attempting a generic community planning process model*

*- Part 2: the case of a vision for electric vehicle systems in Southeast Sweden*

Submitted as:

Robèrt, K-H. Borén, S., Ny, H. Broman, G., 2016. A strategic approach to sustainable transport system development - Part 1: attempting a generic community planning process model. *Journal of Cleaner Production*. In press.

Borén, S. Robèrt, K-H. Ny, H. Nurhadi, Broman, G. Trygg, L., 2016. A strategic approach to sustainable transport system development - Part 2: the case of a vision for electric vehicle systems in Southeast Sweden. *Journal of Cleaner Production*. In press.

#### **Summary**

Paper 1 in this tandem publication presents an iterative multi-stakeholder planning process model (Figure 6) that embeds the FSSD and includes four interdependent planning perspectives ('Resource base', 'Spatial', 'Technical', and 'Governance'). The new process model proved helpful by giving diverse stakeholders with various competences and representing various planning perspectives a common, robust, and easy-to-understand goal and a way of working that was adequate for each of their contexts. In the study presented in paper 2, the process model was applied in cross-sector collaboration among transport stakeholders to develop a sustainable vision for EVs in southeast Sweden. It resulted in a vision of sustainable transport, with a focus on EV systems, within each planning perspective, and an initial development plan towards that vision (Figure 6). Through analyses of strengths, weaknesses and solutions, the seminar participants also identified some major barriers and enablers for EV-system development. Examples of barriers include high prices of EVs and the use of scarce metals in batteries. Examples of enablers include expansion of electricity production based on renewable energy, expansion of charging infrastructures, and extensive recycling of materials. The vision and plan imply a shift to renewable energy and a more optimized use of areas and thus a new type of spatial planning. For example, the vision and plan imply a lower built-in demand for transport, more integrated traffic modes, and more multi-functional use of areas for energy and transport infrastructures. Some inherent benefits of electric vehicles are highlighted in the vision and plan, including near-zero local emissions and flexibility as regards primary energy sources. The vision and plan also imply improved governance for more effective cross-sector

collaboration to ensure coordinated development within the transport sector and between the transportation sector and other relevant sectors. After refinement, the authors also suggested that the planning process model could be applicable to strategic sustainable community planning in any societal sector.

