Pathways to a renewable road transport system in Stockholm 2030

Linnea Hjalmarsson
Mårten Larsson
Linda Olsson
Martina Wikström

Arbetsnotat Nr 48
November 2011
ISSN 1403-8307

Värmeteknik och maskinlära Chalmers
Tema Teknik och social förändring LiU
Teknikvetenskapar UU
Energiprocesser KTH
Energisystem LiU
Foreword

This study is the result of the course *Tvärprojekt i energisystem*, which is part of the interdisciplinary postgraduate school Energy Systems Programme, financed by the Swedish Energy Agency.

The authors wish to thank supervisors Per Alvfors, Jenny Palm and Louise Trygg for valuable input during the project, as well as the directorate of the Energy Systems Programme and the Swedish Energy Agency for the opportunity to engage in this interdisciplinary project. Thanks also to the Local and regional consortium within the Energy Systems Programme and other associates for insightful comments and suggestions.

The authors of this study are:

- Linnea Hjalmarsson, MSc in Policy Analysis and Political Science, Department of Thematic Studies, Division of Technology and Social Change, Linköping University
- Mårten Larsson, MSc in Engineering Biology, Department of Chemical Engineering, Division of Energy Processes, Royal Institute of Technology
- Linda Olsson, MSc in Applied Physics and Electrical Engineering, Department of Management and Engineering, Division of Energy Systems, Linköping University
- Martina Wikström, MSc in Chemical Engineering, Department of Chemical Engineering, Division of Energy Processes, Royal Institute of Technology
Summary

In order to mitigate global climate change, anthropogenic emissions of fossil carbon dioxide (CO$_2$) need to be cut drastically. Road transport is a major source of CO$_2$ emissions, and in urban areas road transport also involves problems such as congestion, noise and particle emissions. Stockholm, the Swedish capital and one of the busiest regions in Sweden, has the ambition to be a pioneer in addressing environmental problems; CO$_2$ emissions in particular. One of the political visions incorporated in Stockholm’s environmental work is to achieve a practically renewable transport system by 2030.

This study investigates if there are favourable conditions to achieve a renewable road transport system in Stockholm by 2030. Three aspects are considered; technology, private economy and regional planning policy. The study is based on three sub-studies, one for each aspect, and conclusions are drawn from the integration of the sub-studies. A scenario assessment implies that the technology to transit to a completely renewable road transport system could exist, and that a mix of technologies would be preferable. Cost optimisations show that renewable fuels and electric vehicles are cost-competitive given certain incentives. Hence, private persons could shift their transportation choices towards alternative vehicles and fuels. Interviews with regional institutional actors and analysis of regional planning documents reveal that integrating energy and transport systems in planning policy could enable the transition to a renewable road transport system in Stockholm. The work has been carried out under the auspices of The Energy Systems Programme (primarily financed by The Swedish Energy Agency).

The study concludes that favourable conditions for a renewable road transport system do exist. However, the main challenge is to coordinate the simultaneous implementation of necessary measures and the study shows that this is best organised at a regional level.
### Acronyms and abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Ampere</td>
</tr>
<tr>
<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>AD</td>
<td>Anaerobic digestion</td>
</tr>
<tr>
<td>BEV</td>
<td>Battery Electric Vehicle</td>
</tr>
<tr>
<td>CI</td>
<td>Compression ignition</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>CO₂-eq</td>
<td>Carbon dioxide equivalents</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DISI</td>
<td>Direct injection spark ignition</td>
</tr>
<tr>
<td>DME</td>
<td>Dimethyl ether</td>
</tr>
<tr>
<td>e.g.</td>
<td>Exempli gratia – for example</td>
</tr>
<tr>
<td>E85</td>
<td>Ethanol 85 %, petrol 15 %</td>
</tr>
<tr>
<td>E95</td>
<td>Ethanol 95 %, additives 5 %</td>
</tr>
<tr>
<td>ETC</td>
<td>European transient cycle</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>EV</td>
<td>Electric Vehicle</td>
</tr>
<tr>
<td>FAME</td>
<td>Fatty acid methyl esters</td>
</tr>
<tr>
<td>FT</td>
<td>Fischer-Tropsch</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse gas</td>
</tr>
<tr>
<td>GP</td>
<td>Glow-plug</td>
</tr>
<tr>
<td>Ha</td>
<td>Hectars</td>
</tr>
<tr>
<td>HDT</td>
<td>Heavy-Duty Trucks</td>
</tr>
<tr>
<td>HPC</td>
<td>Heavy Passenger Cars</td>
</tr>
<tr>
<td>ICE</td>
<td>Internal combustion engine</td>
</tr>
<tr>
<td>IEA</td>
<td>International Energy Agency</td>
</tr>
<tr>
<td>LCA</td>
<td>Life cycle assessment</td>
</tr>
<tr>
<td>LDT</td>
<td>Light-Duty Trucks</td>
</tr>
<tr>
<td>Li-ion</td>
<td>Lithium-ion</td>
</tr>
<tr>
<td>LPC</td>
<td>Light Passenger Cars</td>
</tr>
<tr>
<td>MJ</td>
<td>Megajoule</td>
</tr>
<tr>
<td>NEDC</td>
<td>New European driving cycle</td>
</tr>
<tr>
<td>PHEV</td>
<td>Plug-in Hybrid Electric Vehicles</td>
</tr>
<tr>
<td>PISI</td>
<td>Port injection spark ignition</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate matter</td>
</tr>
<tr>
<td>RME</td>
<td>Rapeseed methyl esters</td>
</tr>
<tr>
<td>RUFS 2010</td>
<td>Regional Development Plan of the County of Stockholm 2010 (Regional utvecklingsplan för Stockholmsregionen)</td>
</tr>
<tr>
<td>SI</td>
<td>Spark ignition</td>
</tr>
<tr>
<td>SL</td>
<td>Stockholm Public Transport</td>
</tr>
<tr>
<td>TTW</td>
<td>Tank-to-wheel</td>
</tr>
<tr>
<td>TWh</td>
<td>Terawatt hours</td>
</tr>
<tr>
<td>V</td>
<td>Volt</td>
</tr>
<tr>
<td>WHWC</td>
<td>World harmonised vehicle cycle</td>
</tr>
<tr>
<td>WTT</td>
<td>Well-to-tank</td>
</tr>
<tr>
<td>WTW</td>
<td>Well-to-wheel</td>
</tr>
</tbody>
</table>
# Table of content

1 **Introduction to study object** ................................................................................................................. 1  
1.1 Purpose of study ...................................................................................................................................... 2  
1.2 Accomplishment of the study .............................................................................................................. 2  
1.3 The energy- and transport system ...................................................................................................... 3  
1.4 Methods used in the study ................................................................................................................... 8  
1.5 Disposition ............................................................................................................................................ 8  

2 **Background** .......................................................................................................................................... 9  
2.1 Short introduction to transport policies at EU and national level ...................................................... 9  
2.2 Stockholm ............................................................................................................................................. 11  
2.3 Institutional planning background ..................................................................................................... 13  
2.4 Renewable fuels and vehicle technology background ....................................................................... 17  

3 **Literature study as basis for assumptions** ......................................................................................... 30  
3.1 Vehicles and fuels ................................................................................................................................. 30  
3.2 Fuel economy ........................................................................................................................................ 30  
3.3 Studies on future use of biofuels in the Swedish transport sector .................................................... 31  
3.4 Well to wheel energy and green house gas emissions ....................................................................... 32  
3.5 Biofuel production potential in the region of Mälardalen .................................................................. 33  

4 **Regional planning for the introduction of an energy efficient and renewable road transport system** ................................................................................................................................. 36  
4.1 Interviews and document study - method ........................................................................................... 36  
4.2 Visionary and governing documents ............................................................................................... 39  
4.3 Behind the documents – results from interviews .............................................................................. 47  
4.4 Planning for an energy efficient and renewable transport system – discussion ............................... 60  
4.5 Concluding remarks ........................................................................................................................... 68  

5 **Assessment of the impact of private economy on Stockholm’s car and motorcycle fleet** ............. 69  
5.1 Modelling cost scenarios – Scenarios and input data ........................................................................ 69  
5.2 Modelling cost scenarios – Limitations ............................................................................................. 72  
5.3 Modelling cost scenarios – Results ................................................................................................... 72  
5.4 Modelling cost scenarios – Conclusions ............................................................................................ 76  

6 **Scenario assessment** ........................................................................................................................... 77  
6.1 Scenario assessment input data ......................................................................................................... 78  
6.2 Scenario assessment output data ...................................................................................................... 81  
6.3 Assessing the scenarios ..................................................................................................................... 85  
6.4 Conclusions from scenario assessment ............................................................................................ 87  

7 **Interdisciplinary discussion** ................................................................................................................ 88  
7.1 Is it possible to achieve a renewable transport system in Stockholm 2030? .................................. 88  
7.2 Implications for the energy and transport systems .......................................................................... 89  
7.3 General aspects on energy use in the transport system .................................................................... 94  
7.4 Other studies ....................................................................................................................................... 96  

8 **General conclusions** .......................................................................................................................... 97  

9 **Future work and lessons learned** ....................................................................................................... 99  
9.1 Working in an interdisciplinary team ............................................................................................... 99  

10 **References** ........................................................................................................................................ 100
1 Introduction to study object

In a carbon-restrained world, the anthropogenic emissions of fossil carbon dioxide (CO\textsubscript{2}) need to be cut drastically. This is foremost an issue for the heavy fossil-dependent transport sector, where fossil-based fuels today accounts for 98 % worldwide (IPCC, 2007) and 92 % in Sweden (Energimyndigheten, 2010), of total energy use. Road transport constitutes for the major part of the transport sector and is considered more carbon-dense than the system in general.

In sensitive urban areas, emissions (both molecular and noise) are an increasing problem, decreasing the quality of life for the inhabitants and cause damage on the built environment. The prerequisites for a transition to a more attractive environment in the city are better compared to other areas. Thus, at dense areas, the inventions can be made in an efficient way given the political will to decide exists.

Oil is the dominating source of energy in road transport. As Sweden has no domestic oil sources, the road transport system is dependent on expensive oil import. By switching to other fuels, energy security could be enhanced. Sweden has abundant biomass resources and good possibilities for producing electricity with low CO\textsubscript{2} emissions, so fuels could be produced domestically. Biomass and biofuels could even be exported, generating income. Regional fuel self-sufficiency could be an important reason to increase both production and consumption of biofuels.

The Swedish Ministry of Environment emphasises the importance of a fossil fuel free road transport system with reduced independence of fuel import – which is assumed to be achieved by energy efficiency, renewable fuels, and electric vehicles. Vehicle manufactures have not until recently, been pressured to produce power train with high energy efficiency. This development will probably continue with the result of a more energy efficient vehicle fleet. A part from the enhanced environmental performance, the flexible feedstock offers a more differentiated fuel. Electric vehicles have electric power transmission, which compared to mechanical transmission is much more energy efficient. With the generated power centralised (big or small scale), there are no tail pipe emissions which is favourable to local environment.

Stockholm, the Swedish capital and one of the busiest regions in Sweden, have the ambition to be a pioneer, internationally, in addressing environmental problems and especially the challenges of a carbon-restrained world. For example, the City of Stockholm has developed the Vision 2030, a document where it establishes how to become a more sustainable city. This implies environmental, societal and economical sustainability. In addition, in the County of Stockholm the new regional planning document has recently been launched, where sustainable development also is in focus. Both political documents, highlights the importance of renewable fuels and to electrify the vehicle fleet as one part of their sustainable strategy. In lines with mentioned visions, a number of targeting initiatives have been developed, such as the Stockholm – Elbilsstad 2030 and the Biogas Öst initiative.

Since the objective is a renewable road transport system in Stockholm by 2030, this calls for a definition of renewable fuel. The study will use the Swedish Transport Administration (Trafikverket) definition, an adaption of the EU directive 2011/77/EG, which may be summarised as fuels from a non-fossil origin, produced with the purpose to be utilised for transport (Trafikverket, 2011).
1.1 Purpose of study
Based on the mentioned visionary political projections, it is relevant to analyse the probability of a long-term commitment and the consequences for the transport and energy system. Therefore, the purpose of this study is to investigate if there are favourable conditions to achieve a renewable road transport system in Stockholm by 2030. This question is studied from three aspects; technical, private-economical and regional planning. This is done in three separate sub-studies looking into one aspect each. The results from those three sub-studies are then analysed in an interdisciplinary discussion to be able to understand how they interact and what implications it has for the question of a renewable road transport system in Stockholm 2030. To concretise the overall question, three collective research questions is used:

- What would a renewable road transport system in Stockholm 2030 look like?
- How may Stockholm reach the goal?
- Which are the consequences of a renewable road transport system?

1.2 Accomplishment of the study
This study is based on three sub-studies, executed with different objectives and using different methods. The results are then not only analysed separately but also in combination, and this is deemed to increase the understanding of the complexity of the issue at hand. The methods used are interviews, document studies, optimisations and scenario assessments. An extensive literature study was also conducted to provide background and input data for the sub-studies. Hence, the methods derive from both social and technological science traditions, an important part of reaching the joint discussions and conclusions has been to understand the different methods and in some cases also take part of them. Taking time to discuss the methods and how they can contribute to the joint purpose has been necessary when analysing the results from the three sub-studies in the joint discussion.

Interviews and document studies are used in an exploration of Stockholm’s regional planning processes and actors. Documents are used as both a background for topics discussed in the interviews, but also as objects for analysis. The documents represent the visionary and governing parts of regional planning. The interviews are used as expressions of regional planning practices, i.e. describing how the actors understand and explain the planning practice behind the documents.

To illustrate how costs might affect private persons’ willingness to buy alternative vehicles, scenarios are modelled using the graphical interface optimisation tool reMIND. Input data include vehicles, fuels, driving distances and costs, and output data include which fuel is used by each vehicle type when the system cost is minimised.

Different pathways to achieve a renewable transport system are studied in a scenario assessment. For each pathway a scenario is created, where the vehicle fleet consists of varying fractions of utilised fuels and powertrains. Output from the scenarios is information about fuel demand and supply, environmental impacts and import dependency.

The literature study provided a foundation for the construction of all the scenarios in this report, as well as the input data and assumptions used in them. The aim of the literature study was to find available fuels and technologies in 2030, fuel consumption, vehicle fleet, driving ranges, GHG emissions, costs and fuel production potential in the region. A criterion in the search was that the fuels and technologies should be competitive and likely to be available in 2030. The data was mainly retrieved from scientific publications, official reports and official statistics. Since the authors come from different scientific traditions there was a very diversified knowledge of the different methods before the study.
Therefore, it is possible that the purpose, studying different aspects of a renewable transport system, is coming from the will and ability to use certain methods to investigate those aspects. However, planning practices could have been studied by using for example participant observation or political game theory and the behaviour of private persons could have been studied from a different behaviouristic perspective, than private economics, when using interviews instead of modelling as method. Alternatives to the scenario assessment of the transport system could have been a back casting study, or a perspective focusing more on economics. It would also be interesting to include the scenarios in the interviews, or to base the scenarios on the results from document studies and interviews to a further extent. The authors, with their varying backgrounds in engineering and social science, may contribute with both profound technical knowledge as well as the understanding of policy mechanisms. This study is an attempt to utilise the heterogeneous background of the authors in order to deepen the system analysis.

Many other studies, both national and international, have been carried out in a more unilateral way, only focusing at one aspect at the time, and thereby risk misinterpreting the role of the other two. Political science and economics may overestimate the impact of technological development; whereas a technical study may not even address the existence of any other aspects. When combining the three aspects, previous unilateral studies may be challenged due to increased understanding of the complexity of the transport system.

The structure of the study, as seen in Figure 1 is both an individual work but mostly a combined effort to increase the understanding of the complexity of the analysis.

![Figure 1 Project report structure](image)

### 1.3 The energy- and transport system

The road transport system is defined by its physical components, for example vehicles, infrastructure and fuel distribution systems. The transport system also includes dynamic variables such as annual travelled distance and the vehicles’ energy efficiency. The definition of the energy system for this study is the physical transport system’s corresponding energy flows, both within but also across system border.
This study analyses the transport system from an energy system perspective. In some aspects, these two systems over-lap with various results. Others are less dependent on one another, even completely detached. However, even though the synergies between the two systems are not visible today they could perhaps benefit from more knowledge exchange. To visualise this, Figure 2 has been developed.

![Figure 2 Schematic illustration of the energy and transport system and their interdependence](image)

There are several advantages with an analysis where both the transport- and energy system are assessed, instead of analysing them separately. Foremost, the interacting dependencies would not be captured or fully explained when assessed alone, for example:

- The vehicle fleet and its energy efficiency determine the total fuel demand. The fuels available in the energy system determine the degree of fuel import.
- Political decisions may address the total cost of owning a vehicle. The decisions could target either the components in the transport system (i.e. purchasing cost) or the energy system (for example fuel price, running costs). Either way, one policy will influence both systems.
- The energy system is highly dependent on existing transport system, in terms of for example distributing the fuel. As much as the transport system is fuelled by the energy system, the energy system is dependent on the transport system.

For this study, three different system boundaries are chosen. The reason is that the relevant system boundaries for the energy and transport system are different in the case of Stockholm and to be able to perform relevant analysis this study has to include all three system boundaries. The initial focus was the transport system in the City of Stockholm, and when the different aspects of the study were discussed it was obvious that it was more interesting to have different system boundaries. It is however only the geographic boundaries that differ and this does not affect the fact that the total system in this study is highly relevant. Table 1 summarises chosen boundaries and in following sections, 1.3.1-1.3.3 the choice of system boundaries will be discussed.

<table>
<thead>
<tr>
<th>System</th>
<th>Point of interest</th>
<th>System boundary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>Biomass potential</td>
<td>City of Stockholm</td>
</tr>
<tr>
<td>Transport</td>
<td>Dictates fuel demand</td>
<td>Region of Mälardalen</td>
</tr>
<tr>
<td>Regional planning</td>
<td>Regional institutional actors</td>
<td>County of Stockholm</td>
</tr>
</tbody>
</table>
1.3.1 Stockholm – transport system

In order to capture the relevant aspect of the transition to a renewable transport system in Stockholm, the appropriate system boundary needs to be established for the transport system (see considered boundaries in Figure 3). The system boundary for the transport system is determined to the City of Stockholm.

Selecting the system boundary to the City of Stockholm would neglect a lot of transports within the system. Even though, it is considered that this system boundary best describes and captures the relevant movements of the commuters, compared to for example the county of Stockholm or the inner city. The City of Stockholm includes over 70% of the commuting travels carried out in Stockholm, a value to be compared to 29% for the inner city system (Stockholmsförsöket, 2005).

At a City level, Stockholm has an influential Environmental and Health Administration, which has been working progressively with renewable transport since the Municipal Board in 1994 initiated Program to promote electric vehicles and other green vehicle technologies (Stockholm Stad, 1994).

The other two considered system levels (county and inner city) are dismissed since they are not as representative for the road transport system as the City of Stockholm.

The County of Stockholm as a system level would include a lot of vehicles that travel across the Stockholm region. There are a lot of available data, describing both energy- and material flows in and out of the system, provided by Statistics Sweden and the Stockholm County Administrative Board. But the conditions for the transition to a renewable transport system vary greatly around different parts of the County. The variations are considered so significant that it would be impossible to make any general proposals in regards of suggested pathways to a renewable transport system.

To condense the system boundary to correspond to the inner city would not only reduce the physical territory, but also bring a system that could be considered as relatively homogeneous in regards of economic and social conditions, i.e. purchasing power. This system level is already today accepted as the zone for congestion fee – an incentive that initially was meant as an environmental initiative (Stockholm Stad, 2003).

Even though the inner city of Stockholm may have the monetary conditions to meet the expense of a transition, several relevant aspects of the transport system become neglected:

- A majority of the vehicles travelling within the Stockholm region would not be accounted for.
- Sufficient infrastructure would have to be developed, not only at this relatively limited physical area.
- To assume “strong purchasing power” might ensure a transition to an environmentally sustainable system but this transition could never be considered as economically sustainable.
Figure 3 Considered transport system levels of Stockholm (Stockholms län, 2011; Stockholm Stad, 2011a; USK, 2011)
1.3.2 The region of Mälardalen – energy system

The region of Mälardalen was chosen as system boundary for the biofuel feedstock collection. 30% of the available biofuel feedstock in the region was estimated to be available for utilisation in the city of Stockholm. According to the Biogas Öst definition, the region of Mälardalen includes the counties of Stockholm, Uppsala, Västmanland, Örebro och Södermanland län and Östergötland.

20% of all vehicles in the region of Mälardalen are located in the city of Stockholm and this study assumed it reasonable that 30% of the available biofuel production potential in the region could be used in city of Stockholm. The reason for this is the concentrated population, which makes it easier to affect a large group of vehicle owners with local initiatives if the region chooses to take lead on the environmental issues. In addition, it is easier to construct a distribution infrastructure and to set off by-products from the biofuel production, e.g. district heating.

The feedstock that is abundant in urban areas is different types of waste, e.g. sludge from wastewater treatment, municipal solid waste and industrial waste. This can make up a part of the feedstock for biofuels, if collected and transported to an appropriate biofuel facility. The biomass potential in an urban area is of course limited, since there is not much land available for crops and forests. Therefore it is considered likely that biomass and biofuel is imported from the surrounding region, which is already the case for biogas.

It is questionable whether it is relevant to consider a small region of Sweden, when most of the forests are located in the north and many of the biofuels can be transported quite easily. The decision is based on the following reasons; regional self sufficiency, reduced energy losses for transportation of gaseous fuels, the advantage of connecting biofuel production to district heating system and the possible synergy effects with other types of industry. To be consistent the same system boundary was used for all fuels.

1.3.3 The County of Stockholm – regional planning

To study planning for renewable fuels and spatial planning, the City of Stockholm could be a relevant system boundary. Then it would be the political and bureaucratic process within the municipality that would be studied. However, the internal processes implementing the currently developed strategies on renewable fuels and electricity, as well as spatial documents, are not yet in process, why they are not possible objectives for this study. The regional planning processes, however, are currently in action and therefore possible study objects.

The regional planning in Stockholm is also interesting for other reasons: the specific character of the larger city and the single example of statutory regional planning in Sweden. The specific character of a larger city or urban area make the County of Stockholm interesting to investigate since the municipal borders are not that visible as in other smaller places where the municipal border is surrounding the only city in the area. This is obvious when looking into the commuting patterns in the Stockholm region (Tillväxtverket, 2011). In addition, the City of Stockholm usually includes statistics and other figures from the whole county when making analyses about transport issues within the City, because statistics only from the City would be incomplete and misleading (Interview City of Stockholm 1).

The fact that the County of Stockholm is obliged to perform a regional spatial planning since the middle of the 20th century is also making the regional level interesting to investigate when it comes to planning issues.
Regional spatial planning is rare in Sweden, but in Stockholm it has been in place for many years, why it is a relevant institutional level to consider when discussing the development of the transport system. It has large spatial implications as well as it crosses the municipal boarders, as described above. Consequently, the County of Stockholm is the most relevant institutional level when discussing the transport system.

1.3.4 Limitations of study
Only assessing the road transport system implies excluding other means of transport such as rail, aviation and maritime. From a local perspective, only rail would to some degree be relevant to include but this study has chosen only road vehicles since they share a legal framework.

Regarding institutions, this study only includes public actors, within the Stockholm region, working with energy and transport issues. Private actors, such as energy companies and vehicle manufacturers, are excluded.

The renewable fuels and their vehicle technologies assumed available and competitive in 2030, are the those that the Swedish Ministry of Environment have chosen to include in their action plan to accomplish a fossil independent vehicle fleet by 2030 (Holmberg, 2009). This implies excluding e.g. fuel cell vehicles and algae-based fuels.

In urban areas, the dominant share of the vehicle-owners are individuals, whose behaviour may be considered cost-sensitive and thus is interesting to capture when assessing a technology transition. Therefore, this study does not include economics other than for the private vehicle-owner.

1.4 Methods used in the study

1.5 Disposition
Chapter 1 introduces the study object, the approaches used when performing the study and the research questions.

Chapter 2 deals with the study’s background. Overarching transport policies are described, as well as the city of Stockholm and institutional planning actors in Stockholm. Vehicle and fuel production technologies are also described here.

Chapter 3 is the result of a literature study; containing information about the projected vehicle fleet in Stockholm 2030, fuel economy of various fuels and powertrains, potentials for biofuel production etc.

Chapter 4 presents the document studies and interviews performed within the policy planning sub-study, and discusses the outcomes.

Chapter 5 presents the cost optimisation sub-study and discusses the results from this sub-study..

Chapter 6 presents the scenario assessment sub-study, and discusses its implications.

Chapter 7 integrates the studies presented in chapters 4-6, utilises this integration to answer the research questions posed in chapter 1 and wraps up the study.

Chapter 8 presents conclusions drawn from this study.

Chapter 9 contains future work and lessons learned
2 Background
In this chapter, a short background of Stockholm and a description of its vehicle fleet, which will be used in the subsequent analysis, is given. A short background regarding the policy framework on the EU and national levels is also presented, to understand which policies frame the regional policy planning in the area of research. The public institutions involved in the regional energy and transport planning are described to improve the understanding of the institutional context in the Stockholm region. An introduction to renewable fuel production processes and corresponding vehicle technologies concludes this chapter.

2.1 Short introduction to transport policies at EU and national level
The focus in this study is the local and regional institutional levels in the Stockholm area. The local municipalities in Sweden have a rather extensive self-government and are able to make sole decisions in many sectors. However, the local level has not sole control over every sector, many things are decided by the national government and then the municipalities are injunctive to implement it. Furthermore, even in those cases when the municipalities have sole control to make decisions they are influenced by the goals and recommendations the national government is promoting (Montin, 2004). For example the national environmental goals are supposed to influence the municipalities in their everyday work. Within the transport sector, there are national policies formulated as national goals that every institution in the country should aim at. Since 1995, when Sweden became a member of the European Union, the decisions and strategies put forward in Brussels are influencing national level, but also local and regional levels. However, many EU policies are not governing policies but guiding policies. These policies are meant to influence institutions, but are foremost used by the institutions in order to achieve their own goals (Montin, 2004).

Since the national government and the EU have major influence on the local and regional institutional levels, the most recent proposals from both levels are presented in the next two parts. The proposals have not been studied in their entirety, but with focus on energy and environmental issues.

2.1.1 EU policy
The European Commission is the EU institution with the power to initiate and lift policies up on the EU agenda. Firstly, they publish a green paper that presents different ideas and measures within a specific policy area. The green paper is supposed to open up a debate among interest organisations, nations and others about an issue. In the next step, the European Commission develops a white paper, which corresponds to a government bill in a nation state. The white paper presents several measure proposals within a specific policy area and is used as a foundation for a legislative work within the union or the development of EU strategies (Tallberg, 2004).

In the following section the white paper on transport, which came during the spring in 2011, is described. In addition, to catch the on-going discussion within the EU on transport matters, especially regarding new vehicle and fuels, the white paper is complemented by a small extract from the Electric Vehicles Conference in Brussels in May 2011.

2.1.1.1 White Paper
In March 2011, the European Commission published a white paper on transport named Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. It focuses on the need for transport to ensure economic growth and personal mobility – “Curbing mobility is not an option” – while adhering to the CO₂ emission target of 450 ppm CO₂ by 2050 (European Commission, 2011: 5).
Infrastructure and mobility planning are considered key elements together with new technologies to help reduce CO₂ emissions. Common rules, regulations and standards for member states are expected to help implement new solutions. The paper emphasises that transport users should pay their full costs, by internalising external costs, applying polluter pays and user pays principles and aligning transport taxation.

Urban transport is treated specifically, as this sector has specific needs due to higher population density and short travel distances. Here local air and noise pollution are additional important factors, while vehicle requirements such as range and performance are less important. In the paper, a goal set for urban transport is to cut the number of conventionally fuelled cars in half by 2030 (European Commission, 2011).

Suggested measures in the paper are the creation of common standards and information campaigns, to encourage people to choose emissions reducing means of transport. Urban area planners should be encouraged by “Urban Mobility Plans” and “Urban Mobility Audits”, which would help restructure infrastructure and transport. Public procurement is considered helpful in increasing the uptake of new technologies. The need for common policy is emphasised: “Coherence at EU level is vital – a situation where (for example) one Member State opted exclusively for electric cars and another only for biofuels would destroy the concept of free travel across Europe” (European Commission, 2011:5).

2.1.1.2 Electric Vehicles Conference, Brussels, 26th of May 2011
In an attempt to put a local issue in a more global context, the authors attended the European Electric Vehicles Conference in Brussels, where politicians and business executives discussed the challenges connected with a large-scale introduction of electric vehicles in Europe.

The keynote speakers and panellists (politicians and business executives) spoke in positive terms about electric vehicles. Intelligent transport systems, smart grids and vehicle-to-grid technology were also mentioned, and the role of electric vehicles in these systems was stressed. However, many difficulties such as charging infrastructure and common standards were acknowledged and the discussion only concerned the vehicle, not the power generation. A Member of Parliament, as well as the Commissioner for Transport, emphasised technology neutrality in policy making, although acknowledging that financing all technologies equally is hard. They agreed that important tasks for policy makers are creating common guidelines, regulations and standards. The actual implementation should be left to the private sector and the member states (Kallas, 2011; Sterckx, 2011).

2.1.2 Swedish policy
The Swedish objectives for the entire transport system are basically the same as the European Commission’s, with economic growth and accessibility as key points. In urban areas, focus is primarily on eliminating bottlenecks. The climate issue is not forgotten, but in the government bill from 2008, the Future travels and transports – infrastructure for sustainable development (Framtidens resor och transporter – infrastruktur för en hållbar tillväxt), climate effects are treated in a separate chapter, detached from other transport and infrastructure issues (Regeringskansliet, 2008).

When road traffic is concerned, the Swedish policy includes a transition from fossil fuels to renewable fuels, electricity and fuel cells. A special interest in electric and fuel cells is expressed. Public transport is endorsed, and a wish that this alternative is used more frequently is expressed. The responsibility of choosing climate friendly means of transport is to great extent placed on private persons. CO₂ taxation is the chief policy instrument to guide consumers towards efficient alternatives (Regeringskansliet, 2008).
For 2030, the Swedish goal is to achieve complete fossil independence within the transport sector (Regeringskansliet, 2009). This is not to be confused with fossil free transport – a car is for instance considered fossil independent if it runs on petrol but could run on ethanol.

The Swedish policy on transports is only a guideline document, which means that it cannot rule the municipalities to act in line with the policy. The government is only able to inform of the national goals and encourage the local and regional actors to act in line with that (Regeringskansliet, 2009). However, the county administration boards in all counties are assigned to reformulate those national goals according to regional conditions and inform the county’s institutions of what they should do to achieve them. In this way the national goals are spread to the regional and local institutional levels.