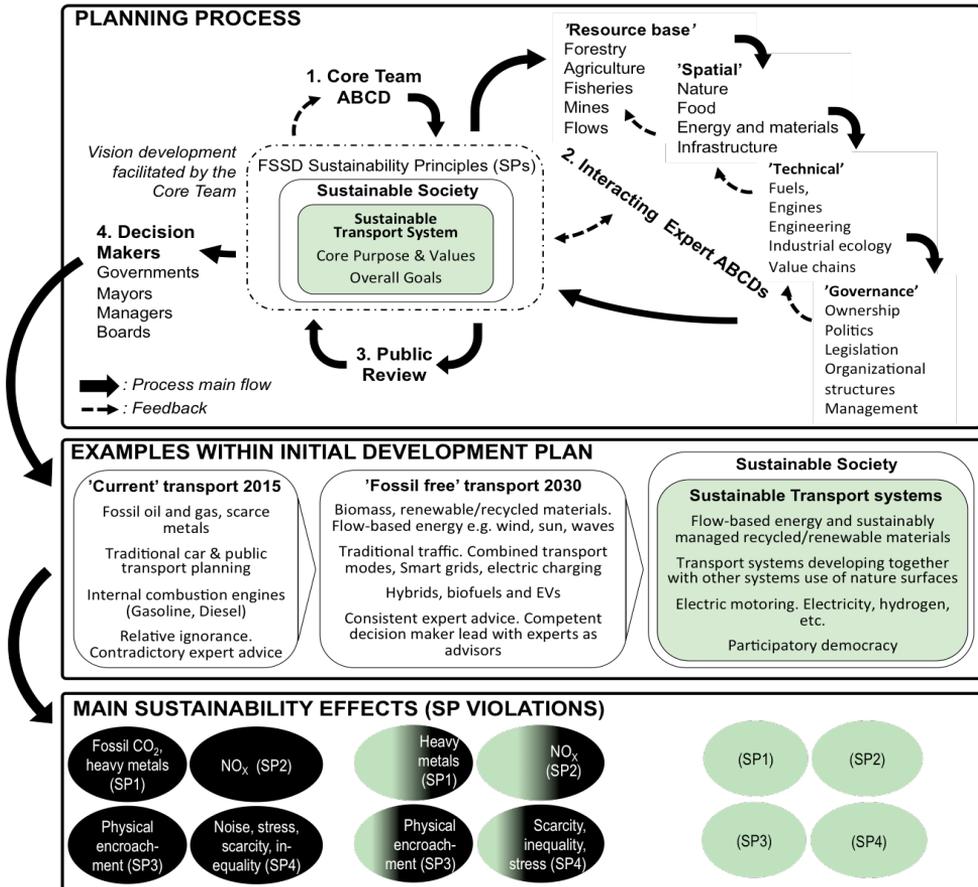


Figure 6: How the iterative process applied on road transport (top) can result in transport system development (centre), gradually phasing out the main sustainability effects (bottom) (Paper 2).

### Relation to the thesis

The work presented in this tandem publication included development and testing of a process model for enhancement of transport planning towards sustainability, and resulted in a vision and preliminary roadmap for how electric vehicles and transport systems at large can be developed to fit into a sustainable society. This is strongly related to the FSSD and specifically its ABCD procedure (Section 2). The result answers the first and the second research questions, and also informs answers to the third research question.

### Author’s contribution

The author of this thesis led the planning and writing process of both papers, took part in the creation of results, managed seminars, compiled results, and finalised the papers after feedback from co-authors.

### 3.2 Paper 3

#### *A strategic sustainability and life cycle analysis of electric vehicles in EU today and by 2050*

Published as:

Borén, S., Ny, H., 2016. A Strategic Sustainability and Life Cycle Analysis of Electric Vehicles in EU today and by 2050, *Proceedings of the 18th International Conference on Sustainable Urban Transport and Environment (ICSUTE)*, Madrid, Spain, March 24-25, 2016. In press.

#### Summary

In this study, sustainability effects of internal combustion engine vehicles (ICEVs) and EVs were compared, in the EU context today and by 2050. SLCA results revealed the major SP effects of today's ICEVs, battery electric vehicles (BEVs), and hydrogen fuel cell electric vehicles (HFCEVs) (Table 1). These were related to the current use of fossil fuels and scarce materials for batteries and fuel cells, and also during most life-cycle phases for all vehicles when fossil fuels are used in mining, production and transport. Still, the studied current BEVs and HFCEVs had less severe violations than fossil fuel cars.

Table 1: Strategic life cycle assessment identifying the major SP effects of today's ICEVs, BEVs, and HFCEVs. Adapted from paper 3.

Life cycle phase	SP effects by ICEV powered by fossil fuels	SP effects by BEV powered by wind-generated electricity	SP effects by HFCEV powered by hydrogen produced from renewable fuels and wind-generated electricity	Sustainability Principle
Extraction	Negative	Negative	Negative	SP1 
Production	Negative	Negative	Negative	
Distribution	Negative	Negative	Negative	
Use	Negative	Negative	Negative	
Waste	Negative	Negative	Negative	
Extraction	Negative	Negative	Negative	SP2 
Production	Negative	Negative	Negative	
Distribution	Negative	Negative	Negative	
Use	Negative	Negative	Negative	
Waste	Negative	Negative	Negative	
Extraction	Negative	Negative	Negative	SP3 
Production	Negative	Slightly negative	Slightly negative	
Distribution	Negative	Negative	Negative	
Use	Negative	Negative	Negative	
Waste	Negative	Negative	Negative	
Extraction	Negative	Negative	Negative	SP4 
Production	Negative	Negative	Negative	
Distribution	Negative	Negative	Negative	
Use	Negative	Negative	Negative	
Waste	Negative	Negative	Negative	

Legend: Negative Slightly negative Neutral

An LCA, including uncertainty considerations, then quantified environmental impacts within these sustainability violations. For example, the LCA showed that BEVs charged with electricity from the EU-27 electricity grid have less life-cycle climate change impact and overall less life-cycle environmental impact than

ICEVs powered by petrol. On the other hand, they have 50 % higher climate change impact and overall higher life-cycle environmental impact than BEVs charged with electricity generated from wind turbines.