2.2 Stockholm

At the end of the year 2010, the number of inhabitants in the City of Stockholm was 847 073 (Stockholm Stad, 2011b). The vehicle density in the City of Stockholm is 363 passenger cars per 1 000 inhabitants (SCB, 2009a) which is a lower value than both the County of Stockholm and national average. Since 2004, the City’s Environment and Health Administration has every three years carried out a citizen survey to monitor the travelling habits. Some of the key results (Stockholm Stad, 2010) are presented below:

- Over 50 % of the responders have access to a passenger car.
- Journeys to work: The share of citizens that foremost do this journey by a passenger car has reduced to 21 % in 2010, from 27 % in 2004. Simultaneously, the share of citizens travelling to work with public transport has increased from 53 % in 2004, to 63 % in 2010.
- Car sharing: All through the survey period, the share of citizens that foremost utilise a passenger car via car-pool have consistently been 1 %.

The number of inhabitants in the City of Stockholm is expected to increase to 1 million in 2030 (Stockholm Stad, 2007). This implies a population increase in City of Stockholm corresponding approximately 20 % until 2030.

2.2.1 The vehicle fleet in the City of Stockholm

In a business as usual case, the vehicle fleet would increase proportionally to the increasing population. This would imply an approximate 20 % increase of road vehicles in the County of Stockholm (Stockholms län, 2009). However, it is estimated that road travel demand internationally might increase by only 10-15 % by 2030, due to improved transit systems, infrastructural improvements and monetary incentives such as congestion fees (Lindfeldt et al., 2010). In addition, Elforsk (2010) estimates Swedish demand reduction to be in the order of 15 % for road transport. As the vehicle density in the City of Stockholm is low compared to the national level, it is in this study assumed that 2010’s level of road transport\(^1\) remains by 2030.

To determine the vehicle composition of the City of Stockholm transport system in 2030, the current vehicle fleet is introduced below. The vehicle types in this study are separated into the categories described in the following section.

\(^1\) Level of road transport is defined by the number of annual travelled kilometres and the absolute number of vehicles.
Each category correlates with predetermined assumptions, in regards of kerb weight, lifetime, annual driving distance, etc. For this study, two Swedish governmental agencies provide vital input data:

- Statistics Sweden (SCB): vehicle fleet data
- Transport Analysis (Trafikanalys, former SIKA): driving distance data

### 2.2.1.1 Passenger cars

Data from Statistics Sweden present all passenger cars as one category. Since different sized vehicles show different characteristics, this study introduces two categories of vehicles (and its acronyms, respectively) based on kerb weight – light-passenger cars (LPC) and heavy-passenger cars (HPC). Another way of categorising passenger cars are by cylinder volume but for this study, where different fuels and technologies are compared, the absolute weight of the vehicle is considered to be a more appropriate measure. In order to utilise data from Statistics Sweden, the ratio between the two vehicle categories needs to be established. There are no data available describing the composition of the ratio between the two passenger car categories in the City of Stockholm. Therefore, national statistics are used to establish this relationship (SIKA, 2008a). The ratio between LPC and HPC, in absolute numbers of physical vehicles, is set to 61 % and 39 %, respectively. A national value may underestimate the number of heavy passenger cars. Contradictory to the prevailing conditions with well-developed public transport and shorter daily commuting distance, tend people in Stockholm to purchase heavier vehicles then other parts of the county (SCB, 2009b). However, this is hopefully just a transient trend and for this study, it’s assumed in 2030 that a national ratio (2010) is valid also in the case of Stockholm.

- Light-passenger cars (LPC) - defined as passenger cars with a kerb weight between 0 and 1 499 kg.
- Heavy-passenger car (HPC) - defined as passenger cars with a kerb weight over 1 500 kg.

Kerb weight intervals in this study are analogous to the Swedish Transport Administration’s definition (SCB, 2010a).

At year-end 2010, the number of passenger cars registered in the City of Stockholm were 303 930 (SCB, 2010b). Using the relationship previously stated, this correlates to 185 397 LPC and 118 533 HPC.

The annual driving distance varies with kerb weight. Transport Analysis doesn’t provide Stockholm-specific annual driving distance data for each passenger car category, but from national data (SIKA, 2008a), the average driven distance may be summarised 10 000 km for LPC and 16 000 km for HPC. These values are consistent with the overall annual driving distance for all passenger cars in the county of Stockholm, 16 690 km (SIKA, 2008b).

### 2.2.1.2 Trucks

In the case of trucks, Sweden Statistics and Transport Analysis provide data for two types of trucks based on kerb weight (SIKA, 2008b); unfortunately this data is county specific. For simplicity, this study is using the kerb weight intervals analogous to the governmental agencies definition. County data for the heavier category of trucks overestimates the annual driving distance profoundly, since its dominating mileage is carried out on highroads (outside system boundary), compared to the lighter type, which foremost function as a city distribution vehicle. To adjust the annual driving distance for heavier category of trucks, general Stockholm-specific truck data is used to compensate.
- Light-duty trucks (LDT) - defined as trucks with a kerb weight between 0 and 3,499 kg. The annual driving distance is 18,000 km (SIKA, 2008b).
- Heavy-duty trucks (HDT) defined as trucks with a kerb weight over 3,500 kg. The annual driving distance is 20,000 km (SIKA, 2008b; SIKA, 2007).

2.2.1.3 Buses
This study, analogous to Sweden Statistics data (SCB, 2010b), only considers an “average bus”. A bus is used for urban public transport. After an inventory of the Stockholm Public Transport (SL) bus fleet, an assumption concerning an average bus is considered valid hence the fleet, consisting of 2,016 buses in 2009, only varies between 12-18 metre corresponding to an insignificant divergence from an average weight (SL, 2009).

Amongst the vehicles in this study, the bus operates with the highest degree of utilisation. This is reflected by the annual driving distance reported by the Transport Analysis, 56,000 km per year (SIKA, 2007).

SL, owned by the Stockholm County Council, reports the number of vehicles in the county of Stockholm. The number of buses listed in the City of Stockholm is lower, 1,081 in 2010 (SCB, 2010b).

2.2.1.4 Motorcycles
To restrict the number of vehicle categories, this study has merged the Statistic Sweden categories “Motorcycles” and ”Mopeds class 1”. This newly formed category is assumed to, in a representative way, illustrate a category of vehicles, with increased urban mobility compared to a conventional passenger car. In 2010, this category hold 15,805 vehicles (SCB, 2010b).

The prevailing usage for this type of vehicle is commuting from the nearby suburbs of Stockholm and within the city centre. The average annual driving distance is 3,000 km (SIKA, 2007).

2.3 Institutional planning background
The traditional way of describing how policies are decided and implemented in a country, is that the decisions are made by the national government, which then distribute them down to the regional authorities and the local authorities for implementation. However, the Swedish policy process is not that simple. Instead the national government and the local government have different jurisdictions in different policy areas. Some policies are decided by the national government and then the local authorities have to act in line with them. Other policies are handled by national authorities, who have jurisdiction within a certain policy sector. Finally, some policies are decided by the local government itself. The regional level in Sweden has no self-government in the same sense as the local; accept for health care and public transport, which are decided by a regional government. Hence, more general issues are not handled within a certain regional institution, but many policies are of regional character. The regional arena in Sweden is full of public and private actors, with different jurisdictions and possibilities, who all want to influence what happens. In this study it is the public actors at the regional institutional level are in focus.

In Sweden, the regional institution level is weak in the sense of power to make governing decisions regarding the region’s territory (Montin, 2004). The municipal self-government is based on constitutional law and deeply rooted in the Swedish institutional tradition. The main foundation for the municipal self-government is the income tax, which the municipalities decide upon. However many obligations are dictated by the state (Montin, 2004).
In addition, the municipal government has sole control over land use, which is interesting for this study. This sole control is a possibility for the municipalities to decide upon spatial plans that cover the whole territory and forcing private interests to act according to those (Nyström, 2003).

Many other European countries introduced regional spatial planning in the middle of the 20\textsuperscript{th} century, since the regional level was considered the appropriate level to decide upon spatial issues (Nilsson, 2006). However, in Sweden, the traditional municipal self-government and the sparse inhabitation meant that the local spatial planning was kept, since it was considered better adapted for spatial issues (Nilsson, 2006). However, the Stockholm region already then consisted of integrated municipalities; people lived in one municipality and worked in another, and therefore regional spatial planning was considered applicable there (Nilsson, 2006). Still, the regional institution that became responsible for the regional spatial planning got no power to govern the municipalities on spatial issues, why the regional spatial planning turned into only a piece of document (Magnusson, 2011). Thus, the municipalities keep their spatial power and the eventual success of the regional spatial planning rests on their will to decide upon regional issues.

However, the regional institutional level in Stockholm concerning the transport system contains several different actors, some of them, such as the Stockholm County Administrative Board and the municipalities, having governing power. Other regional actors that depend on the decision making of the above mentioned are the two administrations under the Stockholm County Council – the Office of Regional Planning and the Stockholm Public Transport. In Stockholm the municipalities are also assembled in an organisation, the Stockholm County Association of Local Authorities, which is assigned to work as an interest organisation for the municipalities. The regional public actors that in different ways influence the Stockholm transport system are further described below and summarised in Table 2.
Table 2 The public and regional actors in Stockholm

<table>
<thead>
<tr>
<th>ACTOR</th>
<th>DESCRIPTION</th>
<th>MANDATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>County Administrative Board (Länsstyrelsen)</td>
<td>State-controlled regional authority within a region</td>
<td>Regional general energy planning and distribution of resources to the Stockholm transport system</td>
</tr>
<tr>
<td>The Stockholm County Association of Local Authorities (Kommunalförbundet Stockholmslän)</td>
<td>An interest association for the municipalities in the Stockholm region</td>
<td>React on the municipalities’ demand for help, knowledge or cooperation in specific issues</td>
</tr>
<tr>
<td>County Council – the Office of Regional Planning (Landstinget – regionplanekontoret)</td>
<td>A department of the County council</td>
<td>The regional spatial and development planning, presented in the Regional Development Plan of the County of Stockholm</td>
</tr>
<tr>
<td>County Council – the Stockholm Public Transport (Landstinget – Storstockholm Lokaltrafik (SL))</td>
<td>A company owned by the County council</td>
<td>The public transport planning and the general transport planning for the county</td>
</tr>
<tr>
<td>Municipalities</td>
<td>Local self-government</td>
<td>Sole control of spatial planning and other decision making on local level</td>
</tr>
<tr>
<td>The City of Stockholm (Stockholm Stad)</td>
<td>Local self-government</td>
<td>Department of Clean Cars: works for the introduction of new clean car technologies The City Planning Administration: the general city planning and thus the transport planning of the city</td>
</tr>
</tbody>
</table>

2.3.1 The Stockholm County Council – the Office of Regional Planning (Landstinget – Regionplanekontoret)

The Office of Regional Planning, an administrative body of the Stockholm County Council, has responsibility for the regional planning. Today the regional planning does not only concern spatial issues, but also economic, social and environmental development. To gain legitimacy and support from the institutions, with decision power, the Office of Regional Planning develops the Regional Development Plan of the County of Stockholm (Regional Utvecklingsplan för Stockholmsregionen (RUFS)) in a broad interaction with both private and official actors in the region (RUFS, 2010). The RUFS works as a guiding document for the public actors when developing their own policy plans. However, its implications on the real planning and decision-making among the actors have been disputed (Magnusson, 2011).

The Office of Regional Planning has many responsibilities, one of which is energy issues. However, transport issues are not part of the office’s regular responsibilities. Even though included in the RUFS, transport issues have been reassigned from this institution to SL.
2.3.2 The Stockholm County Council – the Stockholm Public Transport (Landstinget – Storstockholms Lokaltrafik, SL)

SL, a company owned by the Stockholm County Council, is responsible for the public transport planning in the Stockholm region. As mentioned, since a few years SL is also responsible for the general transport planning in the region. This change is rather recent, and the consequences are not yet clear (all interviews).

2.3.3 The Stockholm County Administration Board (Länsstyrelsen)

The only regional institutional actor handling both energy and transport issues is the Stockholm County Administration Board. The Board is a state-controlled public authority in the region, acting only on governmental orders. Concerning energy issues, the Board is currently developing a Climate and Energy Strategy for the Stockholm region, in cooperation with other actors (Länsstyrelsen, 2011). Governmental investments in infrastructural development and maintenance in the region is distributed by the Board. The investment plan is outlined in a document, the County Plan for Transport Infrastructures in the Stockholm County. This is developed by the Board in cooperation with all municipalities and other concerned actors in the region (Interview Council Administration Board 2). Another important role of the Board is information distribution, regarding important issues in the region, to its municipalities and other actors, with the purpose of influencing their actions (Interview Council Administration Board 1).

2.3.4 The Stockholm County Association of Local Authorities (Kommunförbundet Stockholms län)

The municipalities are regional actors, as well as local actors, because of their self-government and their sole control of land use. In other parts of Sweden, the municipalities in a region have founded associations to which they have transferred some decisional power and the associations have turned into regional councils with their own powerbase. The contrary is the current situation in Stockholm, where the municipal association is only an interest organisation for the municipalities in the region and is not able to raise any questions of its own (Interview Association of Local Authorities). The Association reacts only on the municipalities demand for action on very specific issues, thus it only works with those issues the municipalities believe is important and ask for help in.

The Association works through networking, creating collaborations around specific issues (Interview Association of Local Authorities). The municipalities may choose to act on recommendations of the Association or not. The Association may provide the municipalities with information about specific questions, which they may use to make more informed decisions. The Association also represents the municipalities in many other organisations, such as the Biogas Öst initiative, but the municipalities decide what the Association should say and do (Interview Association of Local Authorities).

2.3.5 The City of Stockholm (Stockholm Stad)

The Stockholm municipality, or the City of Stockholm, is also considered to be a regional actor on the institutional level. It is a municipality and therefore it is only responsible for its local territory, but since the City of Stockholm is the region’s obvious centre according to most sectors, the interest of the City influences the whole region (Interview Association of Local Authorities).

The City’s influence on the region is displayed in the planning documents, for example the Stockholm City Plan, which is regarded an important background document in many of the regional documents (see e.g. RUFS and the County Plan for Transport Infrastructures in the Stockholm County).
Furthermore, the rejection by the City of the earlier RUFS is considered to be a major reason why the plan has lacked influence (all interviews).

The City of Stockholm, and foremost its Environmental and Health Administration (Miljöförvaltningen), has during almost 20 years worked with the renewable transport issue. One of its departments, the Department of Clean Cars, focuses on the introduction of renewable fuels. Information distribution is also an important task for the Department, as well as initiating public procurements believed to reduce the costs of renewable fuels and vehicle technologies (Stockholm Stad, 2010b).

The City of Stockholm and its City Planning Administration plan the land use on municipal territory. The general land use and development planning is presented in the Stockholm City Plan, which outlines the long-term spatial development in the municipality. In the spatial sense, the City Plan handles transport strategies developed and implemented by the planning department in the City of Stockholm (Stockholm Stad, 2010a). As the Department of Clean Cars focuses on the environmental and energy issues of transport, the City Planning Administration focuses almost only on spatial matters of new infrastructures and residential areas.

2.4 Renewable fuels and vehicle technology background

In this study, conventional fossil fuelled transport is challenged by renewable means of transport. This study implies 100% utilisation of renewable biofuels or electricity. This chapter will introduce the fuel production processes and the vehicle powertrains assumed to play a dominating role in the transition to a renewable road transport system in Stockholm in 2030. The measures to accomplish this are:

- Energy efficiency
- Renewable fuels
- Electric vehicles

2.4.1 Vehicle powertrains

There is a range of biofuels to be utilised in the vehicle technologies. Therefore this section starts with a short summary of available biofuels. Currently, the commercial biofuels are biodiesel, biogas and ethanol, and these fuels are commonly denoted 1st generation biofuels. Biodiesel is also denoted fatty acid methyl ester (FAME), and when produced from rapeseed it is specified as rape methyl ester (RME). Fuels from cellulosic biomass that are under development are called 2nd generation biofuels, and they include Fischer-Tropsch (FT) diesel, synthetic natural gas (SNG), lignocellulosic ethanol, dimethyl ether (DME) and methanol. Finally there is a 3rd generation of biofuels where fuels in early development phases are included e.g. hydrogen with fuel cell technology.

Methanol and hydrogen are excluded from the study. Methanol is excluded to limit the study and because it has a similar efficiency to other 2nd generation biofuels included in the study, and similar properties to ethanol. Hydrogen and fuel cell vehicles are excluded because it is often not considered to be available in large scale 2030 (Tseng et al., 2005; Page and Krumdieck, 2009; Miljödepartementet, 2005), although the opinions differ.

The fuels are further categorized after their similarities; biogas and SNG are gathered under biomethane, 1st and 2nd generation ethanol under ethanol, biodiesel and FT-diesel under synthetic diesel.
2.4.1.1 Conventional powertrains

Conventional powertrain technology can be used for new types of fuels, although some adaptations might be necessary to assure energy efficiency and robustness of the vehicle technology. A conventional powertrain consists of a fuel tank connected to an internal combustion engine, that via the mechanic transmission turns the wheels (Figure 4).

![Figure 4 Conventional powertrain](image)

There are two common types of engines; the Otto engine, usually referred to as the petrol engine, and the Diesel engine. The fuel in the Otto engine is ignited by a spark plug, therefore called a spark ignition (SI) engine and in the Diesel engine the heat of compression ignites the fuel.

The energy efficiency of an Otto engine is about 25 % (Figure 5), which is the fraction of the energy available from the fuel used to move the car or for accessories in the car. Diesel engines might reach up to 35 % energy efficiency (Green car congress, 2005).

![Figure 5 Energy efficiency in internal combustion engine](image)

Other types of ignition might be relevant for new types of fuels. In Diesel engines, glow-plug ignition is necessary to assist the ignition of fuels with low cetane number, e.g. alcohols, without additives (Ahlvik, 2008). The glow-plug heats up the engine block around the cylinders so that the ignition temperature can be reached during the compression.

2.4.1.2 Use of renewable fuels in internal combustion engines

Ethanol may be used in SI engines where it has the advantages of high octane number and fast combustion. However, ethanol has difficulties to ignite at low outside temperatures and causes increased corrosion (Park et al., 2010). Ethanol can also be used in compression ignition engines with glow-plug ignition, as mentioned above (Ahlvik, 2008). Biomethane is suitable for the Otto engine, however the efficiency is lower compared to a Diesel engine (Biogasportalen, 2011).

A promising technology is the dual-fuel Diesel engine running both on biomethane and diesel, with advantages like higher efficiency and reduced emissions (Yoon and Lee, 2011). DME may be used in Diesel engines after small modifications, and this solution has high energy efficiency and low emissions (Volvo group, 2011a). Synthetic diesel may be used in the
Diesel engine but some modifications are necessary, when using biodiesel in particular due to the dissimilar molecular composition compared to fossil diesel (Fazal et al., 2011).

2.4.2 Electric vehicles
The electrification of road transport addresses many of the rising societal concerns regarding the utilisation of fossil fuels and polluted urban areas. Electrification of the powertrain enables a diversification of primary energy sources.

2.4.2.1 Technical description of electric vehicles
Within the category electric vehicles (EVs), the degree of powertrain electrification may vary from a conventional mechanical powertrain equipped with a modified more powerful start engine, to a fully electrified powertrain.

To ensure local emission free\(^2\) drive, the powertrain needs to operate with electric propulsion. In this study, two types of EVs are distinguished:

- Fully electric vehicles have an electric engine and an energy storage unit, but no ICE.
- Plug-in Hybrid Electric Vehicles (PHEVs) have both an ICE and an electric engine, and an energy storage unit. The ICE generates electricity, for the electric engine, via a generator. PHEVs in this study all have series hybrid powertrain set-up, see Figure 6, to enable electric propulsion.

In this study, batteries are considered the only option for on-board energy storage. This assumption allows the utilisation of the electricity grid for charging the batteries. Electric vehicles with battery (BEV) is the fully electric vehicle used in this study.

In BEVs, the electrical powertrain is characterised by a high overall energy efficiency, about 80 % (Helms et al. 2010). This is mainly because the electric engine’s energy efficiency, about 90 % (Helms et al., 2010) and low friction losses in the electrical power transmission. The tank to wheel energy efficiency of PHEVs is about 60 %, due to these reasons (Helms et al.,2010).

![Figure 6 Schematic illustration of an EV powertrain - BEV excluding and PHEV including the ICE and generator, respectively](image)

2 Local emission free is defined as absence of emissions caused by a conventional combustion engine, i.e. carbon dioxide, nitrogen oxides, particulate matter and noise. Particulate matter caused by the wearing of the tyres is excluded.
2.4.2.3 Energy storage

The size of the energy storage determines the electric range for both BEVs and PHEVs. The unit cost corresponds to its size, which makes the energy storage the component that most influences the vehicle’s price. The battery is the energy storage technology utilised in this study. There are various battery chemistries, but the battery chemistry predicted to dominate the future market for automotive applications is the lithium-ion (Li-ion) battery (Becker et al., 2009). The Li-ion battery has favourable characteristics in terms of specific energy and power density, compared to other battery chemistries, as illustrated in Figure 7.

Figure 7 Energy and power density for battery technologies, adapted from Campanari et al. (2010)

The wide research front implies an extensive and diverse development of vehicle battery technology. The development of the Li-ion battery has progressed rapidly; the annual improvement rate of the specific energy density averages 6% (Becker et al., 2009). To extrapolate this rate to 2030 is very optimistic. In this study, a more moderate approach of a 2% annual improvement rate is assumed. Also, the battery technology existing in 2030 is assumed to be mature and commercially available.

Battery lifetime depends on charging pattern. Batteries age very quickly if fast charging (400V/80A) is used instead of standard charging (230V/10A). The battery cells are damaged from heat released at high power loads (Elforsk, 2009a). Battery manufacturers report an expected battery lifetime of 10 years, given standard charging (VINNOVA, 2010a), but the lifetime may decrease to 5 years if fast charging is used frequently. The automotive industry has the goal to develop battery technology with the same lifetime as the vehicle (Duval, 2004). Other battery concepts, e.g. battery switch, are also under development.

A large-scale introduction of EVs utilising Li-ion batteries implies an intensification of lithium mining. As of 2011, batteries (all Li-ion batteries, not just for automotive applications) comprise about 23% of the total end-use market for lithium. Global lithium resources have been estimated at 25.5 million tons (Graham et al., 2011).

Several studies (Graham et al., 2011; Oppenheimer and Abell, 2008) report no limitations in global lithium supply, but according to Gaines and Nelson (2009), a large-scale EV introduction would imply that automotive battery demand would only be satisfied until 2025.
A threat of lithium supply deficit may pressure the automotive industry to establish lithium recycling, thereby prolonging lithium supply.

2.4.2.4 AC/DC inverter
Alternating current (AC) is supplied by the electric grid. However, the battery utilises direct current (DC). The inverter is an electrical device that converts AC to DC, or the other way, thereby ensuring the different parts of the powertrain system appropriate voltage.

2.4.2.5 Electric engine
The electric engine converts electrical energy into mechanical energy. Brake energy is recovered via the reversed process with the engine functioning as a generator, converting mechanical energy to electrical energy. The electric engine may be mounted on the steering shaft or placed at the wheels.

2.4.2.6 Challenges for electric vehicle technology
Production series are currently low and the purchase price of EVs is high. Large production volumes and technological progress is a necessity for a large-scale introduction of EVs, and may result in reduced costs.

A Swedish study reports that range anxiety affects possible EV consumers. However, the study also found that 80% of the Swedish daily driving distances are less than 50 km. This could be covered by current battery technology, see Figure 8 (Elforsk, 2009b).

![Figure 8 Travelling pattern visualised by daily driving distance less than 50 km and the accumulated percent of total driving distance below 50 km. Numbers adapted from Elforsk (2009b)](image)

In the case of the PHEV, the size of the battery and the distance driven before recharging determines the ratio between electric kilometres and ICE kilometres. The batteries in a PHEV usually offer between 20 and 60 km electric range. Several studies (Kågeson, 2006; Duval, 2004) consider the most beneficial battery size to be 10-12 kWh, corresponding to an electric range of approximately 40 km.
These studies also show that 66 % of the distance travelled in PHEVs with 40 km electric range is driven in electric mode. The electricity consumption amounts to 40 % of the total fuel input. This implies that 2/3 of all kilometres consume only 2/5 of the total fuel consumption (Kågeson, 2006; Duval, 2004).

2.4.2.7 Electricity considerations
The Swedish electricity distribution grid is well developed. A large-scale introduction of EVs (between 1,9 and 2,6 % assumed 1 million vehicles) is assumed to have no significant impact on the Swedish electricity system (VINNOVA, 2010b). Hence it is assumed that no grid improvements are necessary to balance an increased electricity demand due to the introduction of EVs (Elorsk, 2010).

Sweden has reliable power generation, few power supply interruptions (Elorsk, 2010) and is not dependant on other nations for electricity supply (Energimyndigheten, 2010). This implies that an electrified Swedish transport sector would not be very sensitive to geopolitics. The concept of smart grids is sometimes discussed in connection with EVs. However, this study does not take smart grids into consideration.

Since EVs are fuelled by electricity, their GHG emissions depend on how the electricity is produced. According to Dotzauer (2010), there are different principles of assessing the environmental impact of electricity generation. One principle often used is average electricity, in which the average emissions of the electricity mix are calculated. The electricity mix could for instance be Swedish or Nordic production. Another principle is marginal electricity, in which the emissions of the marginal production unit are calculated. Power plants with low operational costs are utilised first, and with increasing demand plants with higher operational costs are put in operation. The marginal production unit is the unit in operation which has the highest operational costs.

When calculating emissions from already used electricity, average electricity gives a fair assessment of the environmental impact. When calculating emissions from future use of electricity, marginal electricity gives a more accurate assessment since this kind of analysis accounts for changes in demand and supply (Dotzauer, 2010; Sjödin, 2003).

Since Swedish power supply is not isolated within national boundaries, but part of a European market, coal condensing (CC) and natural gas combined cycle (NGCC) power plants are part of the energy system even though they are not included in the Swedish electricity mix. Today, CC power plants are often considered the marginal production units (Sjödin, 2003). In a more long-term future, NGCC is assumed to replace CC power production (Sjödin, 2003), and so NGCC plants are often considered the marginal production units for 2030.

The different ways of calculating GHG emissions from electricity use give very different results. A Swedish mix of mostly nuclear and hydropower emits less than 66 g CO₂ eq/kWh, while CC power emits up to 1050 g CO₂ eq/kWh (Dotzauer, 2010). When assessing the environmental impact of EVs, the method used affects the results to great extent. CO₂ emissions from a PHEV running on CC power are approximately equal to those from the same PHEV running on petrol (van Vliet, 2011).
2.4.3 Fuel production technologies

There is a range of different production technologies for each biofuel, and the purpose in this section is not to cover all possible technology choices, but rather to explain the basic principles of the production. The biofuel production routes for each type of feedstock is visualised in Figure 9. This section also briefly describes the development stage of the technologies and their strengths and weaknesses (Table 3).

![Biofuel production routes](image)

Figure 9 Biofuel production routes, modified from Bram et al. (2009). Options with dotted lines are not considered in this study.
<table>
<thead>
<tr>
<th>Fuel</th>
<th>Strengths</th>
<th>Weaknesses</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st generation biofuels (Used commercially today)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethanol, wheat</td>
<td>Easy to use in todays infrastructure and vehicles. Low local emissions compared to petrol.</td>
<td>Low production potential. Low energy and resource efficiency and competition with food production. High GHG-emissions.</td>
<td>Demirbas (2009); JEC (2007); Börjesson and Tufvesson (2011); Markevicius et al. (2010)</td>
</tr>
<tr>
<td>Biogas</td>
<td>Produced from waste. Negative GHG-emissions, due to avoided methane emissions when treating waste.</td>
<td>Requires expensive infrastructure and transport, and vehicle modifications. Limited production potential. Risk for methane emissions, which is a powerful GHG.</td>
<td>Börjesson and Tufvesson (2011); Börjesson and Berglund (2007); JEC (2007); Miljödepartementet (2005); Mårtensson (2007); Jonerholm et al. (2010)</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>Can be blended with diesel and used in todays infrastructure and vehicles. Lubricating effect on engine parts.</td>
<td>Low production potential. Low energy and resource efficiency and competition with food production. High GHG- and local emissions.</td>
<td>Marchetti (2011); Basha et al. (2008); Börjesson and Tufvesson (2011); Eriksson and Rehnlund (2008)</td>
</tr>
<tr>
<td>2nd generation biofuels (Demonstration processes in operation today)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethanol, lignocellulose</td>
<td>Same as for ethanol from wheat. Low energy consumption and GHG-emissions compared to 1st generation. High production potential.</td>
<td>High energy consumption and GHG-emission compared to 2nd generation biofuels.</td>
<td>Balat (2011); JEC (2007); Demirbas (2009)</td>
</tr>
<tr>
<td>SNG</td>
<td>High energy efficiency and low GHG-emissions. High production potential.</td>
<td>Same as for biogas except the production potential.</td>
<td>Börjesson and Tufvesson (2011); Miljödepartementet (2005); JEC (2007); Perimenis et al. (2010)</td>
</tr>
<tr>
<td>FT-diesel</td>
<td>Easy to use in todays infrastructure and vehicles. Low GHG-emissions. High production potential.</td>
<td>Low energy efficiency compared to 2nd generation biofuels from gasification.</td>
<td>JEC (2007); van Vliet at al. (2009) Balat et al. (2009)</td>
</tr>
<tr>
<td>DME</td>
<td>High energy efficiency and very low GHG-emissions. High production potential.</td>
<td>New infrastructure and modification of vehicles required.</td>
<td>JEC (2007); Volvogroup (2011a); Volvogroup (2011b)</td>
</tr>
</tbody>
</table>
2.4.3.1 1st generation biofuels

2.4.3.1.1 Ethanol from starch and sugar crops
The feedstock for 1st generation ethanol is plants rich in starch (grain) or sugar (sugar cane and sugar beets) (Naik et al., 2010).

The most important process steps are the hydrolysation, fermentation and distillation. The starch is spliced to glucose during the hydrolysation, which can be done chemically with acidic conditions or with the use of enzymes. The glucose is fermented by microorganisms to a mixture of ethanol and water, which is purified through distillation, rectification and dehydration. (Naik et al., 2010)

There are a number of high value by-products from the process, like the distillate, the fermented grain or the straw. These may be used for energy conversion (heat and power production) or sold as new products (stillage for animal food), which can help balance the economy and the environmental impact of the process (Cardona and Sanchez, 2007).

It is widely debated whether 1st generation ethanol production is environmentally sustainable and contradictory results are published in this field. Reasons mentioned for using ethanol is its potential to reduce the GHG emissions and a clean combustion compared to petrol (Demirbas, 2009). Other advantages are that it is a renewable fuel, available today, produced in a well-known process and then easily distributed (JEC, 2006). Disadvantages of ethanol production are the necessity for large areas of farmland, which can lead to emissions from direct and indirect land use change, competition with food and feed production and possibly to losses of biodiversity (Börjesson and Tufvesson, 2011). Other issues that can be raised, especially regarding grain ethanol, are whether it causes soil erosion, loss of organic matter and consumption of large amounts of irrigation water (Markevicius et al., 2010). The extensive use of artificial fertilizers in agriculture cause nitrous oxide emissions, which is a powerful GHG (Börjesson and Tufvesson, 2011). Ethanol has also been criticised for high energy use and almost no improvement in GHG emissions compared to fossil fuels. The data in section 3.4 shows that ethanol is a less desirable alternative compared to many other biofuels but still an improvement compared to petrol.

The biggest producer of Swedish ethanol is Lantmännen Agroetanol with production facilities in Norrköping (Lantmännen Agroetanol, 2011). The ethanol is distributed blended in petrol or as E85, E95 or pure ethanol (Lantmännen Agroetanol, 2011) and in 2010, 400 000 m³ per year was used in Sweden (SPI, 2011).

2.4.3.1.2 Biogas
The feedstock for biogas production via anaerobic digestion is diverse, and includes different kinds of organic waste, e.g. industrial, agricultural, municipal solid waste or wastewater treatment sludge, as well as energy crops, like corn and wheat. The materials can be co-digested or used by them selves (Avfall Sverige, 2008).

The biogas process consists of three major blocks, pre-treatment, anaerobic digestion and purification (Lantzet al., 2007).

The pre-treatment can be mechanical, physical, enzymatic or chemical, and the purpose is to achieve a higher biogas yield during the anaerobic digestion, but pre-treatments cost money and energy and needs to be considered thoroughly (Bruni et al., 2010; Zhong et al., 2011).
During the anaerobic digestion, biogas is produced when microorganisms degrade biological material under anaerobic conditions, and the raw gas contains approximately 50-80% methane and 20-50% carbon dioxide together with small amounts of impurities, e.g., hydrogen sulphide (Lantz et al., 2007). The raw gas can be upgraded to vehicle quality, by stripping of carbon dioxide and purification to remove the hydrogen sulphide and other unwanted compounds (Lantz et al., 2007). The waste material from the AD can be treated in different ways, depending on the type of material, and used as fertilizer (Abdullahi et al., 2008).

A benefit of biogas production, is that the input material is considered waste and therefore, the negative GHG emissions in WTW studies are due to the avoidance of GHG emissions that would have occurred if the waste had not been taken care of in a controlled process, e.g. spontaneous methane emissions from manure (Börjesson and Tufvesson, 2011). A problem is that there still are emissions during the production and the utilisation of biogas, which needs to be controlled and measured to ensure that the biogas production is climate friendly (Börjesson and Berglund, 2007).

Biogas infrastructure for distribution and refuelling is more expensive than for liquid fuels (Miljödepartementet, 2005), and this might inhibit the development of infrastructure of biogas, which in turn creates insecurity for users. 0.58 TWh of biogas was used for Swedish transports during 2010 (SPI, 2011a) and the major part is produced at wastewater treatment plants (Energimyndigheten, 2010).

2.4.3.1.3 Biodiesel

Biodiesel can be produced from vegetable and animal fats, and algae (Marchetti, 2011). Transesterification is the main reaction in the production of biodiesel, where the fat reacts with short chain alcohols, e.g. methanol, and the most abundant by-product is glycerol (Apostolakou et al., 2009). After the transesterification there is a downstream process for separation and purification of the biodiesel (Apostolakou et al., 2009).

The advantages and disadvantages for biodiesel from agricultural feedstock are much like those of ethanol (Börjesson and Tufvesson, 2011). However, in this study biodiesel (RME) achieves GHG reductions compared to petrol (see section 3.4). The potential of cultivating and using rape for RME production in Sweden is limited and only a fraction of fossil diesel use can be substituted by RME (Eriksson and Rehnlund, 2008). A possibility to improve the economy and resource efficiency of RME is by selling the by-products as animal feed.

Biodiesel can easily be blended with diesel and distributed through the existing distribution network. When it comes to engines the advantage is the lubrication effect from biodiesel extending the engines lifespan (Marchetti, 2011), and one issue is that high concentrations of RME has high local emissions and does not function with the new type of particle filter that is used for light vehicles today and will be used for heavy duty vehicles around 2014 (Eriksson and Rehnlund, 2008). There are also difficulties with ignition in Diesel engines, caused by the fuels high viscosity and low volatility (Basha et al., 2008), especially at low temperatures (Marchetti, 2011).

Today 2.06 TWh of FAME are used for Swedish transport and most of it is blended in low concentrations (maximum 7%) in fossil diesel, while a small amount is utilised pure (SPI, 2011a). In 2008 there were no new passenger cars running on pure biodiesel on the market, although there are heavy duty vehicles dedicated to pure biodiesel (Eriksson and Rehnlund, 2008).
2.4.3.2 \textit{2nd generation biofuels}

2.4.3.2.1 Lignocellulosic ethanol
Ethanol can be produced from lignocellulosic materials, like agricultural and forest residues, grasses and fast growing wood (Brethauer and Wyman, 2010). The production process for 2\textsuperscript{nd} generation ethanol resembles the process for 1\textsuperscript{st} generation ethanol, and the main steps are pre-treatment, cellulose hydrolysis, sugar fermentation and ethanol recovery and purification (Piccolo and Bezzo, 2009).

It is necessary to utilise different pre-treatment and hydrolysisation methods, since the structure of lignocellulose is more complex than that of starch. The pre-treatment is supposed to break down the lignin and cellulose structure (Girio et al., 2010), and the choice of pre-treatments depends on the properties of the biomass feedstock and it affects the rest of the process, e.g. the demand for energy and water (Alvira et al., 2010). It is followed by hydrolysis, usually enzymatic (Gnansounou and Dauriat, 2010), which converts cellulose and hemicellulose to monomer sugars, and those are fermented (converted to ethanol) in the next step (Piccolo and Bezzo, 2009). The hydrolysis and fermentation can also be combined and achieve higher ethanol yields with smaller amounts of enzymes (Piccolo and Bezzo, 2009). The rest of the process is the same as for 1\textsuperscript{st} generation ethanol, with the addition of lignin separation.

The major advantage of lignocellulosic biofuels is the low cost and high availability of feedstock (Balat, 2011), especially compared to 1\textsuperscript{st} generation ethanol. Advantages and disadvantages concerning distribution and use in vehicles are the same as for 1\textsuperscript{st} generation ethanol. Lignocellulosic ethanol has low GHG emissions compared to 1\textsuperscript{st} generation biofuels, but not compared to biogas and biofuels produced by gasification (see section 3.4). Also, the 2\textsuperscript{nd} generation ethanol production process has high energy consumption compared to other biofuels (see section 3.2), which is problematic in the perspectives of resource efficiency and economy.

Huge efforts are put into the commercialisation of the production of lignocellulosic ethanol and there are many research and development projects dedicated to this (SEKAB, 2011). In Sweden there is a demo facility for production of lignocellulosic ethanol in Örnsköldsvik, operative since 2004 (SEKAB, 2011).

2.4.3.2.2 Gasification of biomass
Gasification is a technology for producing 2\textsuperscript{nd} generation biofuels from lignocellulosic biomass. The feedstock materials are biomass from forestry, agriculture and cellulosic energy crops, e.g. tops and branches, black liquor from pulp mills and crop residues (Zhang, 2010a).

Gasification is performed at high temperatures and requires a gasifying agent, such as air, steam or oxygen in different mixtures (Balat et al., 2009). The process can transform solid biomass to syngas, which predominantly contains hydrogen, carbon monoxide, methane and carbon dioxide (Wang et al., 2008). The syngas is cleaned (Tijmensen et al., 2002) and can then be utilised in production of FT-diesel, methane or DME (Wang et al., 2008).

The energy and GHG balances of transport fuels produced by gasification are favourable compared to 1\textsuperscript{st} generation biofuels and lignocellulosic ethanol, with the exception of biogas (see section 3.4). Fuels produced by gasification have a high production potential since new types of feedstock can be used. These include different types of waste and energy crops with a high production capacity. The impact on land, water, and air resources and competition with food production are overall lower compared to 1\textsuperscript{st} generation biofuels (Zhang, 2010a).
A possible disadvantage is the necessity for large and expensive production facilities in order to reach high production efficiency. To make the process efficient and economic it may also be necessary to utilise all energy and by-products available in the production, e.g. by combining it with electricity generation (Tijmensen et al., 2002) or district heating (Difs et al., 2010).

**Synthetic natural gas (SNG) from biomass**

The syngas produced by gasification contains methane, which can be separated after the cleaning of the syngas. The syngas methane fraction can be increased by using an appropriate gasification process, e.g. low temperature gasification (Åhman, 2010). The carbon monoxide, carbon dioxide and hydrogen remaining in the syngas are converted to methane and water (van der Meijden et al., 2010). The methane is hereafter purified and upgraded for vehicle use (van der Meijden et al., 2010). Methane produced in this process is called SNG.

SNG has high conversion efficiency (Börjesson and Tufvesson, 2011) but the highest GHG emissions among the biofuels from gasification (see section 3.4). SNG has similar advantages and limitations as biogas when used in the transport sector, and it can be distributed by the same infrastructure as natural gas and biogas.

SNG production via gasification of biomass has been demonstrated in Güssing, Austria (RENET, 2011), and a 20 MW demonstration facility in Gothenburg, Sweden, is planned to be operational 2013 (Göteborg Energi, 2011).

**FT-diesel**

The Fischer-Tropsch reaction converts hydrogen and carbon monoxide from purified syngas into hydrocarbons of different lengths (Balat et al., 2009). When producing FT-diesel, the process temperature and catalyst are chosen to achieve a high fraction of liquid hydrocarbons (Zhang, 2010).

The WTW energy and GHG balance for FT-diesel are favourable, although FT-diesel does not have the same energy efficiency as DME and SNG (see section 3.4). FT-diesel is completely compatible with the distribution chain for fossil diesel (van Vliet et al., 2009), and it has good ignition properties (Balat et al., 2009). This simplifies a fast introduction of the fuel when the production reaches commercial scale.

FT-diesel production demonstration plants are in operation in Germany and Finland, and in Sweden there are plans to produce FT-diesel in small volumes at gasification facilities, e.g. in Piteå, Umeå and Härnösand (Biofuel region, 2011).

**Dimethyl ether (DME)**

DME is conventionally produced from methanol in a reaction catalysed by aluminium (Zhang, 2010a). The purified syngas is first converted to methanol and then to DME. However there is another more efficient production process under development, which enables the conversion of syngas to DME in a single step (Ju et al., 2009). DME has favourable energy and GHG balances in relation to almost all other biofuels (see section 3.4).

Under normal pressure and room temperature DME is a gas, but it can be stored and used as a liquid if pressurised to 5 bar (Volvogroup, 2011b). As of 2011 there is no biofuel with these properties commercially available. Distribution of DME is similar to that of liquefied
petroleum gas, which is available at a few fuelling stations (Volvo group, 2011b). Hence development of both production and distribution is necessary for commercialisation of DME.

In Sweden, a demonstration facility for black liquor gasification with DME production from biomass is operative in Piteå. This is a part of a project evaluating the production, distribution and vehicle technology (Chemrec, 2011). In addition, an industrial scale demonstration plant with the same technology is planned in Örnsköldsvik, and production start is scheduled to 2013 (Chemrec, 2011b).

2.4.4 Polygeneration
For economical and environmental competitiveness of biofuels, the conversion of biomass into liquid and gaseous biofuels needs efficiency improvements. Integrating production processes in a combination that maximises feedstock utilisation can increase the total process efficiency. Achieving several products from one process is called polygeneration. Fuel production processes can be combined with each other or with heat and power production, chemical and biomaterial production, or integrated with already established production processes. A facility converting biomass into this range of products is called a biorefinery. The concept is often built around a paper and pulp mill (Huang et al., 2010).

Black liquor gasification is one way of incorporating biofuel production into the paper and pulp industry (Naqvi et al., 2010). Treatment of stillage from ethanol production by anaerobic digestion (producing biogas) is an example of combining fuel production processes which produces two fuels, thereby increasing the total efficiency of the process (Murphy and Power, 2008). Production of heat and power is often considered when dealing with energy conversion processes, and one option is to integrate the biofuel production into existing heat and power production systems (Difs et al., 2010). There are many synergy effects to be found between production processes and it may be crucial for a large-scale commercialisation of biofuels to find concepts with high total process efficiency and products with high economic value.
3 Literature study as basis for assumptions

3.1 Vehicles and fuels

3.1.1 Passenger car
In this study biomethane, ethanol and synthetic diesel are considered suitable fuels for passenger vehicles. A simplification would be to merely include biomethane and ethanol, as is done by Hådell (2009). The heavy passenger car’s kerb weight is defined from 1500 kg and it is assumed that the fuel consumption is 20% higher than for the light passenger car. This is based on the assumption that the increase in fuel consumption is the same as the increase in kerb weight. In comparison, Cheah (2010) estimates a decrease of fuel consumption to 7% for a weight reduction of 10%.

3.1.2 Bus
For buses, energy efficiency data is obtained from a well-to-wheel (WTW) report on heavy-duty vehicles (Ahlvik, 2008). In this study, ethanol, biomethane, synthetic diesel and DME are considered likely fuels for urban public transport buses.

3.1.3 Light- and heavy-duty trucks
In this study, synthetic diesel and DME are selected as suitable fuels, with data obtained from Ahlvik (2008).

3.1.4 Motorcycles
The motorcycles are assumed to be equipped with a conventional powertrain. Synthetic diesel and ethanol could be used as fuel for the motorcycles, which is assumed in this study.

3.2 Fuel economy
Fuel economy is a measure of a vehicle’s fuel consumption. There are large variations in the fuel economy between different vehicles, and this study uses an average energy consumption 2030 for each vehicle type and fuel. Some of the reports studied included estimated data for 2030 and for those the assumption of an energy efficiency of 25% (further discussed in section 3.2.1) was not applied. When changing the fuel in the vehicle the driveline often needs to be somewhat modified. This can affect the weight and design of the car and the efficiency of the engine, hence the fuel economy of the total vehicle.

Many studies use models and simulations to predict energy efficiency data for future technologies and fuels. A disadvantage of this kind of method is that simulations of model vehicles is not real life testing and highly dependent of input data. The average energy consumption is estimated by driving cycles, which is a predetermined driving pattern that enables comparison between vehicles.

There is a multitude of driving cycles for vehicle testing, developed by different organisations and the driving cycle may be adapted to a specific purpose, e.g. city or highway driving. Results from the same driving cycle are comparable but no comparison may be made between driving cycles. Data for this study is extracted mainly from urban driving cycles.
### Table 4 Fuel consumption 2030 (kWh/100 km)

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Ethanol</th>
<th>Biomethane (biogas, SNG)</th>
<th>Synthetic diesel (FT, RME)</th>
<th>DME</th>
<th>Electricity (BEV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPC</td>
<td>40</td>
<td>39</td>
<td>37</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>HPC</td>
<td>48</td>
<td>47</td>
<td>44</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>LDT</td>
<td>78</td>
<td>81</td>
<td>78</td>
<td>76</td>
<td>35</td>
</tr>
<tr>
<td>HDT</td>
<td>391</td>
<td>403</td>
<td>387</td>
<td>377</td>
<td>150</td>
</tr>
<tr>
<td>Bus</td>
<td>437</td>
<td>457</td>
<td>447</td>
<td>440</td>
<td>110</td>
</tr>
<tr>
<td>MC</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

1. Data for 2010 passenger cars from JEC (2006a) with a 25 % energy efficiency improvement.
2. Data for 2010 passenger cars from JEC (2006a) with a 25 % energy efficiency improvement and 20 % higher energy consumption, due to the higher weight. Calculated from Heavy-duty truck data from Ahlvik (2008) and light duty diesel truck data from Trafikverket (2011). The proportional energy efficiency between different fuels was assumed to be the same for light and heavy trucks.
3. Trafikverket (2011)
4. Data for Ahlvik (2008) with a 25 % energy efficiency improvement
5. Data for a petrol fuelled motorcycle from Trafikverket (2011), and ethanol and diesel is assumed to have the same energy efficiency as petrol.

### 3.2.1 Improvement of fuel economy to 2030

In this study it was assumed that the average fuel consumption for all vehicles would improve by 25 % until 2030, based on Bandivadekar et al. (2008), Byman et al. (2009), Crosby (2009) and Duval (2004).

Every part of the vehicle may be improved to decrease the fuel consumption of the vehicle. Improvement of vehicle aerodynamics, tire rolling resistance and engine efficiency as well as weight reduction and mild hybridisation may improve the fuel economy (Bodek and Heywood, 2008; Bandivadekar et al., 2008). A mild hybridisation, including start / stop system, regenerative braking and electric drive at low loads and speeds, may provide significant energy savings (Bandivadekar et al., 2008).

The internal combustion engine has been optimized for utilising petrol and diesel over a long time and a significant increase in engine efficiency has been achieved. This development is assumed also for new types of fuel, especially for fuels dissimilar to petrol and diesel.

Energy efficiency improvements were historically used to increase power, weight and size, why nearly no improvement in vehicle fuel economy was achieved (Bandivadekar et al., 2008). Another factor to consider is the rebound effect from increased energy efficiency, when the reduction in fuel consumption leads to more driving (Greening et al., 2000). The relevance and magnitude of this effect is a controversial question, and the impact of the effect probably varies between sectors (Greening et al., 2000).

### 3.3 Studies on future use of biofuels in the Swedish transport sector

The purpose of the section is to review literature to find estimations on the possible amount of each biofuel 2030, both per vehicle type and in total. The trends found in this summary are to some extent used as guidelines to create the scenarios. It is important to stress that this is a mixture of predictions and scenarios and that they all are based on specific assumptions.
The Swedish Energy Agency has made a long-term prognosis about the Swedish energy use, where biogas and FAME is considered to be common fuels 2030. The shares of ethanol and FAME are almost equal, while the share of biogas is slightly lower, and biofuels are mainly distributed blended in diesel and petrol (Energimyndigheten, 2011). The predictions are based on the energy- and climate policy measures decided upon in the middle of 2010 (Energimyndigheten, 2011).

Hådell (2009) studied what needs to be done in order to achieve 10 % renewable energy in the Swedish transport sector by 2020. Hådell (2009) presumed that biogas is used mostly for cars and buses, DME for heavy traffic, ethanol blended in petrol and FAME and FT-diesel blended in diesel.

The biofuel production potential in Sweden 2030, according to the Swedish Ministry of Environment, is estimated to 5.8 TWh biogas, 2.10 TWh grain ethanol, 1 TWh RME, 14 TWh cellulose ethanol and 30 TWh synthetic fuels like DME or methanol (Miljödepartementet, 2005). Another report regarding the future energy use in the Stockholm region predicts a biofuel composition of 0.6 TWh biogas, 0.8 TWh ethanol and 3.1 TWh synthetic diesel (Byman, 2009).

In another vision about a fossil independent transport system in Sweden 2030, the biofuel use for every vehicle type is estimated. Here passenger cars, followed by heavy-duty trucks, use the largest amount of biofuel (Sköldberg et al., 2010).

It is clear that in order to achieve a large share of biofuels, the 2nd generation biofuels, with a production potential, lower emissions and lower primary energy consumption are needed. It also seems that biomethane and ethanol are used more for passenger cars and buses, while DME and also synthetic diesel are used more for heavy-duty vehicles.

3.4 Well to wheel energy and greenhouse gas emissions

Well to wheel (WTW) studies covers the whole life cycle of a fuel from the cultivation of crops to the final combustion in the engine and the transport work performed by the fuel. The WTW can be divided in well to tank (WTT) and tank to wheel (TTW). In this section, the focus is energy balance (Table 6) and GHG emissions (Table 5) and the functional units are MJ/MJ final and g CO2-eq/km. The abundance of methodologies and assumptions in WTW studies, as well as regional conditions and different production processes, leads to large variations in results and makes it difficult to generalise and compare WTW studies. This is also a weakness in the JEC report (2007), where the TTW methodology is consequent, but the WTT data is gathered from a range of sources from different processes and regions, studied with different methodology. However this is the most extensive WTW study available and it is widely cited, and most reports studied during this project have to some extent used JEC (2007) data.

In this study, data was chosen based on the criteria of efficient production routes that could be representative for Sweden. Data for 1st generation biofuels, i.e. biogas, ethanol and RME, was found in a life cycle analysis of Swedish biofuels (Börjesson et al., 2010). The GHG emissions estimated by Börjesson et al. (2010) are slightly lower than the emissions estimated by JEC (2007), especially for RME.

The production processes include fossil fuels and artificial fertilizers, and many other emission sources, which possibly can be reduced until 2030, e.g. by using more biomass and biofuel in the processes and recycling more of the fertilizer components.
There are probably many other efficiency measures that can reduce both energy consumption and emissions during the lifecycle of the fuel. Those are however not included in this study, mainly because the 2\textsuperscript{nd} generation biofuel production processes are under development and it is uncertain if they can achieve expected efficiencies and emission levels when producing in large scale.

Table 5 WTW GHG-emissions 2030 (g CO\textsubscript{2}eq/km)

<table>
<thead>
<tr>
<th>Fuel</th>
<th>LPC</th>
<th>HPC</th>
<th>Bus</th>
<th>LDT</th>
<th>HDT</th>
<th>MC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol, wheat\textsuperscript{1}</td>
<td>35</td>
<td>42</td>
<td>394</td>
<td>69</td>
<td>353</td>
<td>42</td>
</tr>
<tr>
<td>Ethanol, lignocellulosic\textsuperscript{2,3}</td>
<td>27</td>
<td>32</td>
<td>355</td>
<td>55</td>
<td>317</td>
<td>34</td>
</tr>
<tr>
<td>Biogas, mixed\textsuperscript{4}</td>
<td>-25</td>
<td>-30</td>
<td>-308</td>
<td>-52</td>
<td>-257</td>
<td></td>
</tr>
<tr>
<td>SNG\textsuperscript{2}</td>
<td>15</td>
<td>18</td>
<td>179</td>
<td>32</td>
<td>158</td>
<td></td>
</tr>
<tr>
<td>Biodiesel, RME\textsuperscript{5}</td>
<td>35</td>
<td>42</td>
<td>425</td>
<td>74</td>
<td>368</td>
<td>46</td>
</tr>
<tr>
<td>FT-diesel\textsuperscript{2,3}</td>
<td>8</td>
<td>9</td>
<td>93</td>
<td>16</td>
<td>80</td>
<td>10</td>
</tr>
<tr>
<td>DME\textsuperscript{2,3}</td>
<td>6</td>
<td>7</td>
<td>89</td>
<td>15</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>Petrol\textsuperscript{2}</td>
<td>86</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Calculated from CO\textsubscript{2}-ekv. Emission data from table 7 in Börjesson et al. (2010), based on system expansion and with emissions from final use in the vehicle included, multiplied energy efficiency data in section 3.2.
2. Emissions data from JEC (2007), minus the energy efficiency improvement of 25 % corresponding to 25 % less emissions. The specific production and vehicle technology for the data was; woodwaste, DISI with DPF for FT-diesel, wood waste, DIC1 without DPF for DME and wood waste and DISI for lignocellulosic ethanol.
3. Calculated from energy consumption data in section 3.2, and WTW CO\textsubscript{2} emissions per energy unit, derived from WTW CO\textsubscript{2} emissions per km for cars and WTW energy per km for cars (including credit for renewable combustion) (JEC 2007), and emissions from combustion in heavy duty vehicle included for ethanol (Börjesson et al. 2010).
4. Calculated as 1, and the biogas data is an average of emissions for municipal solid waste, industry and manure.
5. WTT data from table 6 in Perimenis et al. (2010), and data for emissions from final use in the vehicle from Börjesson et al. (2010).

Table 6 Energy balance (MJ\textsubscript{primary fuel}/MJ\textsubscript{final fuel}). Calculated from data in JEC (2006b)

<table>
<thead>
<tr>
<th>Fuel</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol, wheat</td>
<td>2.69</td>
</tr>
<tr>
<td>Biogas, mixed</td>
<td>1.93</td>
</tr>
<tr>
<td>Biodiesel, RME</td>
<td>2.2</td>
</tr>
<tr>
<td>FT-diesel</td>
<td>2.19</td>
</tr>
<tr>
<td>DME</td>
<td>2.07</td>
</tr>
<tr>
<td>SNG</td>
<td>2.14</td>
</tr>
<tr>
<td>Lignocellulosic ethanol</td>
<td>2.94</td>
</tr>
</tbody>
</table>

3.5 Biofuel production potential in the region of Mälardalen

In this section it is estimated how much of each type of biofuel that can be available in 2030, i.e. the production potential of each biofuel (see Table 7) The potential can be physical, where the total amount of feedstock is accounted for; technical, where technical limitations restrict the potential; or economical, where the potential is decided by economical restrictions. Several other factors, like acceptance and competing use, might influence the realistic potential, which makes it difficult to decide. In this section the aim is to estimate a production potential based mainly on physical and technical limitations, although the scarcity of regional data leads to assumptions, explained for every fuel.
The system boundary for biofuel production potential used in this study (see section 1.3.2) is the region of Mälardalen, and it is assumed that 30% of the biofuel in the region can be used in the City of Stockholm.

### Table 7 Biofuel production potential in the region of Mälardalen (TWh/year)

<table>
<thead>
<tr>
<th>Biofuel Type</th>
<th>Potential (TWh/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogas</td>
<td>1.5</td>
</tr>
<tr>
<td>Ethanol</td>
<td>1.2</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>0.2</td>
</tr>
<tr>
<td>2nd generation biofuel from woodfuel*</td>
<td>2.7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>5.6</strong></td>
</tr>
</tbody>
</table>

*Average for the three fuel produced via gasification (SNG, FT-diesel and DME).

#### 3.5.1 Biogas

There are several estimations of the regional availability of feedstock for biogas. A report regarding Swedish biogas production potential from waste (Avfall Sverige, 2008) estimates the potential in the region of Mälardalen to 2.958 TWh/year, with regard to technical and economical limitations. Another report analyses the potential for biogas production in 2020, estimating a total of 3.4 TWh/year in the region of Mälardalen (Mårtensson, 2007). However, without energy crops, the biogas production potential is only 0.8 TWh/year (Mårtensson, 2007). Jonerholm et al. (2010) estimates the potential to 1 TWh/year in 2020, in a scenario with fast production capacity development and farm biogas production.

Based on these results the biogas production potential in the region of Mälardalen is in this study estimated to 1.5 TWh/year.

#### 3.5.2 Ethanol

When it comes to fuels produced from crops it is available land that decides the production potential. The region of Mälardalen already has a large production facility for ethanol, which is a large part of the Swedish ethanol production. This facility is situated in Norrköping and produces 210 000 m³ ethanol/year (1.2 TWh) (Lantmännen Agroetanol, 2011), thereby demanding 550 000 ton of grain, which covers around 146 000 Ha of arable land (Lantmännen Agroetanol, 2011). This areal is equivalent to 13% of the available arable land in Mälardalen in 2010 (Jordbruksverket, 2011). Grain for this production is gathered from outside the region, also the ethanol is sold outside the region.

The potential for ethanol production used in this study is estimated to 1.2 TWh/year. This is a large volume if only grain from the region of Mälardalen is used and if all produced ethanol is used in the region.

#### 3.5.3 Biodiesel

Rape and turnip rape are grown on 37880 Ha, which could be used to produce around 0.22 TWh RME (Jordbruksverket, 2006). According to Jordbruksverket (2006), only 0.9% is actually used to produce RME, while Hansén and Pettersson (2008) estimate the use to 1.7%. The 37880 hectares for RME production would cover approximately 5% of the arable land in Mälardalen (Jordbruksverket, 2011).

The actual production of biofuels from grain and oil plants is difficult to decide since it competes with food production and is heavily influenced by economy and public acceptance.
As is discussed in section 2.4.3, it is also uncertain how these fuels can fulfil legislative sustainability criteria for biofuels which may be in place in 2030. However the aim in this section is only to decide the order of magnitude of the production potential.

### 3.5.4 2nd generation biofuels

2nd generation biofuels can be produced from a wide range of cellulosic waste material and energy crops. The available unused wood fuel has been estimated to 5.7 TWh/year (Lundmark and Söderholm, 2004), which could be used to produce approximately 2.6 TWh of FT-diesel, 2.76 TWh DME, 2.67 TWh SNG or 1.93 TWh ethanol per annum (calculated from the energy balance in section 3.4).

There are many other feedstocks for which the production potential has not been estimated, e.g. energy crops and agricultural waste, due to time limitations. However, the potential utilisation of wood fuel might not be reached due to technical and economical limitations, so other feedstocks are assumed to be included in the estimated potential. In addition, the realisable potential is limited by competition with alternative uses, mainly heat and power production. Therefore the total realisable potential is assumed not to be higher than the wood fuel potential.
4 Regional planning for the introduction of an energy efficient and renewable road transport system

The regional transport planning in the county of Stockholm is characterised by many actors acting on different issues by their own or in cooperation with other actors, no actor having the general responsibility for the planning in the whole region (further described in section 2.3). In this part the Stockholm regional planning in both documents and practices will be described and analysed to present a deeper understanding for how the regional level and transport and energy planning are managed.

The results from the document study and the performed interviews are presented in section 4.2 and 4.3 and a joint analysis using a few theoretical concepts is discussed in section 4.4. However, to begin with the document and interview studies are discussed in a methodological sense and the persons interviewed are also presented.

4.1 Interviews and document study - method

The regional planning in Stockholm for a renewable and energy efficient transport system is investigated by using the methods of documents study and interviews. The documents are used as both a background for the development of questions for the interviews and also as objects for analysis, in which only a few of all studied documents have been used. The documents represent the visionary and governing parts of the regional planning. The interviews are in this study used as expressions of the regional planning practices, thus a description of the real planning practice behind the documents.

The working process using documents and interviews has been performed in a very inductive way: all the empirical material was collected and compiled to clarify the general findings, then to be able to describe the findings in a more general and conceivable way some theoretical concepts from policy and large technical systems literature are used.

4.1.1 Studying documents – method

The study of the regional planning started with a close reading of the documents that could be found regarding energy and transport planning in the Stockholm region. The document study started with the general regional planning document, the Regional Development Plan of the County of Stockholm, and was then extended to the other documents by cross-references and tips by contacts. Documents were chosen if they involved discussions and plans about the transport system in the Stockholm County. It is the most recent documents that have been selected and all of them are developed during the last five years.

The analysis of the documents has been based on the two concepts, in focus of this study, namely transport and energy. Those two concepts have lead the research through the documents to find remarks and discussions concerning transport and energy issues, connected to the development of renewable fuels and the transport system. However, since the concept of energy is in some ways closely related to the concepts of climate and environment, at least in the question of renewable fuels, those concepts have also been in focus when reading the documents. It is in those cases when climate and environment have been mentioned in relation to transport or energy. In the results from the document study, the parts of the document where energy, transport, climate and environment have been mentioned are summarised and commented.
4.1.2 Studying interviews - method

To get a better picture of the regional planning practice, which is not told in the documents, five interviews focusing on the regional processes were performed. The five persons interviewed are all centrally placed in either the regional process of renewable fuels or spatial planning or both. The interviews are used as sources of information as well as sources expressing the views and perceptions of the involved actors (Esiasson et al., 2004).

To achieve a situation where the interview was more like a conversation the interviews were semi-structured and with a low level of standardisation (Esiasson et al., 2004). This was accomplished by open questions used to make the respondents tell their own story and an opportunity to ask attendant questions; more like guarded conversations (Svensson and Starrin, 1996). For example, the respondents were in the beginning of the interview asked to tell about their work and background and from that knowledge many of the questions were reformulated (if needed) to fit the respondent.