By 2050, there will likely be even more EVs with low sustainability impacts. Then the EU electricity mix should mainly stem from renewable sources, batteries should be recycled, fuel cells should be a mature technology for vehicles (containing no scarce materials), and electric motors should have replaced combustion engines in other sectors. An uncertainty for fuel cells in 2050 is whether the production of hydrogen will have had time to switch to renewable resources. If so, that would contribute even more to sustainable development.

### **Relation to the thesis**

Results in this paper contribute to the identification of current EV systems' sustainability effects, and to the identification of barriers and enablers for EV system development, by comparing cars with different powertrains, and then discuss this comparison in relation to a future scenario directed by EU 2050 energy goals. The results fit into the current reality mapping (B-step) and partly into the identification of solutions towards sustainability (C-step) of the ABCD procedure (Section 2). With regards to EVs in general and their lifecycle environmental impact, the results partly answer the second and third research questions.

### **Author's contribution**

The author of this thesis led the planning and writing process, created the results by co-creation with colleagues, finalised the paper after feedback from co-authors, and will present the paper at the ICSUTE conference in Madrid in 2016.

## **3.3 Paper 4**

*Advancing from efficiency to sustainability in Swedish medium-sized cities: an approach for recommending powertrains and energy carriers for public bus transport systems*

Published as:

Nurhadi, L., Borén, S. & Ny, H., 2014. Advancing from Efficiency to Sustainability in Swedish Medium-sized Cities: An Approach for Recommending Powertrains and Energy Carriers for Public Bus Transport Systems. *In Procedia - Social and Behavioral Sciences*. pp. 586–595.

### **Summary**

In this study, the authors first used an integrated sustainability perspective to build and test a new assessment approach using the FSSD and SLCA to scope an integrated LCA and LCC analysis, which should enhance decisions on bus transport powertrains and energy carriers for Swedish medium-sized cities. Then SLCA and LCA were used to compare energy carriers for combustion engine buses, hybrid buses, and electric buses.

The study shows that electric buses are beneficial from a strategic sustainability and life-cycle perspective, need up to 80 % less energy, have much lower life-cycle emissions (Figure 7), and have lower noise levels than diesel buses. The hybrid powertrain would on average reduce life-cycle emissions by almost 40 % compared to the diesel powertrain. The corresponding number for the plug-in hybrid is around 70 %. Plug-in life-cycle energy efficiency is almost 60 % better than for the diesel powertrain. Moreover, the LCC showed that electric buses, within an eight-year perspective in Karlskrona, had up to 25 % lower total cost of ownership than diesel buses.

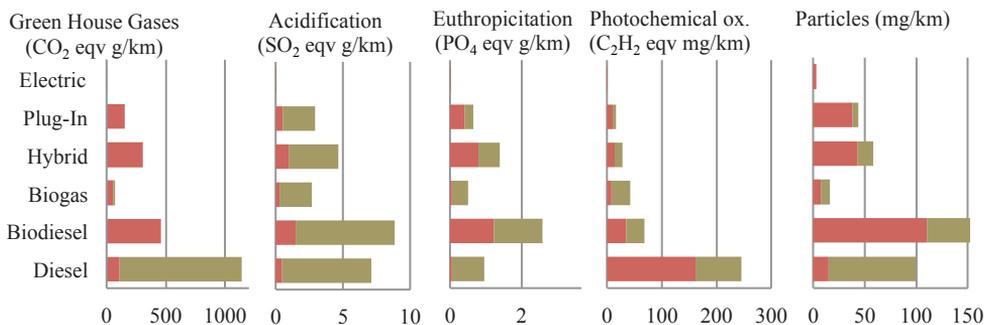


Figure 7: Life cycle emission per energy carrier in Extraction to Distribution phase (green) and Use phase (red) (Paper 4).

The study assumed a conservative development of energy costs and real interest rates in line with historical patterns, and that the electric bus is charged with electricity produced by new wind power plants in a way that does not decrease the share of electricity produced from renewable sources in the grid.

### Relation to the thesis

The contribution to the thesis is mainly related to the current reality mapping and partly to finding solutions towards sustainability by calculations of different bus energy carriers' impacts and contribution to the sustainability and cost perspectives. These findings provided a base of knowledge for research about public transport and electric buses, and their sustainability effects. The findings also provided a base for research about barriers and enablers for EV system development. With regards to electric buses and life-cycle environmental impact, the results answers the third research question, and informs answers to the second research question.

### Author's contribution

The author of this thesis took part in the planning and had a great part in writing and finalising the text and illustrations, created results and illustrations for the SLCA and LCA, and supported the Total Cost of Ownership Analysis. The authors then presented the paper as a poster at the Life Cycle Management conference in Gothenburg in 2013 and several times in regional conferences.

### 3.4 Paper 5

#### *Preferences of electric buses in public transport; conclusions from real life testing in eight Swedish municipalities*

Submitted as:

Borén, S., Nurhadi, L., Ny, H., 2016. Preference of Electric Buses in Public Transport; Conclusions from Real Life Testing in Eight Swedish Municipalities, *Proceedings of the 18th International Conference on Sustainable Urban Transport and Environment (ICSUTE)*, Madrid, Spain, March 24-25, 2016. In press.

#### **Summary**

In this study, the authors aimed to verify calculations in the previous theoretical study in paper 4 by real-life testing of an electric bus during wintertime in eight Swedish municipalities. The average energy use in urban traffic was found to be 0.96 kWh/km (Table 2), which is 8 % lower than assumed in paper 4. The tested bus had a range of about 320 km in cities and 350 km in rural areas. The total cost of ownership (TCO) calculation in paper 1 was updated and found to be slightly lower. The TCO is 25 % lower for electric buses than for diesel buses. Testing, literature reviews, and interviews of passengers and drivers led to the conclusion that the noise level outside the electric bus in slow traffic and during acceleration was lower than for combustion engine powered buses. Passenger and driver interviews also revealed that the electric bus not only runs smoother than an internal combustion engine bus, but it might also, due to its higher popularity, be able to increase the use of public transport. Bus operators highlighted that uncertain costs for electric buses (e.g. for education and maintenance) have to be considered in the procurement process. Public transport authorities pointed out a need for decision support for how to design the bus system regarding range and charging facilities. The possibilities for establishing a charging infrastructure at the tested bus lines were deemed good. The study concluded that electric buses have a great potential to function well in current and future public transport while contributing to sustainable development and a lowered TCO.

Table 2: Average energy use results in each municipality and average results for use in urban traffic (Paper 5).

Municipality	Period	Drivers <sup>a</sup>	Line	Outdoor temp. (°C)	Rain/snow	Distance (km)	Average energy use (kWh/km)
Kalmar	17-18 Dec	5 <sup>b</sup>	401, 411, 412	+1 to +3	No	336	0.90
Jönköping	5-13 Jan	4	1, 3, 12, 18	-2 to +4	Some	1038	0.97
Borås	16-25 Jan	30	1	-1 to +3	Some	1235	1.02
Eskilstuna	3-5,10-12 Mar	3	1, 2, 4, 31	+1 to +10	No	900	0.90
Karlskrona	9-10 Apr	6	1	+10 to +12	No	514	0.96
<b>Sum urban traffic</b>						<b>4023</b>	<b>0.96</b>
Lerum	2-11 Feb	1	525, 526, 532	-6 to +5	Some snow	1824	0.93
Orust	16-26, 28 Mar	1	Göksäterlinjen	0 to +5	Some	2123	0.86

<sup>a</sup> According to number of survey responses

<sup>b</sup> Total number of drivers that answered the survey during the entire test period

### **Relation to the thesis**

The study contributes to the mapping of current perceptions of the electric bus and how well it works in regular bus traffic among public transport authorities, passengers, operators, and other stakeholders. Barriers and enablers for further implementation were found among bus operators and public transport authorities. The study also verified calculations in paper 4 by determining the energy use of the electric bus during the winter in the south of Sweden, and noise from electric, hybrid and diesel buses. Further findings were more practical facts and data of electric buses when used today and suitable timing of implementation in public transport. With regards to electric buses, the result contributes to answers to the third research question.