The questions were sorted in clusters according to interesting themes (Anderson et al., 2006). The interview guides were differently organised depending on the respondents’ workplace, position, background and profession (see appendix 1). The documents were used as background information in the development of the interview guides.

Four of the interviews were performed in person and one was done by telephone, however preceded by a personal meeting. That interview and one other were performed by one interviewer and the other three by two interviewers. In those cases one of the interviewers were asking the questions derived from the interview guide and the other interviewer listened and came up with comments and other complementing questions.

The selection of respondents to interview was done through two contacts on two different centrally placed workplaces that have knowledge within the field and could recommend other persons with knowledge about the study object. It was difficult to find respondents that had enough knowledge about the development and introduction of renewable fuels, why the selection of possible respondents was extended to those working with spatial issues. The reason was that the regional planning is established mostly regarding spatial questions and that renewable fuels to a large extent have to do with spatial considerations. This strategy for selecting respondents cannot guarantee that the most relevant respondents are chosen since they might be unknown to the contacts.

Four of the interviews were pre-booked, but the fifth was performed when a person, earlier contacted about doing an interview, was invited by another respondent to join the interview after that respondent’s interview was finished. Consequently, the fifth interview was not prepared with a specific interview guide and it had to be performed in an improvised way. However, thanks to the background knowledge the documents had provided for the interviewers it was possible to achieve relevant questions and answers anyway. It is important in this case to think of the situation the respondent was in: not prepared for interview and therefore the situation could have made the respondent answering differently than otherwise. However the respondent had been informed earlier by e-mail about what the interviews were supposed to be about and the respondent was only asked questions about its work, why it is possible to assume that the answers were rather similar to an ordinary interview.

All five respondents are civil servants. Given the political character of the transport system becoming clear in the planning process, a politician as respondent would have been desirable.
However, the purpose of studying the planning process was to include those people working with the implementation processes and also the initiation of new planning ideas. In that way, the respondents provided this study with material by informing about the real planning practice without promoting their own political agenda.

The interviews were analysed by thematically grouping answers under some questions. Those questions were both predefined and empirically identified. From those important questions a few analysis questions were derived, which were used in the joint discussion of both documents and interviews.

The respondents that take part in this study are presented below:

**Interview City of Stockholm 1**
The respondent works as a project manager at the Department of Clean Cars, a part of the Environment and Health Administration, at the City of Stockholm. The respondent has been a part of the department’s work to introduce ethanol, biogas and electricity for vehicles.

**Interview City of Stockholm 2**
The respondent works as an overview planner at the City Planning Administration at the City of Stockholm. The respondent has been a part of the development of the recent City Plan and is the administration’s representatives in many organs and collaborations within and outside the municipality.

**Interview Association of Local Authorities**
The respondent has responsibility for the overall environmental and social development issues on the Stockholm County Association of Local Authorities. The respondent is also working with questions of municipal solid waste within the Board on municipal solid waste and energy questions as responsible for the Regional Energy Agency and Energy Consulting within the Stockholm County.

**Interview County Administration Board 1**
The respondent works as an analyst under the Stockholm County Administration Board directorate. The respondent is currently investigating the question of a more renewable transport system in Stockholm and has especially studied the case of biogas.

**Interview County Administration Board 2**
The respondent works as a transport strategist at the section of Infrastructure and Entrepreneurship in the Growth department at the Stockholm County Administration Board. The respondent has foremost worked with the development of the County Plan for Transport Infrastructures in the Stockholm County 2010-2021.

The bold headings above will be used as references, when referred to the interviews in the coming texts.

### 4.1.3 Theoretical framework

To accomplish a deeper understanding of the results from the document and interview study about the regional planning process a few theoretical concepts are used in the final discussion of the region planning under section 4.4. The theoretical concepts are derived from the Political Science policy field and the Large Technical Systems field.
From the policy field the concept of policy entrepreneurs is used. The concept of policy entrepreneurs is mostly used to explain the role of single actors in the agenda setting – which issues will be handled in the political process (Hill, 2005; Kingdon, 2003). In the discussion about the regional planning the policy entrepreneurs could be organisations, individuals and artefacts (Latour, 1987). The agenda is the agenda concerning the planning of the road transport system. Policy entrepreneurs could also be boundary walkers, those connecting two or more policy areas together (Fallde, 2011). This meaning is also used in the discussion to describe how transport and energy planning are connected and in what ways they are not.

Large Technical Systems is Thomas P Hughes’ (1987) description of technological systems that are not only technical, but also socially constructed and society shaping. The large technical system contains many different parts, such as scientific, economic, politic and institutional parts, and they are so interdependent that it is meaningless to separate them (Palm, 2004). Over time, the technological system will acquire what Hughes (1987) calls momentum. When the system is established to such a degree that targeted investments are no longer necessary, the point of momentum is reached. The concept of momentum is thus used in the regional planning discussion to explain why some technologies are more popular to talk about and invest in over others.

4.2 Visionary and governing documents
In the Stockholm region, several documents about energy, environment, climate and transport issues have been presented during the last few years. There are documents that are results of cooperation between several actors. There are also planning documents that the actors have obligations to develop and present. In short, not all documents can be described more closely in this chapter. Some of the documents that have been left out do not only concern the county of Stockholm, but a more extended region including neighbouring counties as well. Other documents left out are those considering internal strategies within the City of Stockholm.

The documents chosen for analysis are the documents the respondents most frequently mentioned in the interviews, why they may be said to influence the regional planning regarding energy and transport. Those documents are summarised in Table 8.

The focus of the following text is to describe how the documents present energy, environment and transport issues, what measures they propose or in what other ways they suggest the problems should be handled. The conclusions drawn from the documents are that there are, what could be called, “energy documents” which discuss transport as one objective of the increasing need of energy efficiency. There are also documents, that could be called, “transport documents”, which almost only discusses transport from one single angle; the development and maintenance of road and rail infrastructures. The energy objectives of transports are often mentioned, but since the solutions seem to be so complex, it is considered in the documents, to leave them to other more suitable discussions and policies. In addition, there are broad documents with both energy and transport considerations, however, the broadness make them more unspecific. The separation of climate and energy issues is also clear, not only in those documents, where the strategies and solutions are separated into two: either climate or energy. This is further discussed in the following descriptions of the documents.
Table 8 The studied regional documents

<table>
<thead>
<tr>
<th>DOCUMENT</th>
<th>RESPONSIBLE INSTITUTION</th>
<th>PLANNING POLICY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional Development Plan of the County of Stockholm 2010 (Regional utvecklingsplan för Stockholmsregionen, RUFS 2010)</td>
<td>The County Council – the Office of Regional Planning (Landstinget – regionplanekontoret)</td>
<td>Transport and Energy planning</td>
</tr>
<tr>
<td>The Energy Future of the County of Stockholm 2010-2050 – the path towards decreasing impact on the climate (Stockholmsregionens energiframtid 2010-2050 – vägen till minskad klimatpåverkan)</td>
<td>Eleven private and public actors – among them the actors in this study: The County Council – the Office of Regional Planning (Landstinget – regionplanekontoret), the Stockholm County Association of Local Authorities (Kommunalförbundet Stockholms län), the County Administrative Board (Länsstyrelsen), the City of Stockholm (Stockholm Stad)</td>
<td>Energy planning with aspects on the transport system</td>
</tr>
<tr>
<td>Joint transport solution in the Stockholm region for Environment and development – until 2020 and towards 2030 (Samlad trafiklösning Stockholmsregionen för miljö och tillväxt – till 2020 med utblick mot 2030)</td>
<td>The government and representatives for the Stockholm municipalities - the Stockholm County Association of Local Authorities (Kommunalförbundet Stockholms län) – and the Stockholm County Council (Landstinget)</td>
<td>Transport planning focusing on infrastructures, with climate considerations</td>
</tr>
<tr>
<td>The County Plan for Transport Infrastructures in the Stockholm County 2010-2021 (Länsplan för transportinfrastruktur i Stockholms län 2010-2021)</td>
<td>The County Administrative Board (Länsstyrelsen)</td>
<td>Transport planning only focusing on infrastructures</td>
</tr>
</tbody>
</table>
4.2.1  Regional Development Plan of the County of Stockholm 2010 (Regional utvecklingsplan för Stockholmsregionen, RUFS 2010)

This is a visionary document with mandate to guide all private and public actors in the Stockholm region towards the regional goals of development and spatial planning outlined in the document. The Regional Development Plan of the County of Stockholm (RUFS) is a long-term document which is developed approximately every ten years (Magnusson, 2011). The last RUFS was launched in 2010 and the process of developing the document was continuing during several years to gain approval and legitimacy for the new plans (Regionplanenämnden, 2010). According to some of the respondents in the interviews, it seems like the document has gained more approval from the regional actors, than earlier RUFS documents have, but it is too early to tell if it is going to be any actual change (Interview City of Stockholm 2, Interview Association of Local Authorities).

The general vision is that Stockholm shall become the most attractive metropolitan region in Europe (Regionplanenämnden, 2010). To achieve the visionary goal, four goals of development are outlined and six strategies, which show how the goals of the vision could be achieved. To concretise the strategies, each of them have several planning goals that are supposed to be used as policy measures. There are also commitments under each strategy and they specify what need to be done to reach the goals (Regionplanenämnden, 2010).

Three of the six strategies concern the transport system and discuss either energy or transport issues or both (Regionplanenämnden, 2010):

- Strategy no 1. Increase renewable capacity and quality within education, transport and the housing sector
- Strategy no 3. Safeguard values for future needs
- Strategy no 4. Further develop a dense, multi-centre region

One of the major challenges concerning the transport system that is outlined in the RUFS is that the region’s total climate influence and energy usage need to decrease while the population and incoming commuters in the Stockholm region will increase significantly (Regionplanenämnden, 2010). Thus, the transport system must develop, without increasing climate influence and energy usage. The document is trying to solve this dilemma by several more or less specified arrangements.

In the RUFS the development of the railway is considered as a major achievement to decrease the region’s climate influence and the commitment is to “develop an attractive and capacity strong public transport which is available for everyone” (Regionplanenämnden, 2010: strategy 1). The attractiveness of the public transport system is considered important (Regionplanenämnden, 2010: strategy 4). The development of roads focuses on the need for new roads in some areas, at the same time as the demand for more roads has to be controlled and restrained. Reasons for restraining are decreasing congestion in the inner city and taking into consideration the road traffic’s effects on the health, environment and climate (Regionplanenämnden, 2010: strategy 1).

Resource efficient energy usage, emissions and transport issues are considered in a joint, detailed discussion in the RUFS. The transport system, as well as the residential sector, is distinguished as the two sectors where the energy usage must decrease the most until 2050 within the region. Because half of the energy used today is within the residential sector and one forth within the transport system (Regionplanenämnden, 2010: strategy 3).
To decrease the energy usage in the region overall, the importance of spatial planning as a measure to influence the energy outcome in all sectors is in focus. The influence of spatial planning in the long run is emphasised and a reason why it must start now (Regionplanenämnden, 2010: strategy 3). The most important change that the document proposes concerning spatial planning, is the will to develop more regional city centres, thus, Stockholm can turn from being a mono-centre region to a multi-centre region. One of the measures that are needed to fulfil this goal is a better possibility to travel between those regional city centres, and foremost that those travels must be on railways. The RUFS also refer to the Stockholm City Plan – the Walkable City – and point out that those regional city centres shall have the same qualities, being walkable, as is outlined in that plan (Regionplanenämnden, 2010: strategy 4).

In order to decrease energy use and transport emissions, a fast introduction of renewable fuels is proposed. The future scenario that is outlined in the document is: year 2020 the transports in the region are to a high degree driven by biofuels, plug-in hybrids and other kind of clean vehicles. In 2030 there will be no vehicles driven by fossil fuels and most of the transport sector consists of plug-in hybrids and electric vehicles (Regionplanenämnden, 2010: strategy 3).

Problems and development opportunities regarding an electrification of most of the vehicle fleet are not discussed in detail in the document, for example nothing is mentioned about the charging infrastructure. However, the problems and opportunities regarding biogas are discussed in more detail, for example by pointing out the municipal solid waste as one of the region’s main production resources.

Concerning the responsibility for a more energy efficient and fossil-free emission transport system the RUFS puts it on institutions on every level, private businesses and also individuals. In the document it is assessed that fossil fuel emissions are harder to decrease within the transport system, than in others sectors. However, since it is not part of the trading sector, it is possible to influence the development on regional and local levels to a higher degree (RUFS, 2010: strategy 3). The RUFS propose also management measures on the regional level to decrease the total transports, as well as similar management measures are needed on the national level as well. However, it is argued that regional measures must be seen as a complement to other national and international measures (RUFS, 2010: strategy 3). Thus, the region is not considered as the best institutional or geographical level to make the crucial interventions. The private sector and the individuals are also pointed out in the document, to have an important responsibility for the new technology development as well as taking initiatives to change their transport (Regionplanenämnden, 2010: strategy 3):

...initiatives from the business world and taking individual responsibility to save energy and adapt to renewable fuels should hurry up. This should happen through dialog and through public support for research, technology development, innovation and technology implementation... (Regionplanenämnden, 2010, p 88)

In summary the RUFS is a regional document that covers both transport and energy issues, and to a large extent makes them a joint discussion.
4.2.2 The Energy Future of the County of Stockholm 2010-2050 – the path towards reduced climate impact (Stockholmsregionens energiframtid 2010-2050 – vägen till minskad klimatpåverkan)

This document is the result of an Energy study over the Stockholm region, initiated by the County Council and performed in cooperation with several private and public actors in the region during the years 2007-2009. The objective of the document is to increase the knowledge among the actors on energy issues and inspire action. The document is also seen as platform for collaboration between the municipalities and between private and public actors in the energy field (Regionplanenämnden, 2009). Thus, the document is only an energy document, but the region’s transports are also discussed in one of the chapters.

The document outlines four factors, which is important to the vehicles’ energy usage: the vehicle’s technical performance, which fuel is used, the distance that is driven and the individual driver’s way of driving. Several measures must, according to those four factors, be combined if the transports will be more energy efficient, as argued in the document (Regionplanenämnden, 2009). To concretise the measures that is needed four specific challenges are outlined and five measures that the public sector is responsible for is described.

The first challenge, described in the document, is that renewable fuels must replace fossil fuels. Electricity and synthetic diesel are seen as the most probable fuels in cars. Biogas and bio-diesel will be used for the public transport and shorter transports on trucks. The document also considers that the second-generation ethanol could be useful in the future. Electricity is considered as the far future solution and until then it is argued that the solution is more energy efficient vehicles and renewables as biogas, bio diesel and ethanol. The measures considered important for the supply of renewable fuels are: that the permission processes regarding all alternatives must be simplified and that different sorts of information must be spread to the individuals so they are able to make more informed decisions, the region must collaborate with energy suppliers to increase the production of biogas and that the public authorities must give support to biogas production plants in the countryside (Regionplanenämnden, 2009).

The second challenge is to influence and change the demand for travels in the way that through policy measures influence people to not use the car to the same extent as before or change to renewable fuels. Examples of those policy measures are: the development of a more intelligent spatial planning that make people transport themselves with other vehicles than the passenger car, economical policy measures and information (Regionplanenämnden, 2009).

The third challenge is to increase the interest for public transport, which according to the document, is performed by providing a well-developed and attractive public system (Regionplanenämnden, 2009).

The fourth challenge is the quick introduction of cleaner and more efficient vehicles. Thus, the focus today, before the technological development for the alternative new technologies has been enough developed, the current combustion engine must be more efficient. The estimation in the document is that the combustion engine has become 20 % more efficient until 2020 and 30 % more efficient until 2030. The measures to reach this goal, that are proposed by the document are: make the public authorities’ fleets more energy efficient by public procurement; take an initiative to perform a technology neutral procurement on energy efficient vehicles within region; use the tax base to increase demand; make incentives for individuals to change to a more energy efficient alternative; and introduce carpools for the public sector (Regionplanenämnden, 2009).
In summary the *Energy Future of the County of Stockholm 2010-2050* is an energy document, produced on the regional level. The importance of technological neutrality in policy measures and support is emphasised throughout the whole document. However, it is especially biogas and electricity that gets the most detailed attention ([Regionplanenämnden, 2009](#)).

### 4.2.3 Joint transport solution in the Stockholm region for environment and development – until 2020 and towards 2030 (Samlad trafiklösning Stockholmsregionen för miljö och tillväxt – till 2020 med utblick mot 2030)

This document is the result of the so called Stockholm negotiation between the government and the public actors in the region in the year 2007. The reason for this negotiation was the newly introduced commuting tax in Stockholm and the issue of how the money from the tax should be distributed in the region ([Stockholmsförhandlingen, 2007](#)). Thus, the document is to the most extent a planning document for maintenance on existing infrastructures and the development of new ones, both road and railway. However, the document also includes a discussion about how the national environmental goals could be achieved in the transport system in the region.

The document picks out three of the 16 national environment quality goals as the most relevant goals for the negotiation: restricted climate influence, fresh air and good built environment. Among those three goals “the climate goal seems to be the most demanding” ([Stockholmsförhandlingen, 2007](#), p 26). The introduction of new vehicle and fuel technologies is described as the most promising to influence the greenhouse gas and other emissions from the transport sector. The government is, in the document, considered to have the institutional responsibility for an introduction like that:

...it is a national responsibility, that in international collaboration decide upon incentives that push the technology development and the introduction of new energy efficient and environmental friendly vehicles forward... ([Stockholmsförhandlingen, 2007](#), p 7)

The document has a long list of other things the government will continue or start to do as well, among all: continue to distribute resources to investments in renewable fuels and also work for a major development and distribution of biogas in the region. The regional actors, on the other hand, undertake two concrete commitments: to implement measures that stimulate travelling by other means of transport than the passenger car and to make environment requests at public procurements of transport services ([Stockholmsförhandlingen, 2007](#)).

In summary this is a transport document that actually discusses energy issues within the climate considerations. However, very few of the possible measures to achieve the climate goal seem to be considered better managed from the regional than the national and even the international level. Even the regional effort regarding biogas is considered in the document to be a governmental issue.

### 4.2.4 The County Plan for Transport Infrastructures in the Stockholm County 2010-2021 (Länsplan för transportinfrastruktur i Stockholms län 2010-2021)

The above-described document, *Joint transport solution in the Stockholm region for environment and development – until 2020 and towards 2030*, has been the base for the County Administration Board, when developing this County Plan for Transport Infrastructures. The purpose of the plan is to describe the prerequisites for and the consequences of the investments in the region that is described in the government’s investment plans for the years 2010-2021.
The main investments are in railways and public transport. The County Administration Board is the government’s authority in the region, why it has the major responsibility for the plan, but also the region’s municipalities and interest organisations have been a part of the discussions (Länsstyrelsen, 2010).

The document bases its discussions on the county of Stockholm as one region, but also extending the region to the surrounding counties as well, since a larger part of the commuting into the region comes from counties west and north of the Stockholm County. Moreover the plan is adapted to an increase in population of 300 000 – 500 000 more inhabitants until 2030 (Länsstyrelsen, 2010).

The document only deals with the question of regional land use and what infrastructural development and maintenance should be prioritised. However, in the part where the most important needs for the development of the Stockholm transport system are discussed, the need of changes in the current transport system and the importance of negative climate impact are mentioned, but not as the purpose of this document try to solve. The transports’ influences on the environment is described as a major social problem, especially regarding the transports’ influences on the climate (Länsstyrelsen, 2010). However, the County plan is described as almost not at all able to contribute to its solution. Instead, it is argued “no measures make enough effects on their own, but several measures must be put together” (Länsstyrelsen, 2010, p 63).

Examples of those measures that will solve the climate and environmental problem regarding transports are; new technologies, information, traffic control and economic policy measures. Moreover, some resources from the governmental budget is reserved for environment and climate interventions, which mean that some money is dedicated to work against traffic noise and some, are dedicated to “performing climate influencing measures in the shape of mobility management, which implies information and communication interventions” (Länsstyrelsen, 2010, p 48).

In summary the County plan includes no discussion of energy efficiency matters, but some reflections upon the climate issue. The investments in mobility management could be seen as an energy efficiency solution according to respondents (Interview City of Stockholm 2), but that is not how those measures are argued for in the document, thus, more as a general environment intervention. Consequently, since the document outlines the investments in the regional transports, it is an important transport planning document in the region, with no energy considerations.

### 4.2.5 The Walkable City - Stockholm City Plan 2010 (Promenadstaden – Översiktsplan för Stockholm 2010)

The Stockholm City Plan is a strategy document that describes how the city shall develop in general over the coming years. This last City plan was decided in the beginning of 2010, and focuses on how the city could become renewable at the same time as it is growing and the number of inhabitants increase. The vision is the walkable city, “where qualities as; the close, the safe and the environment friendly city is in focus” (Stockholm Stad, 2010a, p 1). The City estimates a growth with 200 000 new inhabitants until 2030, which is a huge challenge for the city planning, regarding residential areas but also transport. In addition, the City plan takes also its surrounding area into account, because the commuting area includes the whole Stockholm County as well as cities in other surrounding counties.
Furthermore, because Stockholm is considered as a rather small city in a global perspective and if the City wants to increase its attraction the surrounding areas are important for the development (Stockholm Stad, 2010a). Thus, even though the City plan is a local document, it contains plenty of regional considerations.

The City plan contains a rather extended climate discussion, where it is established that Stockholm has been rather successful decreasing the city’s climate influence compared to other comparable cities in the world, but still the city need to do more (Stockholm Stad, 2010a). One of the goals the document focuses on, to solve the problem, is that Stockholm will be fossil fuel free in 2050, but the difficulties to achieve this goal are also recognised:

...substantial efforts are needed from the City and from all of those who live and act in Stockholm to reach this ambitious goal... (Stockholm Stad, 2010a, p 7-8)

The city clarifies two major strategies to reach the goal, that are to invest in district heating and to make the public transport more attractive. The public transport system is considered as the foundation of the future transport system in Stockholm, why it is first and foremost to the development of railways the investments should go. However, it is not only the public transport which is in focus to improve the climate issues, the City also believe in improving the technology development, facilitate efficient energy usage by a well-reasoned city planning and by public procurement improve the use of environment efficient technologies (Stockholm Stad, 2010a). An example of the well-reasoned city planning, the document refer to, is the development of a joint transport and residential planning, which will improve the planning coordination between different sectors in society. According to the vision, this could lead to a well-functioning transport system with minimal climate impact. It is also advocated in the document, that the region se the transport system in a holistic perspective (Stockholm Stad, 2010a).

In the more specific discussion about what kind of technology development is needed to reach the climate goals renewable fuels are acknowledged. The City believes that it is important with a well-developed infrastructure for production and distribution of renewable fuels in or around the city and that this needs to be in place when the vehicles are on the market (Stockholm Stad, 2010a).

Concerning the City’s policy measures to influence transport and travelling patterns, they are considered to be rather good, since Stockholm is a big city region. The document points out two economical policy measures that are possible for Stockholm to use: the congestion tax and the city parking policy – the access to parking spaces (Stockholm Stad, 2010a).

In summary the Stockholm City plan covers several considerations concerning the city planning, both regarding land use and economic, environmental and social development. It is not only a transport document, but since it is the built environment it focuses on, transports are a main discussion and development issue. Energy efficiency is described as a problematic goal, best achieved using spatial planning, at the same time as renewable fuels and electricity is described as solutions to the climate problem. Thus, the document separates those two problems and promotes rather different solutions.
4.2.6 Other documents

Those five documents presented above are the ones most mentioned in the interviews as important regional documents in the transport and energy planning. Within City of Stockholm there are a few other, more local documents that could have an impact on the regional level as well: The Electric Vehicle Strategy and the currently developing Biogas Strategy. Those are strategies developed within the municipality, describing the city’s specific problems and possibilities regarding those technologies, but since the Electric Vehicle Strategy was used in a Swedish Energy Agency’s report on electric vehicles, the strategies also cover more universal questions about the technologies. Because of City of Stockholm as the natural centre in the region, strategies on electric vehicles and biogas could probably influence the whole region and make other municipalities interested in the introduction of those technologies. Biogas is already a question in focus in the whole region, but introduction of electric vehicles by public procurement is one measure in the Electric Vehicles Strategy, something that is currently performed and several of the other municipalities in the region take part in.

4.3 Behind the documents – results from interviews

The results of the interviews are presented here with the help of a few questions under which the results can thematically be ordered. The first question handles the role of the different actors on the regional arena and how they act to rule the region regarding the transport system. The next two questions discuss what transport planning is in the region on the one hand and what energy planning is on the other. Subsequently the question of the introduction of renewable fuels and electricity is discussed and finally the question of responsibility and policy measures is described.

4.3.1 What roles do the actors have in the region and how is the Stockholm region ruled?

In the last section some of the documents important on the regional level in Stockholm are described and they are also discussed in more details in the interviews. Since the RUFS is such a central and general document the respondents have been asked what role it really plays in the Stockholm region. The RUFS is intended to direct the municipal planning in the region, but most of the respondents attest that it has not been like that at all (all interviews). The reasons the respondents identify are that the RUFS has been out of date when comparing with the municipal planning processes. In addition, it has taken a long time to develop the RUFS why it has been already dated when it should be implemented (Interview Association of Local Authorities). Furthermore the development process has to most extent been a closed process, why the RUFS has felt like an office product (Interview City of Stockholm 2). The last reason has made the RUFS to a document without legitimacy and consolidation among the municipalities, the business world and the inhabitants and consequently the municipalities have to a various extent considered the RUFS in their planning (Interview City of Stockholm 2). One respondent describe it as the municipalities have used the RUFS when they could profit from it but not when they had something to lose:

…the RUFS is used in different ways, if the municipalities consider what the RUFS says as supporting or helping them in their work then they happily refer to the RUFS … if they do not believe they could get any support, or that it can imply negative influence, then they only say: “this is not something good”... (Interview Association of Local Authorities)
In addition, the representative at the City Planning Administration at City of Stockholm attest that the RUFS also has felt like an instrument for the smaller municipalities to gain their interests, why it has not gained any legitimacy among the bigger municipalities (Interview City of Stockholm 2). However, the new RUFS 2010 is described by all the respondents in more positive words and they believe it will have more influence on the real planning in the region (all interviews). The reason is that the development process of the document this time has been very thorough; many different actors were invited to take part. It is, though, too early to tell the result of the latest plan, but considering the respondents’ descriptions the RUFS 2010 may play a role in the regional planning. Still, it is dependent on the municipalities will to make plans, why the power to decide rests on the local level.

The municipalities’ importance for the decisions in the region is pointed out several times in the interviews. The respondent on the Stockholm County Association of Local Authorities stresses that Stockholm is not a region in the judicial sense, but there are a couple of actors that act on the regional arena and they are; the Association itself, the municipalities, the County council and the County Administration Board (Interview Association of Local Authorities). Specific issues that are considered very important for the region and/or very complex give sometimes rise to cooperation networks and working grounds founded among the actors on the regional arena and other interest groups (Interview Association of Local Authorities, Interview City of Stockholm 1, 2, Interview County Administration Board 1). However, general issues about the transport system are not a question for those constellations (Interview Association of Local Authorities).

On the question why the municipalities in Stockholm have not founded a region, the Stockholm County Association of Local Authorities representative answers that independence is considered very important among the municipalities and cooperation could sometimes be seen as a sign of weakness (Interview Association of Local Authorities). However, regarding transports and the development and maintenance of infrastructures the interest in cooperation among the municipalities is bigger, because “a road does not end at the municipal border” (Interview Association of Local Authorities).

All the respondents describe City of Stockholm as a municipality that is strong enough when it comes to resources to act by its own (all interviews). Cooperation is therefore not necessary for that reason; however one respondent attest the City of Stockholm’s importance for initiating new regional problems:

...All of the municipalities are very dependent on City of Stockholm, it is many who commute, City of Stockholm is the engine in the development of the Stockholm region, however one must also consider that there are limited capacity, Stockholm cannot swallow everything, if we for example consider the recycling stations that we have in the region…there are 39 of them whereof 5 is in City of Stockholm and…now is the capacity reached and there are no places to build new ones, this regional thinking...if City of Stockholm has a problem then it will also turn into a regional problem... (Interview Association of Local Authorities)

The collaborations among municipalities are mostly founded among the neighbouring municipalities and then around a very specific issue.
For example, City of Stockholm has much cooperation with some of the neighbouring municipalities regarding the development of new city districts in the outskirts of the City of Stockholm territory and also concerning development plans for public transport on railway (Interview City of Stockholm 2). The City of Stockholm case is rather special since it is the centre of the region and therefore the actor many other municipalities need cooperation with. The respondent in Stockholm City Planning Administration describes the cooperation as a win-win situation, at least regarding the projects close to the City border. However, cooperation with municipalities further far from their territory, as municipalities in other regions, are not considered to have the same importance for City of Stockholm itself, why the involvement could be lesser:

...of course, this is more important for the smaller municipalities, we are not able to give all in those kind of cooperations [regarding the Mälardal railway], but it is clear that those in Västerås and Enköping are promoting it...[they] want to have good connections to central Stockholm and Kista and so on... (Interview City of Stockholm 2)

In the above quotation another angle of the importance of cooperation is brought up; the magnitude of cooperation for smaller municipalities. According to the Stockholm County Association of Local Authorities respondent, many of the smaller municipalities have started to organise themselves in joint corporations and organisations to take care of new challenges. One example is the biogas, which the demands for the product has forced the municipalities to, to a higher extent, take care of the municipal solid waste and then refine it into biogas (Interview Association of Local Authorities). Some of the municipalities rule all the process through cooperation with other municipalities and some take care of the collection of municipal solid waste themselves, but have plants for the preparation process with other municipalities. However, the Stockholm County Association of Local Authorities respondent believe there are incentives for the municipalities to cooperate more than today and that it would be good for the development in the smaller municipalities, but also for the development of the whole region. The respondent describes the situation as following old paths of doing things when the reality has changed. Foremost, it is the roles of the municipal border that has changed since people, to a higher extent than before, move themselves in their everyday life:

...the citizens are very regional and mobile, thus the municipal borders are not of any real meaning, no one thinks about; oh now I have passed Norrtälje, oh now I have passed Österåker or now I have passed Vallentuna and so on... (Interview Association of Local Authorities)

The case of biogas shows how the situation has changed. Since people are not reflecting so much of the municipal borders, they can throw garbage in a different municipality from where they live, thus it is a question of collecting municipal solid waste. In addition, the production need large plants to be effective and every municipality are not able to build big enough for the production, why the municipalities must cooperate to solve the issue (Interview Association of Local Authorities). The biogas process is an example of how cooperation between municipalities in the region, but also in the whole country, probably will be more important in the recent future, according to the Stockholm County Association of Local Authorities respondent.
The City of Stockholm has several collaborations in specific issues that are not spatial, with other municipalities around the country, for example on electric vehicles. In those issues City of Stockholm is not interested in cooperating with its neighbours as long as they are not working actively with the issue, but other municipalities that do. The Department of Clean Cars at City of Stockholm also cooperate with other similar cities around the European Union in projects, to gain interest for renewable fuels and vehicles even on those places and extend the demand for those vehicles. The object is to extend the supply of new vehicle technologies and fuels by extending the demand among local public authorities (Interview City of Stockholm 1).