### **Author's contribution**

The author of this thesis led the planning and writing process as well as the planning, realisation and compilation of the results, finalised the paper after feedback from co-authors, presented the preliminary results at a Nordic seminar in Oslo 2015, and will present the paper at the ICSUTE conference in Madrid in 2016.

## 4 Discussion

*This section discusses the results and their validity, compares the results with those of other related studies, gives key conclusions, and points to further work.*

### 4.1 Aim fulfilment and answers to research questions

The aims of this licentiate thesis are reflected in the research questions presented in section 1.3. The following reasoning shows how the results of this thesis provide answers to these questions:

1. A methodological support for sustainable transport system development was elaborated. It comprises an iterative multi-stakeholder planning process model embedding the FSSD, and includes four independent planning perspectives (further described in paper 1). Because of the embedment of the FSSD, the methodological support is capable of guiding planning for transport system development and other community development from a strategic sustainability perspective. The initial testing through a real case indicates that the support works as intended.
2. By applying the iterative process model elaborated in paper 1, a sustainable vision and an initial development plan were developed for transport in southeast Sweden, with a focus on EVs for personal road transport. The initial plan leads successively towards such a vision, which includes; sustainably managed and sourced energy and materials; optimized use of areas; a small share of hybrids and bio-fuelled vehicles that complement the otherwise electrified vehicle fleet; governance for effective cross-sector collaboration (further described in paper 2). The broad array of involved stakeholders in southeast Sweden has generally acknowledged the vision and initial development plan as being relevant and anchored in the region.
3. Major sustainability effects of EV-based personal road transport systems were found (mainly related to the use of fossil fuels and scarce materials). Barriers (mainly related to high prices of EVs and to the use of scarce metals in batteries) and enablers (mainly related to expansion of electricity production based on renewable energy, expansion of charging infrastructures, and extensive recycling of materials) for development of EV-based personal road transport systems were also found. .

### 4.2 Validity considerations and comparisons with other studies

Anyone using the results of this thesis should though be aware of the following:

- The technology development is fast in regard to charging and energy storage in batteries and fuel cells. This might call for an update of the results.
- The theoretical bus study (paper 4) is based on data from previous decade(s) and the current EURO 5 regulation lower emissions from ICEVs considerably. The LCC results may also change depending on shifts in the

financial market, but the study results are anyhow expected to be useful for strategic purposes due to the inherent advantages of electric vehicles, (e.g. lower noise, higher energy efficiency and the possibilities to reach fossil fuel independency).

- The testing of the electric bus in Jönköping (paper 5) could have been more thorough and could then have been used to verify the energy use calculations in paper 1. Nevertheless, the average test results from the electric bus use in the other cities can be used for further studies also in Jönköping.
- LCA data for HFCEV (paper 3) could have been more aligned with other data if they, along with the other data in the study, had come from the Ecoinvent 3.1 database and the ReCiPe assessment method. The inclusion of the HFCEV data in the paper was considered precise enough, though, for the purpose of the study.
- The EV vision and the coarse initial roadmap (paper 2) should be tested and anchored further. This will be done in upcoming research at BTH. Generally, it should be noted that the proposed new methodological support has so far been tested mainly in the context of the GreenCharge project, having a focus on personal road transport and EV systems in southeast Sweden. This implies a limitation from a validity point of view. However, since the support embeds the well-validated FSSD, it is likely more generally applicable, but, of course, this cannot be claimed with full confidence until the support has been tested more comprehensively.