There is not only cooperation between the municipalities and other public authorities within the region, but also public-private cooperation of different kind. The more formalised examples that are expressed in the interviews are the current public procurement on electric vehicles, which City of Stockholm and Vattenfall (an energy company) arrange together and the development of charging poles between City of Stockholm and Fortum (a company which is the largest net owner in Stockholm). City of Stockholm’s politicians have also initiated negotiations among the actors around specific problems, for example the biogas issue:

[…]it is two of those [biogas] talks during every semester and a lot has happened to make the business recognise the problems, admit that it is a mutual problem, see how we can collectively solve it and who could do what and sort of aiming at a mutual goal... (Interview City of Stockholm 1)

4.3.2 What is transport planning in the Stockholm region?
On the question what transport planning in the Stockholm region is, most of the respondents answer that it is synonymous to infrastructure: development and maintenance of road and rails. However, all of them also point out that there has been a general transport planning before, something that the County Council’s Office of Regional Planning was responsible for. That responsibility has nowadays moved to the Stockholm Public Transport and most of the respondents think it is too early to tell if there are any changes (Interview City of Stockholm 2, Interview Association of Local Authorities, Interview County Administration Board 1, 2). However, one respondent at City of Stockholm believe that the reorganisation of the general transport planning has resulted in no existing general planning at all, since the Public Transport lacks the right competence (Interview City of Stockholm 1). In addition, the Stockholm County Association of Local Authorities respondent describes how this organisational change worried the municipalities so much that a transport director group was founded. The reason to their worry was that the Public Transport is in fact a corporation with other than only public interests (Interview Association of Local Authorities). Thus, currently the transport director group discusses more general transport issues within the region, but it seems rather unknown among the other actors, since it is not mentioned in the other interviews.

At the same time as the municipalities was worried about the future general transport planning, the Stockholm County Association of Local Authorities tried to initiate an action plan for the Stockholm transport system. The objectives were to start a discussion and to strengthen the cooperation within the transport issues among the regional actors.
However, there was no interest from the municipalities to work with that, why the question was moved to the newly founded group:

...we tried to develop an action plan for the transport sector and arranged a workshop and invited City of Stockholm, the County Administration Board and a couple of other actors [...] both SL and the Office for Regional Planning were very active in the issue...they hired a consultant who put together all material and earlier investigations and did a synthesis of that and showed which areas would be interesting to work with on the regional level [...] we did not find that it was not reasonable things to do, but we said that the question has to be moved to this transport director group...they can discuss it and decide whether a regional action plan for transports is needed... (Interview Association of Local Authorities)

Since the transport planning is about infrastructure it is also about the distribution of money to regional and local projects, which is pointed out in several interviews (Interview City of Stockholm 2, Interview County Administration Board 2, Interview Association of Local Authorities). Consequently the County Administration Board and Stockholm County Association of Local Authorities are very active and important actors in the transport planning since it is a question of cost distribution between the government and the state. It is the County Administration Board that decides what projects the government will invest in and the Stockholm County Association of Local Authorities represents the municipalities in the negotiations. Thus, many of the respondents describe the County Plan for Transport Infrastructures in the Stockholm County 2010-2021 as the most important document for the transport planning (Interview County Administration Board 1, 2, Interview Association of Local Authorities, Interview City of Stockholm 2).

On the question if transport planning regarding infrastructures considers energy issues, the two respondents working with that, answer that it is not so. However, sometimes questions of energy can be a part of the Environmental Impact Assessment (Miljökonsekvensbeskrivning; MKB) that needs to be performed before every larger infrastructural project.

...yes...maybe they do [look into energy issues] indirectly by performing Environmental Impact Assessments in those contexts...so...but it is...I would not like to say that it has...that it is high up on the agenda that one look into energy issues in those different [infrastructure] projects...it is not really like that...if one should be honest... (Interview City of Stockholm 2)

However, energy efficiency are not forgotten when planning for the transport system as a whole and therefore City of Stockholm and other regional actors pursue to make people use the most energy efficient and resource efficient transport they could. According to all respondents the solution is to make people chose to use the public transport instead of the private car:

...so it is often...rather it is the environmental load that is analysed...what will “Detour Stockholm” generate in [more transports]? yes and then...one do not translate this into kilowatt terms or so today, as I should say...
...but, on the contrary we see rather that it is possible to achieve transfer effects to more...energy efficient solutions and resource efficient solutions, which really is, simply phrased, from individual transport to more public transport...and it, at least from my perspective, very often concerns that it in fact is much more efficient because you transport so much more people on...the same area...but no, we are probably bad translating this to energy terms... (Interview City of Stockholm 2)

Transport planning is thus very much about infrastructure according to the respondents, but many of them also attest that the lack of biogas has made the production and distribution of biogas a part of the regional transport planning as well (Interview County Administration Board 1, Interview Association of Local Authorities, Interview City of Stockholm 1, 2). Two of the respondents work with general questions about the development of a more renewable Stockholm transport system, where the biogas question is gaining most attention currently. The County Administration Board spreads knowledge among the public, business and local authorities about the Stockholm municipal solid waste as a resource for producing this bio fuel (Interview County Administration Board 1). Stockholm County Association of Local Authorities works together with the municipalities to actually extend the capacity for collection, production and distribution in the Stockholm area (Interview Association of Local Authorities). City of Stockholm is also working on the biogas issue by, for example, assembling the business actors within the biogas market to find joint solutions and to develop biogas strategies for the municipality (Interview City of Stockholm 1).

Even at the spatial planning part of the City of Stockholm’s organisation the question of biogas distribution has become a current interesting question. The respondent tells about the filling stations in the city centre, which in many cases are run on long-term exemptions, and where the long-term strategy in City of Stockholm has been that they will be abolished. However, in recent time the politicians have started to change their minds and it has become an issue of whether people have the right to fuel their car in the city centre or not. One of the major problems with the fuelling stations in the city centre is the transport of fuels to them, why the politicians wanted to know if there was any possibility to distribute fuel in another way than on trucks and if the fuel distributed could be bio fuel. In the department where the respondent work they investigated this question and they found that one interesting solution would be that the fuelling stations in the future could keep their long-term exemptions by becoming a fuelling station with environment friendly profile. They should be able to become that if they connect their fuelling station to the biogas pipeline Fortum is planning to build (Interview City of Stockholm 2).

4.3.3 What is energy planning in the Stockholm region?

The energy planning in the Stockholm region is not structured in the same way as in many other regions around the country. The Stockholm County Association of Local Authorities is responsible for the the regional energy agency, but it is not a regional energy agency in the Swedish Energy Agency’s sense. Thus, the Association does not work project based to try to spread knowledge and procedures to the municipalities, which a regular energy office does, but instead the Stockholm regional energy agency works on those energy issues the municipalities demand for. In addition, the Stockholm County Association of Local Authorities concentrate quite much of the work on what consequences changes on the energy area will have for the municipalities, which imply a much extended coverage of other actors and their decisions (Interview Association of Local Authorities).
In short, the Association’s regional energy planning is to a large extent about defending and map out consequences for the municipalities:

...so our assignment within the energy sector is to sort of track what is said in the RUFS, what the County Administrative Board does and sort of what the other regional actors in this context are doing...compile, do a synthesis and then present for the politicians...so it is the municipality which is the core, they need to run the business, but if they recognise questions that must be solved on the regional level they bring them up through the networks and channels we have...as simple as that...so we have no activities that are run continually... (Interview Association of Local Authorities)

What the energy planning actually contains was not so much discussed in the interviews, why a general summery is not possible. However, the respondents were keener on telling about what they thought the energy planning in the region lacked. One of the respondents on the County Administration Board describes the difficulties to find comparisons between different energy systems on the regional level. It means that biogas is only regarded as a transport issue and it is considered obvious that the biogas should be used there and not in the district heating processes, thus the district heating actors are left out of the biogas debate. The respondent believes that this leads to a situation where the municipalities are left alone with the decision:

...what is best to choose on the regional level, I have not found anything about that and I miss that [...] it is more like that we focus on one issue that the question of biogas is the focus in one seminar and then it is electricity in another sector at another [seminar], but this discussion about what is best for this specific municipality or this specific county, it is missing I believe, so then I can understand that the municipalities have difficulties to choose [...] but one want some kind of general advice, I can think of that if I was a municipality then I would like to have something, that everyone is following the same direction and doing those comparisons... (Interview County Administration Board 1)

In addition, from the same respondent’s point of view there is no investigation of the region’s strengths and weaknesses regarding energy issues. The respondent believes that the region therefore to a large extent follow others and copy their behaviour directly. The reason is that the energy issues are considered to be very complex and therefore also hard to find solutions to (Interview County Administration Board 1).

4.3.4 The introduction of renewable fuels and electricity – what is happening in Stockholm?

As a summary of all interviews, two specific technologies for vehicles are the ones that everyone is discussing and having an option about, namely biogas and electricity. The third bio fuel that is brought up specifically is ethanol, which is both described as a current and a near future solution (the 2nd generation ethanol) as well as a solution of the past:
...I think that we will have those fuels [biogas, electricity and ethanol] we are talking about today and I hope that we have come further to make more trucks to use E95 [...] but I think that in 20 years we have hopefully come a bit longer... (Interview City of Stockholm 1)

...so it is electricity and biogas, as ethanol has disappeared somewhere on the way I believe...that is what one discusses...it becomes somewhat trends and it is maybe not so good for the investors... (Interview County Administration Board 1)

However, the respondent specifically working with renewable fuels also talk about other fuels than the above mentioned. They have knowledge about them and discuss their advantages and disadvantages. Among the other respondents it is only biogas and electricity that are mentioned and the most focus is currently on biogas.

There are many projects around the Stockholm region focusing on introducing renewable fuels and EVs in the area. According to many of the respondents the focus of the work on biogas is no longer to introduce the fuel, but to solve problems that a higher demand than supply in the area has resulted in (Interview Stockholm County Association of Local Authorities, Interview County Administration Board 1, Interview City of Stockholm 1). Thus, the introduction could be considered as successful among the users, but not among the producers yet. Many of the regional actors, municipal collaborations and sole municipalities are taking part in striving towards an increase of the biogas production (Interview Association of Local Authorities, Interview County Administration Board 1, Interview City of Stockholm 1).

The institution that works most actively with the introduction of renewable fuels and electricity is the Department of Clean Cars in City of Stockholm. All the other respondents mention their work and how it probably influences the introduction in a positive way. The respondent on the Clean Cars department tells that their main focus when developing background material and strategies is not local, but regional to the most extent. The reason is that the region is so integrated between the City and other municipalities that it is not possible to see the private and cargo transports in only a local context. However, the department has no expressed regional cooperation with other public or private organisations, but by the way they work; gathering actors together for discussions about mutual problems and public procurements with invitations to other organisations as well, they have some kind of regional cooperation.

The Department of Clean Cars has no specific fuel in focus, but works with technologies that are possible to introduce for the moment, to solve upcoming problems and also with those technologies that the politicians bring up as interesting (Interview City of Stockholm 1). Currently the biogas is an important issue since there are problems that need to be solved. EVs are also considered important because the politicians initiated it. On the regional level, however, there are no initiatives for the general introduction of renewable fuels and EVs; instead there are some collaboration, mostly initiatives from municipalities, regarding specific technologies as biogas (Interview Association of Local Authorities, Interview County Administration Board 1). One of those is BiogasÖst, which is a wide cooperation among actors not only within the Stockholm region, but the whole south eastern part of Sweden (Interview Association of Local Authorities, Interview County Administration Board 1).
When asking the respondents what they think about the technologies everyone is very positive to biogas and there seems to be consensus about that the production and distribution of biogas must increase in the region. Biogas is described as a great opportunity for the Stockholm region to at least produce some of the fuels needed within the region at the same time as garbage can be redefined as an important resource.

EVs, on the other hand, are considered a more future solution since the technology is not yet enough developed. Therefore, EVs are not described as such a positive solution as biogas, but as a more unsure solution that probably not will fit all consumers.

... electric vehicles are good, but it is still very much that need to develop to make the [electric vehicle] to gain attention, but it is the future... (Interview Association of Local Authorities)

No respondents believe either biogas nor EVs is the final solution, not because they would not work, but because of the reactions of the vehicle industry and the consumers. One respondent do not believe in the will of the vehicle industry to actually develop new technologies and alternatives:

...so it is still about delivering fuels that fit into the combustion engine /// so it is not about developing new vehicle models...why shall such enormous money be spent on the development of black liquor gasification from the pulp industry, when you can sell electricity instead and use for electric vehicles? It is much more economically interesting and even financially interesting...but this is what I mean: they lob very strong and then [the vehicle industry] are very offensive in their marketing and present this gasification technology as something very [...] environmental friendly and future etc, even though it is not the future, but it is [...] to force new things into the existing structure...so it needs a structural change, someone must look forward… (Interview Association of Local Authorities)

Questions about how the introduction of the new technologies should be done raise other questions among the respondents about both institutional reorganisation and other solutions to make the transport system more renewable. One of the respondents suggests that the municipal self-government is extended in order to give the municipalities the possibility to solve those problems in a way accommodated to the local conditions:

...so those things that are presented on the national level are usually becoming very empty...being aggregated in vain, thus becoming very misleading, it is important sort of that the work is done on the local level, look at what conditions there are then, regarding fuels, if you are in countryside it is [better] to invest in the private transport /// if you are driving a bus with only two passengers, then the bus all of a sudden becomes more polluting than the private car, so you cannot see everyone in the same shape, but see the structure on a specific place /// then, what is the infrastructure we need at this very place?... (Interview Association of Local Authorities)
In the city that kind of specific plans for local conditions are resulting in new types of spatial planning, as many of the respondents point out (Interview County Administration Board 1, 2, Interview City of Stockholm 2). The development of new biofuels and electricity is considered as one solution to the problem of how we will be able to transport ourselves in the future and not make any impact on the environment (Interview County Administration Board 1). Most of the respondents believe it is impossible to make people travel less than they do today and in addition the Stockholm region has an expressed goal of increasing the regional enlargement which imply more, not less transport needs (Interview County Administration Board 1, 2, Interview City of Stockholm 2, Interview Association of Local Authorities). According to the respondents there are also other problems that complicate the picture; the renewable fuels are not enough for the region’s needs and the newly developed roads in the region are already full from the very first day they are opened (Interview County Administration Board 1, 2, Interview City of Stockholm 2). Therefore, some of the respondents believe that the new vehicle technologies are only one small part and that the real solution is to change how people travel. Spatial planning is important in this case achieving the needed changes in the built environment; making the city more compact. Furthermore the public transport, bicycling and walking must be considered as real alternatives to the passenger car for almost every individual (Interview County Administration Board 1, 2, Interview City of Stockholm 2).

4.3.5 Who is responsible for the introduction of renewable fuels and what policy measures are possible?

The responsibility for the successful introduction of the renewable fuels and EVs is found on every level in society, according to some of the respondents (Interview City of Stockholm 1, Interview Association of Local Authorities). The Swedish government is responsible for the development of environmental goals, prohibitions and subsidies and the local or regional authorities are then responsible to follow this and implement the goals if it will be possible to achieve the governmental environment goals. In this division of responsibilities among the institutions, the respondent in the Department of Clean Cars argue that since it is not possible to reach the environmental goals only with more efficient vehicle engines, it is the local responsibility to work for more renewable fuels on the market (Interview City of Stockholm 1).

One other respondent describe the situation as changed in the way that the government has lost some of its governing role, because the problems have become more local and regional, and that the municipal self-government should be strengthened over transport and energy issues. If the municipalities had more self-government over those issues, they would also have the complete responsibility to develop solutions (Interview Association of Local Authorities). At the same time as the local responsibility is promoted, the same respondent also believes that EU should take more responsibility over those issues (Interview Association of Local Authorities):

...I think that we must discuss this on the European level…to focus, to risk prioritising…and not let the industry rule…
(Interview Association of Local Authorities)

All of the respondents agree that the public authorities have the important responsibility to make rules for the markets so that the individuals are able to make the environmental friendly choices. The individuals who want to choose the right vehicles regarding the environment must be helped in some way:
...and then we must make opportunities, because I mean if I ever really want to drive my car on a bio fuel and it is not possible to fuel it and the society has a function to help and support and ensure that such infrastructure is developed [...] and that can become important in this Catch 22: what shall come first; the car or the fuel?... (Interview City of Stockholm 1)

In this opportunity making the politicians must take their responsibility and be more valiant than they use to and try to make important decisions for the future:

...there have been made a couple of such investigations, where it is looked into what the politicians think that the public want and so on, and the politicians often think that the public want them to be gentler than they in fact need to be... (Interview City of Stockholm 1)

The respondents believe that a great responsibility also has to be put on the individuals to make the right choices. One of the respondents argues that even though everyone has a free choice everyone has also obligations to take responsibility:

...but it is also a responsibility for everyone to buy the right car and [...] or ride the bike when it is possible to do that, thus making the right choices, but everyone also need help to make those right choices... (Interview City of Stockholm 1)

The individuals have obligations, but they are not supposed to be able to choose the right things as long as they have not got any help from the public authorities. Therefore all public institutions on all levels have responsibility to spread easily understood information to the individuals, which will help them making their choices (Interview City of Stockholm 1). One respondent also argue that the institutions not only are responsible to spread information to the public, but to other institutions as well. For example, the County Administrative Board is, as the government’s representative in the county, responsible for distributing information to the municipalities about the national goals and how they can be achieved on the local and regional level. As experts the Board is then able to support the municipalities in their local work on the issue, something that it has not been able to do regarding renewable fuels and electricity since the Board lacks that competence:

...there is nobody who works with questions about fuels and that [this area] shall be coordinated, there is in fact no such person...you have to create such a project, or something like that, it feels like nothing is pointed out... (Interview County Administration Board 1)

It is not only the individuals who have right to get support from the society in their choices, but according to many of the respondents, the corporations also need support in choosing what they will invest in and supply on the market. The institutions must therefore create clear playing rules for the markets, so there will be the right kind of supply for the individuals to choose among (Interview City of Stockholm 1, Interview County Administration Board 1). One of the respondents believes that the situation today is very insecure, why no one has the courage to invest at all:
...I feel like there is no one who has the courage to invest, thus everyone invests a little in everything...but the renewable fuels are still a small part of all fuels... (Interview County Administration Board 1)

Regarding the policy measures that are possible and needed to make the individuals and the industry making the right choices, they propose several different forcing measures and subsidies both on EU, national and local levels. Many of the respondents advocate measures that influence the individuals to change their demand for vehicles and then by doing that achieve changing the industry as well (Interview Association of Local Authorities, Interview City of Stockholm 1). The proposed measures are a definition of a “clean car”; environmental labelling of vehicles; subsidies to the buyer when buying a new “clean car”; prohibition of selling the worst cars; subsidies when scrapping old cars; free parking for “clean cars”; and punishing “unclean cars” with high congestion charges:

...but then it is sort of a combination of removing which is absolutely ropey, inform about what is sort of good or the best and try to steer and that can be done in different ways and economic incentives is then sometimes necessary... (Interview City of Stockholm 1)

One of the respondents argue that almost always a definition and/or marking of the best, most environmental friendly vehicles is enough to change the individuals’ choices. The reason is that the respondent believes that most people want to do the right thing, why clear information that simplifies their choice will have a great impact (Interview City of Stockholm 1).

However, definitions and labels are not effective if they only are established on the local level, why this is a policy measure the government or even the EU must establish (Interview City of Stockholm 1, Interview Association of Local Authorities). The municipalities have the possibility to change those things that has to do with spatial planning; the supply of renewable fuels on fuelling stations and the installation of charging poles in parking spaces, the parking possibilities overall, the congestion charge, the development of the alternatives to the car and public procurement. The parking possibilities are described by one of the respondents as a quite unproven policy measure in Stockholm, but something other larger cities have started to use:

...it is interesting...but it is very undeveloped in Stockholm, so that is something I should want to...work more with...but parking is very political controversial...it is quite troublesome to work with...from a governing position...today it is seen as a human right to always be able to park the car at a subsidised space right in front of one’s destination, we have established that culture and we cannot simply...throw it out just like that... (Interview City of Stockholm 2)

Public procurement is described as a very firm policy measure, which the municipalities in the region already use to promote new vehicle and fuel technologies, but according to the respondents they could use it even more (Interview Association of Local Authorities). City of Stockholm and its Department of Clean Cars use technology specific public procurement as one of their main strategies in promoting new fuels and vehicle technologies. According to the respondent working in the department, it is one of the most successful measures they have used throughout the years to actually spread the use and demand for new technologies.
One reason for the success of public procurement is, according to the respondent, that City of Stockholm has cooperated with other cities around Europe and in Sweden and also with private interests to be able to buy larger amounts of vehicles than City of Stockholm itself had been able to. The success of other public procurements made City of Stockholm to use it also currently, when promoting electric vehicles:

...but then we looked into what need to be done and what is going on and how it looks like and then we agreed that we, who have done a lot of procurements before, and right when it is in such a market introduction phase then technology public procurement [is] a very useful way…and we saw that…because the problem is that there are no [electric] cars, we can load them in power outlets for block heaters in Sweden, we have good electricity, we have everything, but we have no cars, there is no car at all and we tried to buy cars for our own, but they are not here yet – they will be delivered to Paris and London and Tokyo and Los Angeles, but they will not come here and then we had to put…we had to show the vehicle industry that there is a market in Sweden and that we already have an infrastructure, they did hardly know that and so on, we decided that we must do an electric vehicle public procurement… (Interview City of Stockholm 1)

Two of the respondents point out that public procurement could not only be used when the authority shall buy new vehicles to their own fleet, but also when they purchase services. City of Stockholm has for example used public procurement to change the fuel in the garbage trucks and buses. According to the respondent City of Stockholm is currently developing how those demands could be extended to public procurements regarding all kinds of services the municipality buys from external actors (Interview City of Stockholm 1).

Even if the change toward renewable fuels and electricity would be achieved, most of the respondents believe that it is not the main solution. Instead the municipalities must steer the more energy efficient society with the help of spatial planning. Thus, it is not possible to develop fast solutions because it would probably lead to other losses in another part of society. Therefore, the respondents advocate the alternatives to the passenger car as the major solution:

...the alternatives must be so good, the alternatives must be better…than individual travelling with car, that is what it is about...if you make good cycle lanes, then you sort of making closeness to those different points which are central […] you shall not need to go 20 kilometres outside town to buy cheap yoghurt and so on... (Interview City of Stockholm 2)

One of the respondents is arguing, on the contrary, that maybe it is not more policy measures that is needed. Instead it is the process that needs to be changed by making it simpler and cheaper for those taking part:
why are we not producing [biogas]? [...] there are many actors [taking part], sometimes it is the municipal set of regulations according to the spatial self-government, sometimes maybe it is distribution difficulties; more concrete that property owners have to drive two trucks instead of one and it becomes just expensive, so when the decision is put on a property owner they choose to...then they recognise that it will cost money...so it maybe ends there... (Interview County Administration Board 1)

4.4 Planning for an energy efficient and renewable transport system – discussion

In this part the above results from documents and interviews are discussed. The conclusions are mostly empirical, but there are also shorter theoretical implications taken into the discussion. The following discussion is organised in three parts in which the first is about the factors that affect the planning process, the second about the institutional levels and how they relate to each other and the last part discuss energy and transport as different or similar planning practices and policies.

4.4.1 Which factors affect the planning of introducing more renewable fuels in the Stockholm area?

The discussion in this part focuses on three major points; why biogas is the most popular fuel in the region, technology neutrality – why or why not? – and the introduction of electric vehicles as a local development.

The interviews and documents have shown that there is a major believe in supply and demand within the region. The current process to further implement the production and use of biogas is motivated by the actors as they are answering on the demand for more biogas in the region. Thus, the introduction has already happened for biogas and now are the regional actors only acting on the market demand, as the actors describe it. The great demand and the lack of supply for biogas could therefore explain why biogas is the renewable fuel that everyone is currently working with and thus make it the most dominant of the alternatives to fossil fuels. However, there is an alternative explanation, the concept of momentum, that LTS (Large Technical Systems)-researcher Thomas P Hughes (1987) uses to describe why certain technologies are hard to change when they already are in place. The biogas technology has been established among the regional actors as the most known and common technology and therefore it is the one everyone currently is working with and also describes in their visionary documents. Thus, there is a momentum technology in the introduction of renewable fuels in the Stockholm region and it is biogas. When a momentum is established it is harder for the actors to change focus towards other fuel and vehicle technologies, because biogas is the known solution and therefore most interesting for everyone to work with.

The biogas popularity could also be explained from the policy theoretical perspective. The current process to extend the biogas production in the region was initiated by the municipalities through Stockholm County Association of Local Authorities, the City of Stockholm and the County Administration Board. The reason to this initiation was, according to the respondents, the high demand and small supply of biogas and the large supply of municipal solid waste, which is a major resource for biogas production. The initiators connected the policy problems; lack of biogas supply and municipal solid waste in abundance, to the solution of biogas and therefore it became an interesting policy on the agenda (Hill, 2005).
The lack of supply could not only be described as a policy problem, but also as a policy window (Hill, 2005) that opened up the possibility to make biogas high up on the agenda for every actor. The waste problem and how it instead turned into a resource for biogas had happened before in other parts of the country, but the lack of biogas supply in the Stockholm region might have opened the opportunity to do the same thing in Stockholm as well.

The belief in supply and demand is also very clear within the Department of Clean Cars at City of Stockholm. It uses the idea to create future markets for new technologies. The plan is that if some vehicles with new technologies are brought to Stockholm by the public authorities it will increase the demand also among consumers and an increase in demand will lead to an increase in supply as well and a new market will be created. Technology specific public procurements are used as a policy measure within the municipality to get those first vehicles that then will produce a higher demand. It is also used as a path to influence the industry to produce and invest in those technologies and point out for them that Sweden is an important market too.

Those technology specific public procurements shows that City of Stockholm believe in technology specific solutions and it is the most successful pathway when pushing the introduction of new technologies. In some of the regional documents (se for example Stockholmsregionens energiframtid 2009) and also national transport policies (Regeringskansliet, 2009), the importance of technology neutrality in the policy measures is stressed. Consequently the City of Stockholm’s actions challenge regional and national convictions about the importance of technology neutrality. It is then both a question of technological neutrality and specificity and their eventual success in introducing new technologies as both a question of what consequences the different approaches on local and regional level have for the institutional relation and the process of renewable fuels as well.

Above the biogas establishment as a momentum for the process of introducing renewable fuels in the Stockholm region is explained. However, electricity is also a solution on the agenda, because City of Stockholm actively works with it. The reason why the City works with the question of introducing electric vehicles is that the leading politician a few years back launched the idea of “Stockholm - electric vehicle city in 2030” and gave the Department of Clean Cars the task to investigate the prerequisites for those vehicles in Sweden and more specifically Stockholm (Interview City of Stockholm 1). Thus, from the policy theory angle the leading politician is a policy entrepreneur, an active actor that works hard to connect solutions to problems and raise the policy on the political agenda (Hill, 2005). The politician got much support in the launch of the electric vehicle city 2030 from one of the major energy companies in the Stockholm region (Interview City of Stockholm 1), why it also can be discussed if the energy company also should be considered policy entrepreneurs within the City of Stockholm. However, the energy company’s activity is not further investigated in this study.

However, the electric vehicles are not to the same extent on the regional agenda as on the local in the City of Stockholm. Some of the municipalities in the county follow City of Stockholm in their aim for spreading electric vehicles by taking part in the current public procurement on electric vehicles, but not all of them (Interview City of Stockholm 1). Thus, the policy entrepreneurs within City of Stockholm on the electric vehicle issue have not been able to act policy entrepreneurs on the regional arena as well. The lack of success there could be explained by several things: the undeveloped technology in electric vehicles, the lack of interest from the local policy entrepreneurs to act on the regional level or that biogas is the momentum in the region.
The first reason is the one the respondents mention and it is also phrased in the documents; that electric vehicles is the far future and they need more development to become a real alternative. Those expressions could also be interpreted as a confirmation and strengthening of biogas as the regional momentum, since the electric vehicles are described as very unfamiliar and far away solution to the Stockholm regional reality. However, the policy entrepreneurs within City of Stockholm have managed to put electric vehicles on the agenda along with biogas, why is that not possible in the region? The reason that the local policy entrepreneurs lack interest to act on the regional arena as well could be one answer.

City of Stockholm cooperates with several municipalities on the electric vehicle issue; none of them are in the Stockholm region, but in other parts of the country and abroad in Europe. The respondent on the Department of Clean Cars describe it as a matter of exchanging knowledge; they cooperate with those actors that also invest in electric vehicles and their development because City of Stockholm will then be able to gain some knowledge from the cooperation. City of Stockholm cooperates also with other larger cities in Sweden and abroad to exchange knowledge about problems and possibilities in their specific situation regarding renewable fuels and electricity (Interview City of Stockholm 1). Consequently, the lack of cooperation within the Stockholm region on electric vehicles in this case could show the disinterest from the local policy entrepreneurs to act on the issue on the regional arena.

4.4.2 What is the relationship between institutional levels? – the question of responsibility, power and cooperation

This sub-study has discussed the regional institutional level in Stockholm and it has been established early in the text that there is no such thing as a regional institution regarding the transport system. Instead the regional level contains several actors, both public and private, however it is the public authorities that have been in focus for this report. An interesting question following the above described situation is why the regional level is organised like that?

This question has to do with which actors have the power to decide and to govern the region regarding the transport system. In the interviews the lack of more formal and forcing regional cooperation among the municipalities is explained by the major believe in the municipal self-government. The self-government is established in the Swedish constitution and provides the municipalities among all with the right of taxing the inhabitants’ incomes and to have sole control over the spatial planning in their territory. The respondents describe the municipalities as rather prosperous and regarding the City of Stockholm; the dominating actor within the region in the force of its position as the natural centre of the region and the actor all other municipalities depend on.

According to the Swedish political scientist Stig Montin (2004), the municipal development in Sweden has so far, during the 21st century, pointed towards more organised cooperation among municipalities. He explains this by the fairly new challenges the municipalities have met in recent years; lack of resources, more complex problems and the surrounding institutions, among all the European Union (Montin, 2004) To deal with those new challenges municipalities are creating everything from loose networks for cooperation to joint committees and local government federations. The networks and collaborations concerning specific projects are the most common, according to Montin (2004).
The results of this chapter show that this also is the case in Stockholm in the transport system planning; Stockholm County Association of Local Authorities could be regarded as an interest organisation that transforms to a network or collaboration among the municipalities in specific issues as biogas and within the spatial planning City of Stockholm cooperate with their near neighbours about very specific projects. By those arrangements no power of decision is moved from the municipalities to a more regional organisation. This show that the municipalities in the region are not willing to give away any self-government to a regional institution and empower it; the idea of such a thing lacks legitimacy among the municipalities.