In the research community there is currently a focus on climate change effects caused by road transport, often quantified by carbon dioxide emissions during the vehicle's use phase. Some studies include a life-cycle perspective, usually by using a Well-to-Wheel approach (Edwards et al., 2014; Reis, 2010) where environmental impacts typically exclude the disposal and production of vehicles. The FSSD, on the other hand, includes a science-based all-encompassing principled definition of sustainability, where SP 1-3 focus on environmental impacts and SP 4 focuses on social impacts. A few of the most comprehensive LCA studies found (e.g. Bartolozzi et al., 2013; Girardi et al., 2015; Messagie et al., 2014; Offer et al., 2010) cover most of the impacts related to SP 1-3, but still lack analysis of social sustainability impacts. Nevertheless, the results from these LCA studies have been helpful for verification of the LCA results of this thesis work (papers 3 and 4). Differences in results are mainly related to prerequisites and assumptions for each LCA. Moreover, several roadmaps have been published lately that include the development of electric vehicles, which primarily estimate the vehicles' environmental effects in terms of carbon dioxide emissions (H. Johansson, 2012; T. B. Johansson et al., 2013; Sköldberg et al., 2013; Ståhl et al., 2013; The European Commission, 2011). By using FSSD-informed methods and tools, such as SLCA, this thesis goes beyond other studies to include a full

systems perspective and strategic planning towards a future where no SPs are violated.

### **4.3 Conclusion and future research**

The strategic sustainable development perspective of this thesis broadens the analysis beyond the more common focus on climate change issues and reduces the risk of sub-optimizations in community and transport system development. The generic support for multi-stakeholder collaboration could potentially also promote a more participatory democratic approach to community development, grounded in a scientific foundation.

Future research could explore specific decision support systems for sustainable transport development based on the generic planning process model presented in this thesis. Other further work based on the thesis, such as roadmap design, should also consider the thesis by Nurhadi (2015), which is focused on business models for EV systems. It is also proposed that future studies should include more modes of transportation, on land and at sea, as their integration with road transport of people likely would facilitate higher total system efficiency.

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## ABSTRACT

Electric vehicles can play an important role in a future sustainable road transport system and many Swedish politicians would like to see them implemented faster. This is likely desirable to reach the target of a fossil independent vehicle fleet in Sweden by 2030 and a greenhouse gas neutral Swedish society no later than 2050. However, to reach both these targets, and certainly to support the full scope of sustainability, it is important to consider the whole life-cycle of the vehicles and also the interaction between the transport sector and other sectors. So far, there are no plans for transitions towards a sustainable transport system applying a sufficiently wide systems perspective, in Sweden or elsewhere. This implies a great risk for sub-optimizations.

The overall aim of this work is to elaborate methodological support for development of sustainable personal road transport systems that is informed by a strategic sustainable development perspective.

The Framework for Strategic Sustainable Development (FSSD) is used as a foundation for the work to ensure a sufficiently wide systems perspective and coordinated collaboration across disciplines and sectors, both in the research and application. Maxwell's Qualitative Research Design and the Design Research Methodology are used as overall guides for the research approach. Specific research methods and techniques include literature studies, action research seminars, interviews, and measurements of energy use, costs, and noise. Moreover, a case study on the conditions for a breakthrough for vehicles in southeast Sweden has been used as a test and development platform.

Specific results include a preliminary vision for electrical vehicles in southeast Sweden, framed by the principled sustainability definition of the FSSD, an assessment of the current reality in relation to that vision, and proposed solutions to bridge the gap, organized into a preliminary roadmap. The studies show that electric vehicles have several sustainability advantages even when their whole life-cycle is considered, provided that they are charged with electricity from new renewable sources. Electrical vehicles also imply a low total cost of ownership and could promote new local 'green jobs' under certain conditions. Particularly promising results are seen for electric buses in public transport. As a general result, partly based on the experiences from the specific case, a generic community planning process model is proposed and its usefulness for sustainable transport system development is discussed.

The strategic sustainable development perspective of this thesis broadens the analysis beyond the more common focus on climate change issues and reduces the risk of sub-optimizations in community and transport system development. The generic support for multi-stakeholder collaboration could potentially also promote a more participatory democratic approach to community development, grounded in a scientific foundation. Future research will explore specific decision support systems for sustainable transport development based on the generic planning process model.