However, the biogas case show that the municipalities are sometimes willing to collaborate in more formal and forcing ways as well, since some of them in this case have started corporations together to take care of a joint production. The reason why those collaborations have come into being is described by the respondents as the case of economy of scale and more efficient utilisation of resources. This reason is also described in Montin (2004) as the original reason for collaborations among municipalities. In addition, the more upcoming reason for cooperation according to Montin is the region’s competition power (2004), which is somehow also present in the case of biogas. The networking within the Stockholm County Association of Local Authorities has had the ambition to increase the biogas production within the region and thus decrease the region’s dependence on other regions’ productions. Consequently, by networking within the Stockholm County Association of Local Authorities the municipalities have strengthened the region’s competition abilities on the market of renewable fuels. The influence of the Association on the regional planning for biogas, and the municipalities power over the Association itself, proves that the Stockholm region is governed by the local authorities.

The organisation, or perhaps the lack of organisation, of the regional level in Stockholm could also be seen from another angle. The Office of Regional Planning has since the middle of the 20th century had the responsibility to establish the regional spatial planning in Stockholm. In recent years the Office of Regional Planning has got an extended responsibility to along with the spatial planning also plan for the regional development. When the regional development planning first was launched by the government after the Swedish joining of the European Union, it was the County Administration Board that had the responsibility to develop it (Nilsson, 2006). However, according to Nilsson (2006) the responsibility to develop those plans where soon moved to the regional actor that was supposed to possess more legitimacy and power to implement it, than the County Administration Board has. The joint document (the RUFS) regarding both spatial and development planning in Stockholm region is today, as described above, developed by the Office of Regional Planning. The question is if the Office has this power and legitimacy to implement the RUFS that was intended by the government, as Nilsson describes it: “the regional development responsibility should be moved from the government’s County Administration Board to an institution that was more firmly established in the region’s political life” (Nilsson, 2006: 102). The strength of the self-government among the region’s municipalities as described above shows that the Office of Regional Planning has neither that legitimacy nor power to implement the RUFS. Interviews have also described the RUFS as a lame document during almost all time, because it is too slow and it has been not enough negotiated with the municipalities to gain support. Within the planning of the transport system it is still the RUFS that describe its development, but since a few years the continuous general transport planning has moved from the Office of Regional Planning to the Stockholm Public Transport. Even in this case the important influence of the municipal power and the lack of legitimacy and power among the regional institutions are demonstrated.
The municipalities forced Stockholm Public Transport to create a multi-actor group, which in association with the public transport company should take care of the general transport planning, because the municipalities were worried about a company taking over this issue.

When the responsibility for the introduction of renewable fuels is described in documents and interviews it is rather often that the government is established as the major responsible institutional level. Comparing this statement to, what is described above about a strong believe in the municipal self-government, it looks like two separate and opposing opinions take place within this planning issue. In addition, the respondents also emphasise the importance of an even strengthened municipal self-government to be able to deal with those fairly new issues. The question of power and responsibility could be the reason why those separate opinions are used at the same time.

The municipalities pursue the greater self-government in relation to the state, but striving to be the legitimate institution of power is not the same as being responsible for everything. It is much easier to hold the government responsible for mistakes, investments and general planning, than being responsible themselves. However, some decisions and policy measures that the actors demand is not the municipality able to make decisions about and therefore it must be handled by the government. The regional level is never in question regarding those issues, not in the interviews and not in the documents, why it is reasonable to conclude that the regional institutions have no power or responsibility concerning new renewable technologies in fuels and vehicles.

### 4.4.3 What is the relationship between regional energy and transport planning?

In the policy literature the idea of an analytical separation of different policy areas are quite common (e.g. Fallde 2011, Palm 2004). In Magdalena Fallde’s dissertation about renewable fuels in the public transport, she uses three separated policy areas to explain which actors had the most influence on the process. Transport, energy and environment are identified as three different policy areas that are distinguished in the study. In this part this idea of different policy areas, that sometimes contribute in the same processes or sometimes are totally separated in other processes, is used to analyse the transport and energy planning in the Stockholm region. Fallde differentiates the policy area “environment” from the other two and argue that it is a horizontal policy area (Fallde, 2011), thus that it is a policy area that are a part of all the other policy areas as well. This view is also confirmed in this study, since the negative climate impact is a major consideration in the energy documents, as well as environmental considerations are parts of the transport documents.
Consequently, this part will analyse the separated policies of transport and energy and moreover add a dimension of the two policy areas when they are and should be the same (the area where the two ellipses cross each other in Figure 10).

The results of the interviews and documents analysis have showed that there is a separation between energy and transport planning, both in documents and both in practices. In the energy documents, as well as in the biogas practice, the transports are discussed as one sector, which along with all the other sectors within society need to become more energy efficient and decrease the fossil emissions. In the transport documents and practices, on the other hand, it is the infrastructure development and thus the spatial and financial problems it meets that are in focus. There are no energy considerations when planning for new roads and rails, but the fossil CO\textsubscript{2} emissions are taken into account in the environment consequences description that is made in the planning of every infrastructural project.

In addition, in the transport documents the problem of the transport system’s large amount of energy utilisation is brought up as a problem, but then dismissed as a problem too big and complex for the documents discussing the development of new infrastructure to take into consideration. It is there recommended to discuss the energy utilisation problem in general documents instead, where more sectors also are taken into account. In this study two of those general documents have been studied; the RUFS 2010 and the Stockholm City plan. Those documents are discussing transport in more energy terms and they conclude, in exactly the same way as most of the respondents as well, that the main solution to decrease the fossil fuel emissions and become more energy efficient in the regional transport system is the public transport system. The goal is to extend and improve the system as well as make more people to use it for their daily travels.

**Figure 11 How the energy and transport planning are separated and integrated**

Summarising the above described results in the two policy areas transport and energy: infrastructure and to the most extent spatial planning is separated into the transport planning ellipse (see Figure 11). The spatial planning could be argued to not only include the land use, but also the planning for public transport (which also has to do with land use issues regarding rails), which is put forward as the major solution to the decrease in energy utilisation in the transport system, why it should be placed in the area between the transport and energy ellipses. The public transport is also mentioned in the energy planning as a solution as well. In the middle circle should also renewable fuels, thus in this case biogas be placed, since it is seen as both energy and transport planning. Biogas is not discussed in the Stockholm region to be used for other sectors than transports. One of the respondents points out that it could be used in the district heating instead of transports, but that it is not anything that is discussed or analysed.
Electricity used in vehicles should also be placed in this middle area, since electricity is traditionally part of energy planning, but has become, at least in City of Stockholm, a transport solution to decrease energy utilisation.

The question is what this means, to group the transport and energy planning as separated policies and if it is desirable that specific issues can be distinguished as both transport and energy planning and also if something is missing in the middle area. Maybe it is not necessary to discuss energy issues in the infrastructure and spatial planning, as it is even one more problem to those planning practices. However, the transport sector use ¼ of the total energy utilisation and in contrast to the residential sector the transport’s energy utilisation is increasing (Regionplanenämnden, 2009). When planning for the development of new infrastructure, everyone know that a new road in the Stockholm region will be totally filled with traffic from the very first day, thus the total transports are probably increasing at the same time. Consequently, the energy utilisation in the transport system rises as well and if we want to decrease the energy utilisation in the complete society, eventually also the infrastructure and spatial planning need to discuss the energy issue.

In the policy literature the concept of “boundary walkers” is used to describe actors or policy entrepreneurs that move across the policy areas (Montin, 2004; Fallde, 2011). According to the actor-network theory, actors are not only individuals and organisations, but also artefacts (Latour, 1987) and thus in this case the public transport, the biogas and the electricity could be explained as boundary walkers. They cross the transport and energy planning borders and consolidate the goals of the two policy areas into joint goals. The question is why specifically those three parts cross the borders. The biogas case could be explained in the light of which policy entrepreneurs have run the development process and what resources they have had. The main policy entrepreneurs were the municipalities in the Stockholm region and they had major resources important for the biogas; land for production plants and the power over the municipal solid waste within their territory. The municipalities have also much transport needs within their organisation and they have the possibility through public procurement to influence private producers of services as well. Consequently, in the biogas case the municipalities acted policy entrepreneurs that became boundary walkers to establish biogas as both a transport and energy policy. This differ from the results of Fallde (2011), who had investigated two municipalities which still own the local energy companies and in those cases it was the energy companies that acted boundary walkers to establish biogas as the fuel used in public transport in the municipalities. In the Stockholm case it is different, since the municipalities do not own the local energy companies anymore and thus they have not been active regarding biogas.

The case of electricity is quite similar to the biogas case, with one exception; the energy companies. Electric vehicles are seen as possible new clients for the energy companies, why they are active in the development process currently going on all over the country (Interview City of Stockholm 1). Stockholm is no exception, and early in the planning for an introduction of electric vehicles the major net owner in Stockholm was a partner to the city in testing EVs and developing charging poles in parking spaces. Another energy company has also been partner to City of Stockholm in the current public procurement on electric vehicles. Consequently, City of Stockholm in association with the energy companies have acted both policy entrepreneurs and boundary walkers to connect the energy planning with the transport planning and foremost make a solution to the local emissions in Stockholm.
Mostly, those working with spatial and infrastructure planning launch the public transport as a solution to make the transports more energy efficient. From the results of this study the major issue for those actors is scarcity in land resources and financial resources. Since it is scarcity in all those parts of the transport system, more people must travel on the existing roads, but it is not possible that they do it by passenger cars, why the public transport system’s development and success is the only solution. Those scarcities include the energy utilisation as well, even if it is not the major concern in the planning process. Consequently, in this case there are no policy entrepreneurs acting boundary walkers, instead it is only the public transport itself that do it. However, in this case a future scenario could be made out; that it will be an institutional boundary walking. The Stockholm Public Transport is today in charge of the general regional transport planning and since it is rather new; the respondents have had no comments on how it works. However, if energy considerations are a part of the future general transport planning, then it will happen under the same institutional roof as the public transport. Consequently, SL could become an institution of joint transport and energy planning, acting on the regional level and probably also having power to influence the municipalities in their spatial and energy planning.

There is however an alternative way of analysing the separated policy sectors, transport planning and energy, and it is from the transport system view. The transport system covers all aspects of transport from road or rail infrastructures to distribution of new fuels. The complete transport system planning is found in the general planning documents, i.e. the RUFS and the Stockholm City plan. They may not have the power to actually change anything, but they could be interpreted as policy entrepreneurs that try to take control of the whole transport system. The purpose of the documents is to influence all those aspects of the planning that they cover, both infrastructure and energy issues regarding transports. Palm (2004) separates in her dissertation the policy entrepreneurs, which strive for control of the whole technological system, from the other policy entrepreneurs that only strive to take control of one part of the whole system. The RUFS and the Stockholm City plan and those working with those documents are then system building policy entrepreneurs, trying to plan for the complete transport system, mostly by spatial planning, but also using the public transport to minimise the problems with scarcity. The Stockholm County Association of Local Authorities and the department of Clean Cars at the City of Stockholm are both examples of policy entrepreneurs that only strive to take one minor policy within the larger system up on the agenda; biogas and electric vehicles. The introduction of renewable fuels and electric vehicles is in this view a small part of the whole transport system and since the policy entrepreneurs that strives to put new technologies on the agenda are not trying to influence the complete system, the policy of new vehicles and fuels is rather separated from the transport system. Consequently the discussion of fuels and electricity is never on the complete transport system agenda.
4.5 Concluding remarks

The major conclusions are:

- Biogas is the technology in focus
  - It has been established as the regional technological momentum
  - It is a solution that can be connected to a problem
- Little regional cooperation
  - More regional cooperation is asked for
  - Strong municipalities
  - The regional planning has no power
- Energy and transport planning are to the most extent two separate policies
  - The energy and transport planning have to be more integrated if the road transport system shall become more renewable
5 Assessment of the impact of private economy on Stockholm’s car and motorcycle fleet

Aside political visions and technological improvements, the people who actually use vehicles are an important factor in the transport system. In this section, the impact of private persons’ economy on vehicle choice is analysed. Studies have shown that despite there being many reasons why people choose alternative vehicles, economy is the most important factor (Eppstein et al., 2011; Ozaki and Sevastyanova, 2011).

5.1 Modelling cost scenarios – Scenarios and input data

To illustrate how costs might affect private persons’ willingness to buy alternative vehicles, five cost scenarios have been modelled using reMIND. reMIND is a graphical interface tool, using mixed integer linear programming (MILP) to solve optimisation problems. In this case, the objective is to minimise the total system cost. The modelled scenarios are:

- **Reference** – “business as usual”
- **Expensive oil** – as Reference but with higher fossil fuel prices
- **Expensive biofuel** – as Reference but with higher biofuel prices
- **Expensive energy** – higher prices on all fuels
- **Electric subsidies** – as Expensive energy but promoting electric vehicles and plug-in hybrids

The scenarios are modelled with limited access to biomethane in the region. Two limitations are used; 0.45 TWh/year and 1.25 TWh/year. The lower limitation of 0.45 TWh/year represents the assumption that only 1st generation biogas is available; while the higher limitation of 1.25 TWh/year represents the assumption that 2nd generation technology is mature enough to produce SNG (see section 3.5). All scenarios are modelled with both limitations.

The only variables changed in the scenarios are costs, which are specified in Table 11. All other data, which can be found in Table 9 and Table 10 are fixed.

The scenarios were selected with probable future fuel costs in mind. With the threat of “peak oil” and the growing concern of global warming, oil prices are likely to rise. Biofuels are rather heavily subsidised today, but in the future they may need to bear a larger share of their own costs. Also, the increasing use of biomass in various sectors may lead to higher biomass prices. Electricity price, traditionally low in Sweden, might well stay rather low but increase slightly because of adaptation to the European electricity market. On the whole, energy prices may be higher in 2030 due to environmental concerns about energy use. Electric vehicles are rather expensive today, and unless battery costs drop drastically it is possible that they will be subsidised as a means for the government to incentivise purchasing. Still, battery costs are expected to drop somewhat with increased commercialisation.

5.1.1 Vehicle data used in the cost scenarios

The vehicle fleet modelled is that of Stockholm’s light passenger cars (up to 1500 kg), heavy passenger cars (between 1500 and 3500 kg), and motorcycles (mopeds are included with motorcycles). No distinction is made between juristic and natural persons even though a large part of the fleet is owned by juristic persons, which may tend to behave differently from natural persons when purchasing a vehicle. The fuels modelled are electricity, ethanol, biogas and petrol. See Table 9 for which combinations of vehicles and fuels are modelled.
Diesel will probably be a common fossil fuel 2030, since diesel consumption has lately increased rapidly while petrol consumption has decreased (Energimyndigheten, 2010). However, diesel has been left out of the model based on the assumption that costs and efficiencies will match those of petrol. Other biofuels are deemed unlikely to be widely used in the kinds of vehicles modelled, as is discussed in section 3.3.

Table 9 Fuels and vehicles represented in the cost scenarios

<table>
<thead>
<tr>
<th>Fuels and Vehicles</th>
<th>LPC</th>
<th>HPC</th>
<th>MC</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEV</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Petrol PHEV</td>
<td>x</td>
<td>x</td>
<td>-</td>
</tr>
<tr>
<td>Ethanol PHEV</td>
<td>x</td>
<td>x</td>
<td>-</td>
</tr>
<tr>
<td>Ethanol ICEV</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Biomethane ICEV</td>
<td>x</td>
<td>x</td>
<td>-</td>
</tr>
<tr>
<td>Petrol ICEV</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

For simplicity, only new vehicles are considered, i.e. the model is based on that all passenger cars, motorcycles and mopeds are replaced. The time frame considered for owning the vehicle is 10 years. This length of the time frame was chosen for the sake of comparison, as other authors use a depreciation period of 10 years (Huang et al., 2011; van Vliet et al., 2011). Also, 10 years is considered a typical battery lifetime, as discussed in section 2.4.2.3. Vehicle data is shown in Table 10. The number of vehicles and their yearly distances are acquired from section 2.2.1. This and other vehicle data used in the model is shown in Table 10.

Table 10 Vehicle and fuel consumption data used in the cost scenarios

<table>
<thead>
<tr>
<th>Fuels and Vehicles</th>
<th>No of vehicles</th>
<th>Distance [km/year]</th>
<th>Petrol use [l/100 km] ([kWh/100 km])</th>
<th>Ethanol use [l/100 km] ([kWh/100 km])</th>
<th>Biogas use [Nm$^3$/100 km] ([kWh/100 km])</th>
<th>Electricity use [kWh/100 km]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LPC</td>
<td>185400</td>
<td>10000</td>
<td>4.50 (43.2)</td>
<td>6.09 (39.6)</td>
<td>4.02 (39.0)</td>
</tr>
<tr>
<td></td>
<td>HPC</td>
<td>118600</td>
<td>16000</td>
<td>5.25 (50.5)</td>
<td>7.31 (47.5)</td>
<td>4.82 (46.8)</td>
</tr>
<tr>
<td></td>
<td>MC</td>
<td>15800</td>
<td>3000</td>
<td>3.38 (32.5)</td>
<td>4.57 (29.7)</td>
<td>-</td>
</tr>
</tbody>
</table>

Petrol use is estimated by manufacturer data for “typical” new light and heavy passenger cars, and then the volume is reduced by 25% to account for future increased fuel efficiency (Honda, 2011; Volkswagen, 2011). For MCs and mopeds, data for common models is used, with a 25% reduction (Motostat, 2011; Sveriges Radio, 2005). Petrol use is assumed to be 4.50 l/100 km for LPCs, 5.25 l/100 km for HPCs and 3.38 l/100 km for MCs. All other data is acquired from section 3.2.

In the model, improvements to conventional ICE vehicles (mixing ethanol in petrol, conservation of brake energy) are not taken into account. Plug-in hybrids are expected to run 66% of the yearly distance on electricity and the rest of the distance on liquid fuels, as stated in section 2.4.2.1.
5.1.2 Costs used in the scenarios
The costs used in the scenarios are listed in Table 11. Costs are in 2007 price levels.

Vehicles’ costs are not taken into account, as most vehicle parts are the same regardless of which fuel the vehicles utilise. For simplicity it is assumed that for equivalent vehicles, costs not directly related to fuel do not differ.

Table 11 Costs used in the cost scenarios

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Ref. Exp. oil</th>
<th>Exp. biofuel</th>
<th>Exp. energy</th>
<th>El. subsidies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol$^3$ [SEK/l] (SEK/kWh)</td>
<td>14.44 (1.50)</td>
<td>16.24 (1.69)</td>
<td>14.44 (1.50)</td>
<td>16.24 (1.69)</td>
</tr>
<tr>
<td>Electricity$^4$ [SEK/kWh]</td>
<td>1.98</td>
<td>2.05</td>
<td>1.98</td>
<td>2.46</td>
</tr>
<tr>
<td>Ethanol$^5$ [SEK/l] (SEK/kWh)</td>
<td>9.05 (1.39)</td>
<td>9.05 (1.39)</td>
<td>10.86 (1.67)</td>
<td>10.86 (1.67)</td>
</tr>
<tr>
<td>Biomethane$^6$ [SEK/Nm$^3$] (SEK/kWh)</td>
<td>11.34 (1.17)</td>
<td>11.34 (1.17)</td>
<td>13.61 (1.40)</td>
<td>13.61 (1.40)</td>
</tr>
<tr>
<td>Batteries$^7$ [SEK/kWh]</td>
<td>1800</td>
<td>1800</td>
<td>1800</td>
<td>1200</td>
</tr>
<tr>
<td>Local fees$^8$ [SEK/year]</td>
<td>8000</td>
<td>8000</td>
<td>8000</td>
<td>8000/-</td>
</tr>
</tbody>
</table>

In the Reference and Expensive oil scenarios, likely price levels$^9$ are derived from literature (Ajanovic & Haas, 2010; Offer et al., 2011; Thiel et al., 2010; Energimyndigheten, 2011). In the other scenarios, a 20% increase in electricity and biofuel prices is assumed. This increase represents that when petrol is phased out, tax revenue is lost and must be gained elsewhere. The CO$_2$ tax is designed for environmental reasons. Basically, the use of fossil fuels is taxed, but in the future more CO$_2$ emission sources may be taxed. Assuming a CO$_2$ tax of 1 SEK/kg CO$_2$ (Energimyndigheten, 2010) and emissions of 100 g/km, the original prices increase by approximately 20%. As of 2011, biofuels are exempt from CO$_2$ tax, but in a situation where biofuels are more common a CO$_2$ tax might apply.

5.1.3 Assumed subsidies used in the scenarios
The assumed EV subsidy (used in scenario Electric subsidies) is based on the currently discussed “super environmental car subsidy” (supermiljöbilspremien), which means a subsidy of 40000 SEK when purchasing a new passenger car with CO$_2$ emissions below 50 g/km and energy use below 0.3 kWh/km. The car must also comply with noise and safety requirements (Swedish Transport Agency, 2011).

---

$^3$ Based on Energimyndigheten (2011)
$^4$ Based on Energimyndigheten (2011)
$^5$ Based on statistics by SPI (2011b)
$^6$ Based on statistics by EON (2011)
$^7$ Based on Offer et al. (2011) and Thiel et al. (2010)
$^8$ 0 SEK/year for BEVs and PHEVs (cars only), 8000 SEK/year for other cars
$^9$ The petrol price is derived from projected oil price, which is prognosticated to between 106 and 147 USD/bbl (Energimyndigheten, 2011; European Commission, 2010; International Energy Agency, 2008).
As of 2011, only electric cars reach the emission requirement, and with the high cost of electric cars this is where a subsidy is needed as a purchase incentive. The subsidy equals approximately 1/3 of the price difference between a BEV and an equivalent conventional car today, and therefore a subsidy of 33% of the battery cost is used in the model. The “super environmental car subsidy” does not apply to electric motorcycles or mopeds, but in the model those vehicles are subsidised.

Locally, owners of low-emission passenger cars sometimes receive car-related benefits such as free parking. A possibility for increasing the number of electric passenger cars in Stockholm is to introduce some kind of such benefit. Since the vision for Stockholm is an all-electric transport system, the introduction of a hefty benefit for EV owners is highly plausible. In the model (scenario Electric subsidies), this is represented by a yearly benefit equivalent of today’s parking costs. This subsidy does not apply to motorcycles and mopeds but only to passenger cars.

5.1.4 Assumed battery sizes used in the scenarios
To overcome range anxiety when purchasing and driving an electric vehicle, the battery needs to be a decent size. In this model, a range capacity of 200 km is considered enough to satisfy inner-city vehicle owners. Hence, battery capacities are set to 32 kWh for light BEVs, 40 kWh for heavy BEVs and 6 kWh for motorcycles and mopeds.

For plug-in hybrids, range anxiety does not apply. Instead, battery capacity affects the car’s weight (and thereby its performance) and the owner’s behaviour (the smaller the battery, the more often it needs to be charged). Covering a distance of 50 km electrically should require most commuters to charge the battery just once every day and the weight of the battery should be sufficiently low. In this model, this gives a battery capacity of 8 kWh for light PHEVs and 10 kWh for heavy PHEVs. For a background to these calculations, see section 2.4.2.

5.2 Modelling cost scenarios – Limitations
Of course public transport and freight transport are important sectors when it comes to reducing use of fossil fuel. Public transport was not modelled as it is relatively easy for local government to influence this sector. Freight transport was not modelled as it is a complex sector both when it comes to vehicle types, possible fuels and costs, and was deemed out of scope for this particular project.

The Swedish car fleet is among the oldest in Europe, and per kilometre it is also the most fuel-consuming (Kågeson, 2007). The average lifetime of a passenger car is 17 years (Bil Sweden, 2009; Wang 2011), and the average age of a passenger car is 10 years (SCB, 2011), so by 2030 part of the vehicle fleet will be utilising today’s technology. Even if the majority of cars sold around 2030 are fossil-free, a large part of Stockholm’s vehicles may still be dependent on fossil fuel. This clearly has to be taken into consideration when analysing the cost optimisation results.

5.3 Modelling cost scenarios – Results
The result from the Reference scenario, with only 1st generation biomethane (biogas) available, is shown in Figure 12. In this scenario, the available amount of biogas is utilised and the rest of the car fleet is made up by ethanol PHEVs. All motorcycles and mopeds run on electricity.

The same result is obtained when the petrol price increases (thereby also increasing the electricity price), and when all fuels are more expensive.
The available amount of biomethane influences the results greatly. With 2\textsuperscript{nd} generation biomethane, SNG, available, the whole volume of biomethane is still utilised, see Figure 13. The same result goes for scenarios Expensive oil and Expensive energy.

Biogas is currently a hot topic in the Stockholm region. The demand for biogas is greater than the supply, even though there are few biogas vehicles on Stockholm’s streets (SCB, 2011). The model shows that with the assumed pricing, biogas and SNG are economical choices. In this simplified model, all available biogas is used, which corresponds to the situation described by respondents in section 4.3.

Figure 12 Percentage of total vehicle fleet utilising different technologies and fuels in scenarios Reference, Expensive oil and Expensive energy, with 1\textsuperscript{st} generation biomethane available

Figure 13 Percentage of total vehicle fleet utilising different technologies and fuels in scenarios Reference, Expensive oil and Expensive energy, with 1\textsuperscript{st} and 2\textsuperscript{nd} generation biomethane available
With higher biofuel prices, biomethane is still the least costly alternative for passenger cars. The number of vehicles that do not use biomethane are however not ethanol PHEVs but petrol PHEVs, as petrol is more economically competitive than ethanol. Figure 15 and Figure 14 show the scenario *Expensive biofuel* with 1st and 2nd generation biomethane available. It seems that when fossil fuel prices are sufficiently high, additional policy is not needed in order to promote alternative fuels and vehicles.

**Figure 15** Percentage of total vehicle fleet utilising different technologies and fuels in scenario *Expensive biofuel*, with 1st generation biomethane available

**Figure 14** Percentage of total vehicle fleet utilising different technologies and fuels in scenario *Expensive biofuel*, with 1st and 2nd generation biomethane available
With subsidies for electric vehicles, BEVs are still not utilised. Instead, the entire passenger car fleet is made up by ethanol PHEVs as seen in Figure 16. In this case, biomethane is not competitive.

![Figure 16 Percentage of total vehicle fleet utilising different technologies and fuels in scenario Electric subsidies, regardless of how much biomethane is available](image)

According to the cost scenarios, electric cars are (not unsurprisingly) not good value for money. This is of course based on the assumption that batteries are purchased with the vehicle. If e.g. renting the battery would be considered, the result might turn out differently. Unless either electricity prices or battery costs drop, a plug-in hybrid is a better choice. This result is also found by van Vliet et al. (2011). But there are two issues here worth discussing. One is that in the model, 66% of PHEV kilometres are supposed to be driven in electric mode. This average number is appropriate to use in a model, but reality is much more complex. The other issue is that in the scenario where EVs are subsidised, both BEVs and PHEVs are assumed to receive a subsidy (although the BEV subsidy is bigger).

Electric motorcycles and mopeds seem highly competitive regardless of cost variations, and for mopeds this is probably true. But it is not realistic to believe that an electric motor will be a popular option when purchasing a new motorcycle. Other features, such as performance and range, probably affect the choice of motorcycle more than they affect the choice of car, since a motorcycle often is more than a means of transport. It is also a plaything or a lifestyle attribute, and so some models will not be considered no matter how economically competitive they are. Mopeds on the other hand are little more than a means of urban transport, making economy a very influential factor. Reliability and environmental friendliness are probably important factors as well. It seems reasonable that reliable and cost-effective electric mopeds will be a popular alternative to petrol mopeds.

The cost scenarios show that heavy PHEVs are more competitive than light PHEVs. This is somewhat surprising, as a lighter passenger car is cheaper and more fuel efficient. However, the model takes yearly distance into account, and heavy passenger cars are used much more than light ones. With the high purchase cost of PHEVs (due to the batteries), fuel cost needs to be low enough to compensate for the purchase cost.
The kilometre cost of a PHEV is less than that of a biogas passenger car, so once the purchase cost is compensated for, driving a PHEV is cheaper than driving a biogas car. This explains why, according to the model, heavy PHEVs are more competitive than light PHEVs.

In these scenarios, only fuel and battery costs for new vehicles are accounted for. Aside from economy, there are plenty of reasons why people choose to buy a certain vehicle, such as performance and reliability (Eppstein et al., 2011; Ozaki and Sevastyanova, 2011). Even though biomethane is an economically competitive alternative, the availability of fuelling stations could influence the willingness to buy a biomethane car. When it comes to EVs, doubts about performance might influence car buyers to choose conventional ICE vehicles instead. Zhang et al. (2011) claim that technology push (fewer conventional and more alternative vehicles in the market) affects the purchasing of EVs positively. This in combination with social pressure, which has been recognised as a powerful factor (Ozaki and Sevastyanova, 2011), could reduce doubts about reliability and performance and escalate the number of electric and biofuelled vehicle buyers.

5.4 Modelling cost scenarios – Conclusions

- Given assumed costs, PHEVs and biogas ICEVs are economically competitive
- For BEVs to be competitive, large subsidies or cheap electricity is needed
- A high enough fossil fuel price makes alternative fuels competitive
- Heavy PHEVs are more competitive than light PHEVs
- Availability is the governing factor for biogas usage
6 Scenario assessment

This sub-study analyses three different pathways to achieve a renewable transport system in Stockholm by 2030. For each pathway a scenario is created, which generates information about fuel demand and supply, environmental impacts and import dependency. The variable parameter in the scenarios is the composition of the vehicle fleet with regard to utilised fuels and powertrains. In addition to the three renewable scenarios, a reference scenario with only fossil fuels is constructed.

The purpose of the scenario assessment method is to study the consequences a future renewable transport system would have on the energy system and the global emissions of greenhouse gas emissions, in this study expressed as CO₂ equivalents. The construction of the scenarios and the input data are based on a literature study and the authors’ assumptions regarding future vehicle use.

Data regarding the number of vehicles, average driving distances and fuel economy data for different vehicle and fuel combinations is retrieved from sections 2 and 3, and as discussed in section 3 a 25 % fuel economy improvement is assumed. Data for a “reasonable” fuel mix (scenario 3) for each vehicle type was estimated based on sections 2 and 3. CO₂ emissions per used energy quantity is gathered from section 3.4.

The advantage of the scenario assessment method is to be able to study implications of a renewable road transport system by simple calculations. The aim of the sub-study is not to calculate exact numbers for the future transport system, but rather to assess magnitudes and discover trends. Hence no certain conclusions can be drawn from the results of the scenario assessment. The findings should be regarded as possible outcomes, with the chosen assumptions and data in mind.

A weakness of this method is reliability of results. The results depend on the robustness of input data as well as the many assumptions made. To increase input data robustness, data has been gathered from a wide range of sources, who mostly use different methods to produce data. To further strengthen reliability, data is gathered from sources deemed independent and trustworthy, e.g. official EU documents and peer-reviewed scientific papers. As assumptions are necessary in this kind of scenario assessment, they are as far as possible also motivated by literature.

For all three renewable scenarios, the composition of 2\textsuperscript{nd} generation biofuels is fixed. Out of the biomass feedstock (1.87 TWh) available for 2\textsuperscript{nd} generation biofuel production, the assumed product composition is presented in Table 12. This composition is based on what the authors regard as ideal utilisation of the most energy efficient production technologies for 2\textsuperscript{nd} generation biofuel, with the additional goal of minimising fuel import.

<table>
<thead>
<tr>
<th>Table 12 Distribution fuel production</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 % biomass</td>
</tr>
<tr>
<td>20 % Biomethane</td>
</tr>
<tr>
<td>40 % DME</td>
</tr>
<tr>
<td>40 % Synthetic diesel</td>
</tr>
</tbody>
</table>

Electricity aimed for EVs is often declared to be renewable and/or fossil-free. In this sub-study electricity is assumed to be renewable, which in a Swedish perspective implies that electricity is predominantly produced in hydro and nuclear power plants.
These have CO₂ emissions corresponding to up to 66 g CO₂ eq/kWh (Dotzauer, 2010). The environmental impact of power generation is further discussed in sections 2.4.2.7 and 7.2.3.

### 6.1 Scenario assessment input data

To define the physical road transport system (i.e. the fleet composition) and the corresponding energy system (e.g. powertrain energy efficiency and fuel production process technologies) is necessary for the scenario assessment.

#### 6.1.1 Fuel economy per vehicle category

In Table 13, the fuel economy for each vehicle technology is stated. For PHEVs, the total fuel demand depends on the ratio between electricity and biofuel use. The biofuel data is specified in section 3.2. The fuel economy for each type of EV is the retrieved from (Bandivadekar et al., 2009; Crosby, 2009; Amjad et al., 2011; Safarianova et al., 2009)

<table>
<thead>
<tr>
<th></th>
<th>LPC</th>
<th>HPC</th>
<th>LDT</th>
<th>HDT</th>
<th>Bus</th>
<th>MC</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEV Fuel economy [kWh/100 km]</td>
<td>20</td>
<td>25</td>
<td>55</td>
<td>160</td>
<td>110</td>
<td>3</td>
</tr>
<tr>
<td>PHEV Fuel economy [kWh/100 km]</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>20</td>
<td>30</td>
<td>75</td>
</tr>
<tr>
<td>PHEV Share of energy electricity [%]</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>20</td>
<td>30</td>
<td>75</td>
</tr>
<tr>
<td>Ethanol [kWh/100 km]</td>
<td>39</td>
<td>48</td>
<td>78</td>
<td>391</td>
<td>437</td>
<td>48</td>
</tr>
<tr>
<td>Biogas, mixed (biogas, SNG) [kWh/100 km]</td>
<td>39</td>
<td>47</td>
<td>81</td>
<td>403</td>
<td>457</td>
<td></td>
</tr>
<tr>
<td>Synthetic diesel (FT, RME) [kWh/100 km]</td>
<td>37</td>
<td>44</td>
<td>78</td>
<td>387</td>
<td>447</td>
<td>48</td>
</tr>
<tr>
<td>DME [kWh/100 km]</td>
<td>76</td>
<td>377</td>
<td>440</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 6.1.2 Green house gas emissions

This study focuses mainly on CO₂ as a GHG. Table 14 shows CO₂ emissions per energy carrier.

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol, wheat₁</td>
<td>88</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lignocellulosic ethanol²</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biogas, mixed³</td>
<td>-67</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SNG³</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RME¹</td>
<td>95</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Synthetic diesel²</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DME²</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. (Börjesson et al. 2010).
2. (Concawe 2007).
3. Average for biogas from municipal solid waste, industry and manure in Börjesson et al. (2010).
4. (Perimenis et al. 2010).

#### 6.1.3 Travel pattern

The number of vehicles in the City of Stockholm, and the estimated annual driving distances, are listed in Table 15. The data is based on literature and assumptions presented in section 2.2.
Table 15 Input data for transport system

<table>
<thead>
<tr>
<th></th>
<th>LPC</th>
<th>HPC</th>
<th>LDT</th>
<th>HDT</th>
<th>Bus</th>
<th>MC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2030</td>
<td>10 000</td>
<td>16 000</td>
<td>18 000</td>
<td>20 000</td>
<td>56 000</td>
<td>3 000</td>
</tr>
<tr>
<td>Annual kilometres</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of vehicles</td>
<td>185 400</td>
<td>118 600</td>
<td>44 600</td>
<td>4 800</td>
<td>1 100</td>
<td>15 800</td>
</tr>
</tbody>
</table>

6.1.4 Composition of fuels and vehicle technologies

Scenario 1: Advanced biofuel production technology

In scenario 1 (Figure 17), vital technological development of existing renewable fuel technology (both in terms of fuel production processes and vehicle technology) is assumed:

- Increased energy efficiency and environmental performance of production processes. A successful introduction of 2nd generation renewable fuels is assumed, analogous with projections from the Swedish Ministry of Environment (Holmberg, 2009).
- Increased energy efficiency of vehicles by technical means, e.g. mild hybridisation, weight reduction and tyre rolling resistance reduction.

Although the powertrain in 2030 is assumed to in some degree be electrified, this scenario assumes a low market penetration of EVs. Since the PHEV does not compromise in accessible range, it is assumed to gain more market shares than the BEV.
Scenario 2: Electrified road transport system

In scenario 2 (Figure 18), each vehicle category consists of the largest theoretical share of electric vehicles achievable and reasonable. Since not all vehicles benefit from electrification, non-electrified vehicles are assumed to utilise the renewable fuels best suited to vehicle types.

Figure 18 Vehicle fleet composition scenario 2

Scenario 3: Favourable fuel production and vehicle technologies

In scenario 3 (Figure 19), a dynamic composition of a renewable vehicle fleet is assumed. For each vehicle category and corresponding fuel, “best practise” technologies are assumed. Limitations regarding biofuel production potential is also taken into consideration, in order to reduce fuel import dependency.
6.2 Scenario assessment output data
The output data from the scenarios form the basis for a comparison between the three scenarios’ impact on the energy system. Generated data include:

- Fuel demand (Table 16, Figure 20Figure 21Figure 22)
- Distribution of fuel for every vehicle (Figure 23Figure 24Figure 25)
- CO₂ emissions for each scenario (Figure 26)
- Energy demand and CO₂ emissions for the fossil reference scenario (Table 17)

### Table 16 Fuel demand per scenario and fuel

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Biofuel future</td>
<td>EV future</td>
<td>Mixed fuel future</td>
</tr>
<tr>
<td>Electricity [TWh/yr]</td>
<td>0.08</td>
<td>0.81</td>
<td>0.32</td>
</tr>
<tr>
<td>Ethanol [TWh/yr]</td>
<td>0.81</td>
<td>0.20</td>
<td>0.31</td>
</tr>
<tr>
<td>Biomethane [TWh/yr]</td>
<td>0.78</td>
<td>0.12</td>
<td>0.62</td>
</tr>
<tr>
<td>Synthetic diesel [TWh/yr]</td>
<td>0.64</td>
<td>0.22</td>
<td>0.61</td>
</tr>
<tr>
<td>DME [TWh/yr]</td>
<td>0.44</td>
<td>0.14</td>
<td>0.48</td>
</tr>
<tr>
<td><strong>Total fuel demand [TWh/yr]</strong></td>
<td><strong>2,7</strong></td>
<td><strong>1,5</strong></td>
<td><strong>2,4</strong></td>
</tr>
</tbody>
</table>
Scenario 1
Energy demand per fuel, in total 2.7 TWh

Figure 20 Fuel composition for scenario 1, and energy demand for one year

Scenario 2
Energy demand per fuel, in total 1.5 TWh

Figure 21 Fuel composition for scenario 2, and energy demand for one year
Figure 22 Fuel composition for scenario 3, and energy demand for one year

Figure 23 Distribution of fuel for each vehicle type in scenario 1, for one year
**Scenario 2**

*Fuel demand per vehicle technology*

- DME
- Synthetic diesel
- Biomethane
- Ethanol
- Electricity

Figure 24 Distribution of fuel for each vehicle type in scenario 2, for one year

**Scenario 3**

*Fuel demand per vehicle technology*

- DME
- Synthetic diesel
- Biomethane
- Ethanol
- Electricity

Figure 25 Distribution of fuel for each vehicle type in scenario 3, for one year
Figure 26 Accumulated CO2 emissions per scenario, for one year. 1st generation biomethane (biogas) is considered to have negative emissions, hence the sub-zero value.

Table 17 Generated data; fossil reference scenario

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total energy demand [TWh/yr]</th>
<th>Petrol demand [TWh/yr]</th>
<th>Diesel demand [TWh/yr]</th>
<th>Total CO2 eq. [tonnes/yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil reference scenario</td>
<td>2.9</td>
<td>2.1</td>
<td>0.8</td>
<td>853 000</td>
</tr>
</tbody>
</table>

6.3 Assessing the scenarios

By altering the composition of fuels an vehicles, the energy system is affected. When assessing the impact of the scenarios, the generated data form the basis for a discussion about how an energy and resource efficient renewable future can be conceived.

6.3.1 Fuel demand analysis

In scenario 1, the biofuel production potential does not meet the demand. Hence, this scenario depends on multiple fuel import. The fuel import amounts to 1 TWh (0.15 TWh biomethane, 0.5 TWh ethanol, 0.26 TWh synthetic diesel and 0.11 TWh DME), which corresponds to 40% of the total fuel demand. If similar fuel production conditions to Mälardalen prevail nationwide, this import may be considered possible to achieve within Sweden.

In scenario 2, no fuel import is necessary. Fuel export may even be considered possible. A possible outcome of this scenario is that 1st generation ethanol and biodiesel could be phased out, leaving 1st generation biomethane (biogas) and 2nd generation biofuels to be distributed in a favourable way. A surplus of biogas could be used for power generation. A significant share of the system’s energy demand (54%) corresponds to electricity. A study assuming a fossil-independent and profoundly electrified Swedish vehicle fleet in 2030, predicts electricity to account for 42% of the total fuel demand (Bergman, 2010).
Since the City of Stockholm has potential to more extensively electrify its vehicle fleet compared to a Swedish average, the results from this study may be correlated with Bergman’s (2010) results.

In scenario 3, the most energy efficient production technologies for 2nd generation biofuels are utilised, with the additional goal to minimise fuel import. Also, 1st generation biofuels are prominent on the market. Biogas constitutes 80% of total biomethane demand and biodiesel covers more than 10% of total synthetic diesel demand. 1st generation ethanol accounts for 100% of total ethanol demand. This implies a total fuel import demand of 0.28 TWh, corresponding to 20% of DME demand and 30% of synthetic diesel demand. The shortage in regional fuel supply (10% of total fuel demand) may be possible to obtain without import from other countries.

### 6.3.2 Emission reduction potential

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Fossil reference scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ total [tonnes]</td>
<td>78 401</td>
<td>67 672</td>
<td>52 201</td>
<td>853 000</td>
</tr>
<tr>
<td>CO₂ reduction</td>
<td>91%</td>
<td>92%</td>
<td>94%</td>
<td>[-]</td>
</tr>
<tr>
<td>compared to fossil</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>reference case [%]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂/TWh [tonnes/TWh]</td>
<td>29 037</td>
<td>45 114</td>
<td>21 750</td>
<td>29 413</td>
</tr>
</tbody>
</table>

As seen in Table 18, Scenario 1 has a dominating share of biofuels, which implies high utilisation of both 1st and 2nd generation biofuels. As scenario 3 is developed to be resource efficient, the biomass is utilised most beneficially, favouring 2nd generation biofuels. As 1st generation biofuel production has higher CO₂ emissions, this explains the difference between the scenarios’ emissions reductions. Scenario 2 illustrates a vehicle fleet with a high share of EVs. EVs have local CO₂ free operation, but as discussed in section 2.4.2.7, this does not mean that no CO₂ is emitted. Even though scenario 2 is energy efficient, the fuel and electricity production is associated with high levels of CO₂ emissions.
### 6.4 Conclusions from scenario assessment

**Table 19 Summary of conclusions from scenario assessment**

<table>
<thead>
<tr>
<th>Scenario 1 (Advanced biofuel production technology)</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Improved environmental performance compared to fossil reference case</td>
<td>High degree of fuel import dependency</td>
</tr>
<tr>
<td></td>
<td>Differentiated fuel market</td>
<td>Different production technologies associated with different costs; difficult to obtain fair subsidies</td>
</tr>
<tr>
<td>Scenario 2 (Electrified road transport system)</td>
<td>Improved environmental performance compared to fossil reference case</td>
<td>Not only EVs need subsidies, but also the biofuelled vehicles</td>
</tr>
<tr>
<td></td>
<td>Most energy efficient vehicle fleet compared to other scenarios</td>
<td>Expensive technology</td>
</tr>
<tr>
<td></td>
<td>Fuel import independent</td>
<td>Battery technology means a large risk for consumers</td>
</tr>
<tr>
<td></td>
<td>Diverse energy sources</td>
<td></td>
</tr>
<tr>
<td>Scenario 3 (Favourable fuel production and vehicle technologies)</td>
<td>Improved environmental performance compared to fossil reference case</td>
<td>Dependant on local fuel production</td>
</tr>
<tr>
<td></td>
<td>Efficient utilisation of resources</td>
<td>Different production technologies associated with different costs; difficult to obtain fair subsidies</td>
</tr>
<tr>
<td></td>
<td>Best environmental performance, compared to other scenarios</td>
<td></td>
</tr>
</tbody>
</table>
7 Interdisciplinary discussion
This study considers three aspects; technical, private-economical and regional planning, apart and interacting, and their implications on a transition towards a renewable road transport system. Unlike other studies, both national and international, this study has been carried out in a multilateral way.

7.1 Is it possible to achieve a renewable transport system in Stockholm 2030?
This study implies that the appropriate conditions needed for a renewable road transport system in Stockholm 2030 exist. The most vital conditions and major uncertainties found for each aspect are:

- There is a sufficient amount of biomass to fill Stockholm’s needs in a renewable future, if the biomass is used in the transport system.
- Commercialisation of 2nd generation biofuel production is a challenge.
- Monetary incentives are necessary for the introduction of new fuels and vehicles. These incentives should be allocated and directed appropriately.
- Other factors than economy affect the choices made by private persons when purchasing vehicles.
- Transport and energy policies should be more integrated. Regional planning is best executed by one legitimate actor.
- Energy policy includes transport aspects, but transport policy does not include energy aspects.

These findings, as well as other aspects on energy use in road transport, are used as basis for the discussion in this chapter. The study has also found an interdependency between the energy and transport systems, as illustrated in Figure 27 The interdependency of the energy and transport systems.

The interactions between the energy and transport systems become evident when assessing scenarios to achieve a renewable road transport system, see section 6. With the varying fleet conditions used in the scenarios, the Stockholm transport system’s total energy demand varies by 60 % (most energy efficient scenario compared to least energy efficient one). The scenarios’ deficit in fuel supply is assumed to be filled by import. However, the distribution systems to the system boundary and within the system are assumed to be sufficient to meet the fuel demand. As the fuel distribution system is a transport system component, this dictates the availability of fuel within the system boundary. Since the vehicle technologies state the fuel demand, the composition of the vehicle fleet has high impact on the energy system. This illustrates the interdependency between the systems and the importance of a balance between the two.
Since private persons’ behaviour is sensitive to costs, the result that a shift in transportation towards alternative vehicles and fuels is economically beneficial has implications for society as a whole. If private persons can be convinced to buy alternative vehicles, it is likely that sectors such as goods transport and public transport also utilise alternative technologies. There is also a possibility of positive feedback loops. With increased use of e.g. biogas it is likely that the biogas supply increases, thereby influencing more people to switch to biogas as fuel, which in turn might increase supply and so on.

Economically, there is a possibility to reach a large number of renewable fuels and vehicle technologies in the private vehicle fleet by 2030. With a continued political support for biofuels, biomethane is a competitive option. In this context, “support” does not only cover costs but also availability. Supply needs to match demand and there has to be good enough access to fuelling stations. With political support for plug-in hybrids, they too are competitive. PHEVs are an especially good alternative in the city of Stockholm, as they can reduce both local noise and molecular emissions. Electric mopeds are also interesting options, both economically and environmentally. Overall, increasing petrol and diesel prices are likely to shift fuel consumption towards biofuels and electricity.

In a renewable transport system the regional planning in the Stockholm area is integrated and discussed in cooperation among the different actors; municipalities, County Council – the Office of Regional Planning and Stockholm Public Transport and County Administration Board. The issue of renewable fuels and electric vehicles is included in this general transport system discussion. To improve the integration of transport and energy planning, the regional planning need more planning power. Thus the regional planning must be well consolidated among the municipalities and they need to be willing to cooperate in order to achieve common goals. This could imply the establishment of a more general regional actor, who has local support and responsibility for all aspects of the energy and transport planning, which currently is located to different actors. However, extended cooperation between the municipalities and a more complete discussion and decision-making on the regional level about transport and energy issues, could lead to the same result.

A consequence of a more integrated regional planning level is that knowledge is built up regarding all current technologies and biogas loses its role as momentum. By gathering this knowledge on a regional level it could be more widely spread among the different actors, and negative momentum could be prevented. This is already today illustrated in the case of the City of Stockholm and its Department of Clean Cars, where knowledge about renewable technologies has been gathered during a long time. Today, the most widespread knowledge about current technologies is found there. In the line of work of the Department of Clean Cars, the regional level could take initiatives to public procurement promoting one or several specific technologies, both to assemble a knowledge base and spread new technologies.

In a renewable road transport system, transport planning includes the complete system; infrastructure, vehicles and fuels. Energy issues and an extended system view are included in the new transport planning. Transport planning, both strategy documents and practices, is integrated with energy planning and therefore policy measures concerning the complete energy system are collective.

7.2 Implications for the energy and transport systems
The renewable energy use in the transport system of Stockholm is already significant and development is on-going. In 2001, biogas and ethanol cars were practically non-existent, but since then they have increased enormously (SCB, 2011).
In 2010, ethanol and biogas cars made up approximately 5% of the Swedish car fleet while in Stockholm they made up approximately 13% (SCB, 2010). Considering this development, it seems likely that in 2030, a large fraction of Stockholm’s vehicles will run on alternative fuels. However, improvement of today’s biofuels and the commercialisation of new vehicles and fuel production technologies, e.g. EVs and 2nd generation biofuels, are essential in this development process. Challenges and possibilities for these technologies are discussed in this section.

7.2.1 Biofuels
There are many challenges to address for biofuels fuels to be a significant part of a renewable road transport system. For some biofuels the difficulties lie in the production process, e.g. biomass cultivation or process efficiency, while for others the challenge lies in distribution systems and vehicle technology. Other, non-technical, difficulties are that biofuel knowledge is thinly spread among decision makers and that proper land use poses a planning problem.

7.2.1.1 1st generation biofuels
The challenge for all biofuels, but especially for gaseous fuels, is the synchronisation of market development, infrastructure and production. An example of this is biogas, which requires specific fuelling stations. Potential consumers want assurance that they will have access to biogas before acquiring a biogas car, while biogas suppliers want assurance that there is a large enough customer base before setting up a new fuelling station. In those cases public authorities, especially the municipalities, have a major opportunity to solve this problem, by subsidising biogas fuelling stations. This study has shown that the City of Stockholm and the Department of Clean Cars work actively with this, by gathering regional biogas market actors and through their input and support are able to introduce both new vehicles new fuelling stations.

Once the biogas vehicles are in traffic and the fuelling stations are operating, biogas will probably be a lasting alternative because of the infrastructure investments. Biogas could then, be established as the major new technology in Stockholm, as a renewable momentum as described in section 4.1.3. Today, private biogas cars comprise a minor share of the vehicle fleet. Hence, incentives are probably needed for biogas to become a more popular alternative.

The issues of where to produce biogas, from which kind of biomass, where the biomass originates from and which alternative uses there are for the biomass, add to the biogas complexity. Also, biogas is a regional product. There is no existing infrastructure for the transport of biogas, as there is for e.g. electricity and petrol; hence biogas is often used near the production site. The possibility of consuming a lot of biogas in the Stockholm area creates a need for production of large volumes of biogas in the same area. However, even if the production of biogas would increase in the Stockholm area, the distribution problems would remain. One example of how the City of Stockholm considers solving the problem is the launch of environmental friendly fuelling stations. By pressuring the owners of the gas stations in the city centre to connect to the planned pipeline for biogas, the infrastructure will be in place.

Regarding the production volume there is a limitation in the availability of cheap and suitable material. Stockholm’s planners view biogas as a solution to their large resource of municipal solid waste, but this point of view may change. The emission reductions of biogas depend on which feedstock is used and which reference system is replaced. Hence the GHG emission balance would be less favourable with feedstocks which require more energy for converting. In Stockholm it is necessary to reorganise the waste collection system to separate the organic fraction and transport it to the biogas production site.
The reorganisation and new collection patterns might require more resources and it would be necessary to evaluate this option and compare it to the current system. Until now many feedstocks have been acquired without cost, or the biogas producer has even been paid to handle the feedstock. As the feedstock becomes more expensive and difficult to collect it is vital that the biogas production process becomes more efficient and robust. This is also important in order to assure reliable deliveries and to compensate for the resources needed for distribution infrastructure.

Ethanol is quite easy to incorporate into the transport system, why it was very popular among the planning institutions a few years back. However, ethanol suffers from other limitations. Crop based biofuels like 1st generation ethanol and synthetic diesel, e.g. RME, are widely debated. However, most studies agree that these fuels are less energy efficient and have higher GHG emissions than compared to 2nd generation biofuels. These biofuel production processes need major improvements if they are to fulfil future biofuel sustainability criteria. The possibilities for ethanol production process improvements lie mainly in the use of by-products from the process. E.g. production of biogas from the stillage, or combustion of straw, could significantly improve the energy balance. Improvements to the 1st generation ethanol production process seem to be limited, since this is a well-known process and since large areas of arable land are needed. The same reasoning applies to RME. The ethanol industry is working towards the development of 2nd generation ethanol from lignocellulosic biomass and if successful this will probably replace the 1st generation ethanol completely.

Economically, biogas in particular but also ethanol could be interesting options for private persons. As shown in this study, a transition to biofuels requires incentives and/or high petrol and diesel prices, so in order to maintain or even increase the popularity of biofuels political support is needed regarding both costs and availability.

7.2.1.2 2nd generation biofuels
2nd generation biofuels bring improvements and solutions to some of the issues of 1st generation production technology, concerning both production and distribution. However, none of these fuels are without disadvantages. The major challenge for 2nd generation biofuels is the launch of commercial production facilities that are competitive regarding resource efficiency, emissions and economy.

Fuels produced from gasification have high energy efficiency and low GHG emissions compared to other biofuels, but not compared to biogas. Based on the WTW studies in this report, DME is the most attractive alternative in this sense, followed by SNG and FT-diesel. Lignocellulosic ethanol is less favourable compared to these three fuels, but definitely more favourable compared to 1st generation ethanol and biodiesel. FT-diesel and ethanol are more favourable when reviewing the possibilities for introduction in the current fuel infrastructure and vehicle technology. FT-diesel is attractive because it can be introduced without any changes in the system. Ethanol is fairly compatible with the current transport system, and it has already been introduced via 1st generation production. The technical challenge for 2nd generation ethanol and synthetic diesel is mainly improvement of production efficiency and GHG balance.

There are also other challenges for 2nd generation biofuels. Ethanol will probably have problems “coming back” to the political planning agenda. Regional actors consider ethanol being “out” of the trend list – they view ethanol as something that was on everyone’s lips a few years ago but now has passed. Consequently, ethanol could have problems to get political support, even if it was to come back.
Another vital question is if other 2nd generation biofuels will become commercialised at all, especially if subsidies are needed. In section 4 it is shown that usually, no other fuels than biogas, electricity and ethanol are mentioned by regional actors. Knowledge about other renewable fuels is limited among public actors and this needs to improve for the fuels to get support.

Improvement of the lignocellulosic ethanol production process can be achieved by integrating the process with other processes and utilising by-products efficiently, e.g. producing biogas from waste material and using lignin in heat production. For SNG and DME the challenge lies in the distribution and vehicle technology. There are synergy effects between SNG and biogas, since they use the same vehicle technology and infrastructure. Both production routes (gasification and anaerobic digestion) can be helped forward by natural gas covering the demand exceeding the biomethane production, and by utilising natural gas infrastructure. DME requires similar distribution system as biomethane, but an additional challenge is that DME can be liquefied at low pressures and there is virtually no infrastructure for this kind of fuel in place yet.

Choosing which biofuels are most favourable and deserve development support is difficult. Therefore well-defined and measurable biofuel sustainability criteria need to be developed, in order to make sure that biofuels really fulfil their purpose as part of a renewable road transport system. Biofuels fulfilling these criteria need to be economically supported during their development phase; otherwise they probably cannot compete with existing fuels. The type of support necessary should vary with the properties and development stage of the fuel, and it should preferably aim to reduce the fuel’s weaknesses.

Development of 2nd generation biofuels may be necessary to ensure sufficient quantities to supply the road transport system. Today the biogas demand is greater than the supply, and according to the cost scenarios used in this study this situation may remain unless new production methods are introduced.

7.2.2 Other aspects on biofuel use

A Swedish report estimates the total Swedish biofuel production potential 2030 to 53 TWh/year (Miljödepartementet, 2005). This could cover more than half of the energy needed in the current transport system. Other literature is more pessimistic. One study concludes that biofuels (in this case ethanol) are uncompetitive from an economic perspective, especially unless 2nd generation biofuels are commercialised (Torchio and Santanelli, 2010). Another study assumes that biofuels will be used mainly mixed into petrol and diesel, sometimes to such a high degree as 25 % (Thiel et al., 2010). Biomass may be cost-effectively used in heat and power production; hence maybe it should not be used in the transport sector (Grahn et al., 2009). In 2030, Swedish and European prognoses expect a small share of biofuelled cars to operate in a market of conventional, fossil fuelled cars (European Commission, 2010; Energimyndigheten, 2011). According to some studies, biofuels are an interim solution (Robèrt et al., 2007) or not a feasible solution at all (Torchio and Santarelli, 2010). Yet other transport system studies do not even mention biofuels (Doucette et al., 2011; Thiel et al., 2010; Wang, 2011).

Kågeson (2007) argues that by utilising a lot of biofuels Sweden might set a bad example. His point of view is that the projected global biomass capacity is not sufficient to accommodate extensive biofuel use, and if other industrialised countries were to follow Sweden’s lead the transport sector would not have a renewable future (Kågeson, 2007). If the case is right, it might be a problem that biogas is the major fuel the regional actors are investing in and working with.
7.2.3 Electricity
Electricity is often declared an environmental friendly energy carrier, both in popular and scientific contexts and especially when transport is considered (Effekt Klimatmagasinet, 2010; Wang, 2011). Since EVs have zero local emissions, they indeed seem clean alternatives. However, electricity production may cause large emissions elsewhere. In Sweden, electricity production is almost emission-free. Swedish electricity is produced by nuclear, hydro, wind and co-generation power plants, all of which have very low CO₂ emissions. There is little electricity import (Energimyndigheten, 2010). Hence it seems that in Sweden, EVs are indeed environmental friendly means of transport. However, taking into account the marginal electricity principle introduced in section 2.4.2.7 and considering CC or NGCC power plants as marginal units, EVs are not so emission free.

7.2.4 Electric vehicles
EVs might increase only slowly in the market. Battery costs are still high, fast charging technology is still in development, and many car owners are sceptic (NyTeknik, 2011). Because of those problems the public authorities could be considered to have responsibility to support EVs. The City of Stockholm are currently doing this, but this study shows that EVs are not widespread within Sweden, since no policy entrepreneurs try spreading EVs on a regional level as well as within the City. The City of Stockholm thus risks becoming an isolated island in its investment in EVs. However, the case of the current EV public procurement could partially counteract this.

In 2030 there will probably be plenty of BEV and PHEV alternatives, but the slow market introduction will probably mean that there are still a lot of conventional cars in traffic. However cities like Stockholm are likely to be forerunners in introducing EVs, since they fit very well into urban traffic. The flexibility of the PHEV might make it a more interesting option to consumers compared to the BEV, not only because of range security but also because of the daily possibility to select the cheapest fuel.

The size of an EV subsidy and the requirements for receiving a subsidy probably affect the choice between a BEV and a PHEV – at least if economy is the dominating factor. If the car is to be used in an urban context (raising the electric distance from 66%, assuming frequent charges), or if it is a family’s second car, range security is not an issue. A large BEV subsidy might then make the choice a BEV. But if the car is to be used only in the city or if it is a family’s second car – should it really be subsidised? Under these premises, should not options that reduce the need for the car be considered?

7.2.5 Combining renewable technologies
The planning of renewable fuel introductions in Stockholm’s transport system is characterised by trends. A while back, ethanol was in vogue. Today, it’s all about biogas. Tomorrow’s alternative fuel is electricity. The planners recognise their own role in choosing and promoting alternatives, but are afraid to decide what to go for – and so tend to go for a little bit of everything. The interview respondents in this study consider this an inconvenient situation, since they believe that market actors hesitate to invest when they are unsure what public authorities want.

This study shows that a future renewable road transport system includes several technologies, why planning policies must support several fuel production and vehicle technologies at the same time. It is important that policy measures developed to support new technologies are not technology neutral in the sense in which policy documents use the concept. Resources should not be given to the technology that is best suited to the specific policy measure; instead resources should be distributed among the different technologies.
That way all fuel production and vehicle technologies may improve and achieve an equal level of commercialisation. Public authorities should continue to act neutrally towards the different technologies, but only in the sense that they provide equal opportunities to act on the market.

One suggestion for how to make the most energy efficient technologies accepted by the market is to make the transport system part of the European emission trading market. Kågeson (2007) and Banister (2005) argue that with a common European emission trading market, covering all energy-using sectors, costs will guide resource use. Such a system would also steer energy resources towards proper use. For instance biomass will replace fossil fuels in sectors where replacement is least expensive (Kågeson, 2007; Banister, 2005). However, when mentioning the European emission trading market in the interviews in this study, the local planners instead believe that leaving transports out of the emission trading market is an opportunity for change towards a more renewable system (interview KSL). As long as the transport system is left outside the emission trading market it is possible for local and regional actors to influence the system.

7.3 General aspects on energy use in the transport system

This study shows that the introduction of efficient technologies can reduce energy use in the transport system. However, technology is only part of the solution. Other influencing aspects are discussed in this section.

7.3.1 Revenue loss

When fossil fuels are phased out of the transport system, the state will lose tax revenue. In order to maintain an economic balance, income must be generated from other sources. One way of doing this is to tax the fuels that substitute fossil fuels. By taxing biofuels and electricity, the popularity of these fuels is likely to decrease and thereby slow down the transition to renewable transport. Instead, travel could be taxed per kilometre, as suggested by Banister (2005) and Kågeson (2007). This way using transport would be costly, but specific fuels would not be unfairly priced. Hence, this could add to cost competitive technology neutrality.

7.3.2 Rebound effect

Kågeson (2007) studied the rebound effect when replacing a petrol ICEV with a diesel ICEV. He found that the rebound effect would likely cut the emission reductions in half (the technology switch would mean an 18% emission reduction, but with the extra rebound distance the reduction would merely be 9%). The rebound effect is connected both to vehicle owners’ economy and to their perceived sense of being environmental friendly (Elbilsupphandling.se, 2011). Since the lower cost of choosing a vehicle emitting less CO\textsubscript{2} is a strong incentive, prices ought probably not to be raised in order to mitigate the rebound effect. However, clearly declaring emission figures and accounting for the benefits of reduced vehicle use might diminish the rebound effect.

7.3.3 Comparison with other sectors

In other sectors, such as the manufacturing industry, it has been shown that energy use can be reduced drastically. Reductions are made partly by utilising more energy efficient technology, but also by elimination of unnecessary energy use (Trygg, 2006). Energy efficiency within the transport sector often equals more fuel efficient vehicles and alternative fuels. A basic assumption is often that the need for transport will not decline, so when modelling or discussing a future transport system, the assumed distance covered by transport is often equal to that of today – or longer (see e.g. European Commission, 2010, van Vliet et al., 2011).
Aside the projected increase there is also a risk of rebound effect to consider; that new technology may lead to an increase in car use since a longer distance can be travelled resulting in the same amount of CO₂ emissions.

**7.3.4 What is energy efficient?**

In this study, planning documents and practices have shown that in Stockholm there is a widespread belief among regional actors; that the amount of needed transport within the region will increase until 2030. The people who live in the region today will not reduce their travel, and the population is estimated to increase. There is also a political vision of regional enlargement, which implies much more transport within a larger region.

Åkerman & Höjer (2006) differentiate between *desired travel* (leisure trips) and *structurally enforced travel* (going to work, going grocery shopping etc.). They draw up a vision of cities where restructured planning actually leads to an increase in *structurally enforced travel*, but where the majority of these trips are made on foot, by bicycle or using public transport. With this change in daily travel patterns the amount of *desired travel* is allowed to increase, still meeting the 450 ppm CO₂ target (referring to the CO₂ level target for 2050 in the white paper from the European Commission, see section 2.1.1.1) According to this study, a high fuel price will only affect *desired travel* unless combined with other policy measures, thereby not reducing CO₂ emissions very much but perhaps affecting people’s perceived happiness.

Visions of dealing with increasing travel through restructured planning are also found in this study. There is a widespread conviction among the region’s planners that a more energy efficient Stockholm transport system is first and foremost reached through a change in spatial planning goals. These goals include integrating transport planning with real estate planning and increasing travel by other means of transport than the passenger car.

Kenworthy (2006) describes how this may look like in a study of sustainable cities where urban planning and transport infrastructure are two out of ten key dimensions. Cities ought to be densely populated, with workplaces located close to housing (Kenworthy, 2006). Walking, cycling, public transport and reduced car dependence ought to be facilitated. These measures are also found by a British backcasting study, considering policy options with the objective of reducing transport sector CO₂ emissions by 60 % by 2030 (Hickman and Banister, 2007). Their conclusion is that policy targeting social factors would bring about greater emission reductions than policy targeting technological factors. Social factors include (among other measures) walking, cycling and using public transport to a higher extent than today while using cars less than today. Technological factors include e.g. renewable vehicles and fuels.

Restructuring city planning might be tricky, as today’s cities are made for cars. According to Kågeson (2007) and Banister (2005), during the past decades passenger car traffic greatly affected urban planning. Because of easy car access cities were not densely planned, and a lot of urban space was used for parking places and roads (Kågeson, 2007; Banister, 2005). The dependence on the passenger car and how it still makes some planning issues politically controversial is also found in this study. Within the City of Stockholm, planners are looking into the issue of parking spaces and how they could be reduced. It has not yet been possible to decide upon reductions in parking space availability due to this issue’s political controversy. Consequently, the history of accommodating spatial planning for the passenger car is playing a major role in current spatial planning even though Stockholm tries planning a more sustainable city.
This discussion serves to point out that energy efficiency is not merely a question of new vehicles and fuels, but also includes spatial planning and interventions to changes in citizens’ behaviour. Transport planners must take the whole transport system into consideration when planning for a renewable Stockholm road transport system.

7.4 Other studies
A range of scenario studies on both energy and transport systems are available, and they cover different regions and time spans. The purpose of the studies may be to forecast the future and see in which direction current conditions lead, or it may be backcasting, where a future scenario is fixed and how to get there is investigated. This study uses both kinds of scenario methodology to evaluate the possibility of a renewable road transport system 2030. In this section, some studies and prognoses concerning similar issues are presented.

7.4.1 Comparisons with other studies
Hådell (2009) evaluated the possibility of reaching a target of 10% biofuels in the transport sector 2020. The conclusion was that with the right measures 11.4% could be reached (Hådell, 2009).

The introduction of new technology is the focus in this study, although the importance of other factors (e.g. behavioural change and restructured urban planning) is also acknowledged. A Swedish backcasting study, modelling energy demand in Stockholm County’s transport system in 2030, concludes that a mix of factors (a higher fuel price, more fuel efficient vehicles and less car travel due to behavioural change) leads to greater reductions in energy use than a big breakthrough in vehicle technology or a tripling of fuel price (Robèrt et al., 2007).

The conclusion that economy, technology and behaviour are all important factors for the reduction of energy use within the transport sector is shared by another Swedish study, this one outlining a Swedish renewable (compliant with the 450 ppm CO₂ target) transport system 2050. Åkerman and Höjer (2006) find that while vehicles must become much more energy efficient, short-distance car travel must also be reduced drastically from today’s levels if Sweden is to comply with the 450 ppm CO₂ target. While new technology is clearly an important part of a future transport system, changing transport behaviour is also essential (Åkerman and Höjer, 2006).

7.4.2 Prognoses
Various institutions have made prognoses about the future energy use within the transport sector. The European Commission assumes that by 2030, 8.3% of cars in the EU will run on biofuels. The remaining 91.7% are assumed to run on fossil fuels. 0.0% is assumed to use electricity as fuel. With the addition of some policies, numbers are up to 11.3% biofuels but still 0.0% electricity (European Commission, 2010). The Swedish Energy Agency has made a long-term prognosis for the Swedish energy use, where the main scenario includes a share of 7.5% biofuels in the domestic transport sector. Here, biogas and FAME are considered to be the fastest growing biofuels (Energimyndigheten, 2011). Based on these prognoses all of the scenarios in this study seem unlikely. The prognoses are based on the current policies and trends in society, which makes it obvious that considerable changes in these systems are necessary to reach a renewable transport system 2030.
8 General conclusions

The conclusion is that favourable conditions to achieve a renewable road transport system in Stockholm by 2030 theoretically exist.

The technological aspects include biofuels, electricity and vehicles that utilise those fuels. This study shows that fuel and vehicle technology could exist to provide several renewable futures. However, an ideal setup of technologies implies a more efficient resource management and lower overall energy demand. Assumptions regarding favourable theoretical technological development are widely spread but are yet not proven since this development lies in the future. The challenges for biofuels are mainly the commercialisation of 2nd generation fuel production technology and to further increase the energy efficiency in the production process. For electric vehicles, the main uncertainties are the battery technology development and the expected correlated cost reductions.

This study has shown that with regards to private economy, political support is necessary to make renewable fuels and vehicle technologies economically competitive. In addition, rising petrol and diesel prices are a prerequisite for renewable fuels and vehicle technologies. However, human behaviour constitutes an uncertainty. Factors such as performance and reliability affect decisions when purchasing vehicles and these may be difficult to overcome by economics.

The planning policy regarding renewable transport is dependent on several factors; the public actors’ technological knowledge; the political will to change; and the legitimacy of the actors to implement necessary planning. This study implies that for a transition to a renewable road transport system, regional planning with system knowledge and local trust would be best suited to achieve this. Today, energy policy includes transport issues but transport policy does not include energy aspects. To achieve a more renewable transport system, this study implies that transport policy needs to include energy issues and the two policy subjects need to be integrated (see Figure 28).
When combining the three aspects, it becomes clear that the favourable conditions may have trouble coexisting. Today, energy and transport policy are not integrated within planning policy. This has a negative influence on the technology development, since long-term solutions are required. This study implies that unless structural changes in the planning organisation take place, planning policy is not likely to change by 2030. Hence, technology development might slow down and private persons might not dare invest in alternative vehicles and fuels.

This study shows that a combination of technologies is required to achieve high system energy efficiency and substantially reduce CO₂ emissions. All technologies need political support measures based on their development stage and their specific challenges in order to achieve technology neutrality based on cost competitiveness. This kind of technology neutrality is not to be confused with the technology neutrality mentioned in planning policy processes, where the expression is used in the sense that all technologies have equal commercialisation conditions. If in regional planning policy all fuels were treated as actively as biogas, more fuels would have a commercial possibility.
9 Future work and lessons learned
Expanding the system boundaries and including a larger region would be interesting, as a renewable Stockholm road transport system affects many more actors than those considered in this study. Examples of actors who could be included in a further study are energy companies, small and medium-size enterprises and non-governmental organisations. External effects and societal costs would also be interesting to consider, perhaps using cost-benefit analysis.

This study discusses the importance of favourable conditions working simultaneously. An aspect that is excluded in this study, but is crucial when implementing new technologies, is the consumers’ acceptance. To understand the consumer from other perspectives than the private economical one could be interesting when transiting to a renewable road transport system.

In this study the biofuel production potential is limited and it would be interesting to make more precise estimations of the actual potential. This would include more precise calculations on available biomass and the influence of alternative biomass use. It would also be relevant to explore the most resource efficient way of utilising land and biomass resources for the transport system.

9.1 Working in an interdisciplinary team
The authors of this report came into the project with different backgrounds and different perspectives on the selected subject. Frequent meetings were held, where the structure and the aim of the study were discussed and decided upon. The meetings where always very structured, with an agenda and timetable. Between the meetings individual work was carried out and the progression was presented at the next meeting. The authors find this concept useful, as the frequent contact ensured that the project was well focused while all authors were able to pursue their own points of interest. Assembling the authors’ results and constructing a common discussion was done in group and allowed to take a lot of time. The authors find that this was very important for the outcome of the study as well as for all project members’ understanding of the study.

A lesson learned the hard way is that when working with shared data, one cannot be clear enough about which data to use where and when in order to avoid mistakes. Also the authors wish to point out the value of using a stable file managing system. Dropbox is a particularly nice system as it can be used both on- and offline, and notifies users when updates are made. This means that over-worked authors can be comforted by the notion that other project members are working, too.

Another lesson learned is that it is very helpful to decide upon the structure of the report at an early stage and assign an author to each section. The content in each section should preferably be clearly defined in order to avoid that two authors write about the same topic.

Working together, the communication can never become too clear. Implicit perceptions have to be spelled out in order for a successful collaboration and to minimise the excess work. The production of this study has made the authors more aware of their scientific baggage, which is valuable both for individual projects but foremost for future collaborations.
10 References


Balat, M. Production of bioethanol from lignocellulosic materials via the biochemical pathway: A review. Energy Conversion and Management 2011; 52 (2) : 858-875.


European Commission. Roadmap to a single European transport area – towards a competitive and resource efficient transport system, 2011.


Difs, K, Wetterlund, E, Trygg, L, Söderström, M. Biomass gasification opportunities in a district heating system. Biomass and Bioenergy 2010; 34 (5): 637-651


European Commission. EU energy trends to 2030. 2010.


Magnusson, D. Between municipal and regional planning: The development of regional district heating systems in Stockholm. Local Environment 16 (4): 319-337.


Murphy, JD, Power, NM. How can we improve the energy balance of ethanol production from wheat? Fuel 2008; 87 (10-11): 1799-1806.


Tijmensen, MJA, Faaij, APC, Hamelinck, CN, van Hardeveld, MRM. Exploration of the possibilities for production of Fischer Tropsch liquids and power via biomass gasification. Biomass and Bioenergy 2002; 23 (2): 129-152.


**Studied documents not referred to in the report**

SATSA 1.1. handlingsprogram Effektiv Trafik – Förstudie om hantering av trängsel, sårbarhet och trafikens klimatpåverkan I tidsperspektivet 2012-2020. 2008


**Interviews**

Interview City of Stockholm 1. 2011-06-17

Interview City of Stockholm 2. 2011-06-21

Interview Association of Local Authorities. 2011-06-16

Interview County Administration Board 1. 2011-06-20

Interview County Administration Board 2. 2011-06-20
Appendices

Appendix 1 – Interview guides

Interview City of Stockholm 1
– Project manager at the Department of Clean Cars, a part of the Environment and Health Administration, at the City of Stockholm

- Miljöbilar i Stockholm har framförallt arbetat med etanol, biogas och el
  o hur ser nutid och framtid ut, vilka är i fokus?
  o Finns det några andra drivmedel som blivit mer/mindre intressanta? Varför?
  o Vad avgör att man satsar på vissa?
- Om man ser till hela Stockholmsregionen - Hur ser introduktionen av dessa drivmedel ut?
  o Vem/vilka aktörer arbetar med den typen av frågor? På vilket sätt? Planering?
  o Sker det samverkan på det här området? Vilka typer av samverkan/samordning? På vilket sätt samverkar man?
  o Vad gör Stockholm Stad?
  o År planeringen för en introduktion av förnyelsebara drivmedel inkluderad i den lokala och/eller regionala transportplaneringen? På vilket sätt? Varför/varför inte?
  o Vad bör enligt dig planeras regionalt?
- Vems ansvar är det att verka för att den typen av fordon får genomslag i samhället?
  o Bör olika styrmedel införas? Varför/varför inte?
  o Vilka styrmedel tror du behövs?
  o Vilka styrmedel kan kommunen påverka?
  o Vilka tekniker bör man stödja; ingen/några/all? 
  o Vad lämpar sig bäst i Stockholm? Vad ska man satsa på?
  o Vad Stockholmsregionen ska satsa på - vad baserar man i så fall sina beslut på?
  o Ni har använt er av teknikupphandlingar för att driva utvecklingen framåt – vilken är Vattenfalls roll i elbilsupphandlingen?
  o Om elbilar blir det vanliga – hur tror du att man kommer att lösa skattbasen som skatten på bensin och diesel idag drar in till staten? Eftersom det huvudsakliga argumentet för elbilen idag är att den är billigare i drift.


Personer

Du pratade förra gången om mälardalsrådet som samverkans organisation ibland annat dessa frågor – finns det någon tjänsteman där som skulle kunna intervjuas om drivmedelsfrågor?
Finns det någon inom Stockholm Stad som arbetar mer med samhällsplaneringsfrågor som skulle kunna svara på frågor om drivmedelsfrågornas vara eller icke vara i den världen?

**Interview City of Stockholm 2**

- **Overview planner at the City Planning Administration at the City of Stockholm**
  
  - Kan du inleda med att kort berätta om ditt arbete med transportfrågor i Stockholm Stad/region?

**Stockholms ÖP 2010**

- Laga kraft?
  - Betydelsefulla åtgärder när det gäller klimat: främja teknikutveckling, underlätta effektiv energianvändning med hjälp av en genomtänkt stadsplanering, genom upphandling främja tillämpningen av miljöeffektiv teknik. För att nå Stockholms klimatmål är en fortsatt miljöteknikutveckling av central betydelse – ”det är då viktigt att det finns en väl fungerande infrastruktur för produktion och distribution av alternativa drivmedel”
    - Hur arbetar man konkret med dessa frågor?
    - Finns de med i planförfarandet?
  - Vision 2030: ett välfungerande transportsystem med minimal klimatpåverkan – ”för att klara detta högt ställda mål krävs större samordning mellan olika samhällssektorer, en utvecklad trafik- och bebyggelseplanering samt ett helhetsperspektiv på regionens transportsystem”
    - Vad innebär det konkret?
    - Vad är det som krävs som inte finns nu?

**Regional transportplanering**

- Regional transportplanering – vad är det för dig?
  - Hur fungerar transportplaneringen i Stockholmsregionen?
  - Vilka områden fokuserar man på? *(energi)*
  - Hur arbetar ni konkret?
  - Samverkan?
  - Vilken roll har Stockholm Stad? Och övriga regionala/lokala aktörer?

**Energi**

- Energifrågor – är de en del av ditt arbete? På vilket sätt?
  - Hur arbetar man med energifrågor på ditt område? *(transporter)*
  - Vad gör ni?
  - Samverkan?
  - Vilken roll har Stockholm Stad? Vilken roll har övriga aktörer?

**Fossilfria drivmedel**

- Om jag säger förnyelsebara drivmedel (i motsats till fossila bränslen) – Vilka tänker du på då?
  - Vilka diskuterar ni i regionen/kommunen?
o Hur ser introduktionen av dessa drivmedel inom vägtrafiken i Stockholms län ut?

o Vem/vilka aktörer arbetar med den typen av frågor? På vilket sätt? Planering?

o Sker det samverkan på det här området? Vilka typer av samverkan/samordning? På vilket sätt samverkar man?

o Vad gör Stockholm Stad, din avdelning? Vad vill ni? Vad kan ni göra?

o Hur arbetar ni gentemot andra avdelningar inom kommunen (Miljöbilar)?

o Är planeringen för en introduktion av förnyelsebara drivmedel inkluderad i den lokala och/eller regionala transportplaneringen? På vilket sätt? Varför/varför inte?

- Vems ansvar är det att verka för att den typen av fordon får genomslag i samhället?
  o Bör olika styrmedel införas? Varför/varför inte?
  o Vilka styrmedel tror du behövs?
  o Finns det möjlighet att införa regionala styrmedel tror du?
  o Vilka tekniker bör man stödja; ingen/några/alla?
  o Vad lämpar sig bäst i Stockholm? Vad ska man satsa på?
  o Vad Stockholmsregionen ska satsa på - vad baserar man i så fall sina beslut på?


Interview Association of Local Authorities
– a person who has responsibility for the overall environmental and social development issues on the Stockholm County Association of Local Authorities

- Kan du inleda med att kort berätta om ditt arbete med energifrågor i Stockholmsregionen?

Energi

- Energifrågorna – hur arbetar ni konkret med dem?
  o Vilka fokusområden ingår i energifrågan? (transporter)
  o Vad gör ni?
  o Samverkan?
  o Vilken roll har KSL? Vilken roll har övriga aktörer?

Regional transportplanering

- Regional transportplanering – vad är det för dig?
  o Hur fungerar transportplaneringen i Stockholmsregionen?
  o Vilka områden fokuserar man på? (energi)
  o Hur arbetar ni konkret?
  o Samverkan?
  o Vilken roll har KSL? Och övriga regionala aktörer?
  o Vilken roll har kommunerna?
Fossilfria drivmedel

- Om jag säger förnyelsebara drivmedel (i motsats till fossila bränslen) – Vilka tänker du på då?
  - Vilka diskuterar ni i regionen?
  - Hur ser introduktionen av dessa drivmedel inom vägtrafiken i Stockholms län ut?
  - Vem/valka aktörer arbetar med den typen av frågor? På vilket sätt? Planering?
  - Sker det samverkan på det här området? Vilka typer av samverkan/samordning? På vilket sätt samverkar man?
  - Vad gör KSL? Vad vill ni? Vad kan ni göra?
  - År planeringen för en introduktion av förnyelsebara drivmedel inkluderad i den lokala och/eller regionala transportplaneringen? På vilket sätt? Varför/varför inte?

- Vems ansvar är det att verka för att den typen av fordon får genomslag i samhället?
  - Bör olika styrmedel införas? Varför/varför inte?
  - Vilka styrmedel tror du behövs?
  - Finns det möjlighet att införa regionala styrmedel tror du?
  - Vilka tekniker bör man stödja; ingen/några/alla?
  - Vad lämpar sig bäst i Stockholm? Vad ska man satsa på?
  - Vad Stockholmsregionen ska satsa på - vad baserar man i så fall sina beslut på?


Elfordon

- Är elfordon aktuella för Stockholmsregionen? Varför/varför inte?
  - Stockholm Stad har en elbilsstrategi – är det någon annan aktör som arbetar aktivt med introduktion av elfordon?
  - Bör Stockholmsregionen arbeta med elfordsnointroduktion (infrastruktur)? Vilka problem/möjligheter finns?
  - Vilken/vilka aktörer har ansvaret för att elfordon blir ett möjligt alternativ?

Biogas

  - Varför är biogas så framträdande? Varför önskvärt?
  - Vilka aktörer är aktiva i arbetet?
• Vad krävs för att biogasen ska bli ett vanligt drivmedel i Stockholms län?  
  Infrastruktur? Problem? Möjligheter?  
• Bör man göra dessa satsningar?  
• Hur går arbetet?  
• Vad gör KSL?

**Interview County Administration Board 1**

- **Analyst under the Stockholm County Administration Board directorate**

• Kan du inleda med att kort berätta om ditt arbete med drivmedelsfrågor i Stockholmsregionen?

**Fossilfria drivmedel**

• Om jag säger förnyelsebara drivmedel (i motsats till fossila bränslen) – Vilka tänker du på då?
  o Vilka diskuterar ni i regionen?
  o Hur ser introduktionen av dessa drivmedel inom vägtrafiken i Stockholms län ut?
  o Vem/vilka aktörer arbetar med den typen av frågor? På vilket sätt? Planering?
  o Sker det samverkan på det här området? Vilka typer av samverkan/samordning? På vilket sätt samverkar man?
  o Vad gör Länsstyrelsen? Vad vill ni? Vad kan ni göra?
  o Är planeringen för en introduktion av förnyelsebara drivmedel inkluderad i den lokala och/eller regionala transportplaneringen? På vilket sätt? Varför/varför inte?

• Vems ansvar är det att verka för att den typen av fordon får genomslag i samhället?
  o Bör olika styrmedel införas? Varför/varför inte?
  o Vilka styrmedel tror du behövs?
  o Finns det möjlighet att införa regionala styrmedel tror du?
  o Vilka tekniker bör man stödja; ingen/några/alla?
  o Vad lämpar sig bäst i Stockholm? Vad ska man satsa på?
  o Vad Stockholmsregionen ska satsa på - vad baserar man i så fall sina beslut på?


**Regional transportplanering**

• Regional transportplanering – vad är det för dig?
Hur fungerar transportplaneringen i Stockholmsregionen?
Vilka områden fokuserar man på? (energi)
Vad är bra i den regionala planeringen ur ditt perspektiv?
Vad anser du saknas?
Vilken roll har Länsstyrelsen? Och övriga regionala aktörer?

Energi

- Energifrågorna – hur arbetar ni konkret med dem?
  - Vilka fokusområden ingår i energifrågan? (transporter)
  - Samverkan?
  - Vilken roll har Länsstyrelsen? Vilken roll har övriga aktörer?

Elfordon

- Är elfordon aktuella för Stockholmsregionen? Varför/varför inte?
  - Stockholm Stad har en elbilsstrategi – är det någon annan aktör som arbetar aktivt med introduktion av elfordon?
  - Bör Stockholmsregionen arbeta med elfordsntroduktion (infrastruktur)?
    - Vilka problem/möjligheter finns?
  - Vilken/vilka aktörer har ansvaret för att elfordon blir ett möjligt alternativ?

Biogas

  - Varför är biogas så framträdande? Varför önskvärt?
  - Vilka aktörer är aktiva i arbetet?
  - Vad krävs för att biogasen ska bli ett vanligt drivmedel i Stockholms län?
    - Infrastruktur? Problem? Möjligheter?
  - Bör man göra dessa satsningar?
  - Hur går arbetet?
  - Vad gör Länsstyrelsen?
Appendix 2 – Fossil fuel scenario
The fossil fuel scenario is included as a reference scenario for comparison with the scenarios with a renewable transportation system. We assumed a 25% energy efficiency improvement, and that 90% of LPC and HPC use gasoline and the rest diesel, that buses and HDT use diesel and LDT and motorcycles use gasoline.

Fossil fuel scenario 2030 - Energy consumption. Total 2.9 TWh/year

![Energy consumption chart](image)

Figure 29 Energy consumption in fossil fuel scenario

Fossil fuel scenario 2030 - GHG-emissions. Total 853 kT/year

![GHG emissions chart](image)

Figure 30 GHG emissions in fossil fuel scenario
Table 20 Fossil fuel scenario. Total energy consumption and GHG-emissions. Calculated from Stockholm’s vehicle fleet, average driving distance, energy consumption data in Table 21 and GHG-emissions data in Table 22.

<table>
<thead>
<tr>
<th></th>
<th>Gasoline (GWh)</th>
<th>Diesel (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPC, 90 % G, 10 % D</td>
<td>653</td>
<td>68</td>
</tr>
<tr>
<td>HPC, 90 % G, 10 % D</td>
<td>802</td>
<td>84</td>
</tr>
<tr>
<td>LDT, G</td>
<td>623</td>
<td></td>
</tr>
<tr>
<td>HDT, D</td>
<td>385</td>
<td></td>
</tr>
<tr>
<td>Bus, D</td>
<td>276</td>
<td></td>
</tr>
<tr>
<td>MC, G</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Total energy/fuel</td>
<td>2101</td>
<td>812</td>
</tr>
<tr>
<td>Total emissions/fuel (kT)</td>
<td>613</td>
<td>240</td>
</tr>
<tr>
<td>Total energy</td>
<td>2914</td>
<td>GWh/year</td>
</tr>
<tr>
<td>Total emissions</td>
<td>853</td>
<td>kT CO2-eq/year</td>
</tr>
</tbody>
</table>

Table 21 Energy consumption for fossil fuels

<table>
<thead>
<tr>
<th></th>
<th>Gasoline (kWh/100 km)</th>
<th>Diesel (kWh/100 km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPC(^1,2)</td>
<td>39</td>
<td>37</td>
</tr>
<tr>
<td>HPC(^1,2)</td>
<td>47</td>
<td>44</td>
</tr>
<tr>
<td>LDT(^3)</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td>HDT(^4)</td>
<td></td>
<td>387</td>
</tr>
<tr>
<td>Bus(^5)</td>
<td></td>
<td>447</td>
</tr>
<tr>
<td>MC(^6)</td>
<td></td>
<td>48</td>
</tr>
</tbody>
</table>

1. Same calculations and references as synthetic diesel in section 3.2.
2. Calculated from DISI engine table 5.1.5 in JEC (2006), with 25 % energy efficiency improvement, and 20 % increased energy consumption for HPV.

Table 22 WTW GHG-emissions for fossil fuels (g CO2-eq/kWh) (JEC, 2007)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>292 gCO2-eq/kWh</td>
</tr>
<tr>
<td>Diesel</td>
<td>295 gCO2-eq/kWh</td>
</tr>
</tbody>
</table>
Appendix 3 – Agenda electric vehicle conference in Brussels

08:30 – 09:00
Coffee and Registration

Guests are asked to arrive in good time so that the conference can start as scheduled.

09:00 – 10:00
Keynote Presentations

Moderator: Mr Christian Egenhofer, Senior Research Fellow, CEPS

09:00 – 09:20
View from the European Commission

Mr Siim Kallas, Vice-President & Commissioner for Transport, European Commission

09:20 – 09:40
View from Industry

Mr Akihito Tanke, Executive Advisor to the President, Toyota Motor Europe

09:40 – 10:00
View from the European Parliament

Mr Dirk Sterckx, Member, European Parliament

10:00 – 11:15
Session 1: Incentivising electric vehicles: when and how?

With the necessity for cleaner and more sustainable transport, has the case for electric vehicles, as opposed to other emissions reduction “tools”, been sufficiently made? Given that
large parts of Europe still rely heavily on coal for their power, how can electric cars realistically be deemed “green”? And how do electric vehicles compare with optimised combustion engine cars on a well-to-wheel basis? Should Europe be incentivising Electric vehicle or CO2-efficiency? With regards financing, many member states have utilised subsidies and tax incentives to make electric vehicles a more attractive option to consumers. However, are pricing mechanisms the only measures that would truly encourage the uptake of electric vehicles?

Moderator: Mr Christian Egenhofer, Senior Research Fellow, CEPS

10:00 – 10:15
Introductory Presentation

Ms Isabel Fernandez, Chief Commercial Officer, EMEA, GE Capital

10:15 – 11:15
Panel Discussion

Mr Hugues Van Honacker, Policy Officer, DG Move, European Commission
Mr Kulveer Ranger, Mayor's Environment Advisor & Digital London, Mayor of London
Mr Ian Faye, Project Manager, Robert Bosch GmbH
Mr Arne Richters, Manager Clean Cars, Transport & Environment

11:15 – 11:30
Coffee Break

11:30 – 12:30
High-Level Keynote Industry & Infrastructure Session

This keynote session will feature high level industry players. It will be followed by a brief Q&A.
Moderator: Mr Pete Harrison, EU Energy and Environment Correspondent, Thomson Reuters

11:30 – 11:50
Keynote Presentation

Mr Harry van Dorenmalen, Chairman Europe, IBM

11:50 – 12:10
Keynote Presentation

Mr João Dias, National Coordinator of the Program for Electric Mobility in Portugal, MOBI.E

12:10 – 12:30

Keynote Presentation

Mr Shai Agassi, Founder and CEO, Better Place

Afternoon

12:30 – 13:30

Session 2: Infrastructure and charging solutions – where next for Europe?

While electric vehicles are seen by car manufacturers as a means of meeting increasingly stringent global emissions targets, inadequate infrastructure will delay a widespread shift to electric vehicles. What needs to be done from policy and practical perspectives to create a sustainable network of charging stations? Has standardisation been sufficiently implemented by member states to allow consumers to conveniently recharge their vehicles at accessible, high power, fast charging stations? Will the grid be able to endure the increased requirement for electricity until the development of smart-grid systems for the vehicle-to-grid connection interface becomes a well-established alternative? Is contactless charging the way forward? How will consumers pay for their electricity usage?

Moderator: Mr Pete Harrison, EU Energy and Environment Correspondent, Thomson Reuters

12:30 – 13:30

Panel Discussion

Mr David Dossett, President, CENELEC
Mr Stefan Tostmann, Head of Unit Energy Technologies and Research Co-ordination, DG ENER C2, European Commission
Mr Federico Caleno, EV Recharging Infrastructure Project Manager, Networks Technologies Business Development, Enel Distribuzione Spa
Mr Stefan Becker, Political Affairs and Communications, Energy Mix, Environment, Efficiency, E.ON AG

13:30 – 14:45

Lunch

14:45 – 17:00
Session 3: Ensuring a safe, user-friendly experience for the consumer – what should policymakers and industry be doing?

Electric cars are becoming more and more attractive with the advancement of new battery technologies but uncertainties remain over the overall weight, life cycle and cost of a battery system. Will there be adequate schemes for recycling and reusing batteries? What are the safety risks particular to electric vehicles? How will the high voltage required to power an electric vehicle be handled during maintenance and after collision and how will electric vehicles respond to severe weather conditions or additional weight such as luggage? With the necessity for the availability and extensive distribution of vehicle parts, how convenient will it be for consumers to repair their electric vehicle?

Moderator: Mr Martin Du Bois, Partner, Cambre Associates

14:45 – 15:05
Keynote Presentation

Mr Jean-Luc di Paola-Galloni, Vice Chairman, ERTRAC, Group Corporate Vice-President Sustainable Development and External Affairs, Valeo

15:05 – 17:00
Panel Discussion

Mr Bernard Lycke, Director General, CECRA - European Council for Motor Trades & Repairs
Mr Henk de Pauw, Senior Officer, NORMAPME
Mr Ronald de Haan, Senior Manager International Products & Profitability Business Development, LeasePlan Corporation N.V
Mr Giacomo Mattinò, Deputy Head of Unit, DG ENTR, European Commission