TU Delft | Movares Energy

Electric Mobility: on the Road to Energy Transition

A technical and actor assessment of social costs of electric mobility

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PREFACE AND ACKNOWLEDGEMENTS

At the beginning of 2011, I was looking for a Master Thesis Project. Inspired by a Summer Course on electric mobility, I was aiming at a project on that subject. My interest in energy-related subjects steered me towards the electricity network aspects of electric mobility. I visited Movares Energy, with a request to study electric mobility on their behalf and found my graduation committee. The project started in May 2011 and now preludes the end of my student life. The project was challenging at several points and also allowed me to learn new things, not only on the subject, but also on how to do such a large project on my own. This document is the result of all these learning experiences and as the reader can see from the amount of pages, there have been quite a lot of learning experiences. The reading guide below will help the reader through the document, especially when one is interested in specific aspects of the project. Below the reading guide I will say a few words to thank the people that helped me during my project.

Reading guide

Those readers interested in basic information on electric mobility, the technology development of electric vehicles and on grid operation are referred to chapter 2. Also for information on system analysis and creating a system diagram for a socio-technical problem, one is referred to chapter 2. Chapter 3 provides insight in analysis on, implications of, and possible ways to limit, grid impact of electric mobility. If one is interested in the perspectives and involvement of municipalities and network operators on electric mobility, one is referred to chapter 4. This chapter also provides insight in existing institutions and degrees of freedom in institutions related to social costs of electric mobility. Finally, chapter 4 provides insight in the applicability and feasibility of the four layer model of institutions for describing these actors' perspectives. For information on a possible strategy to reduce grid impact of electric mobility, the reader is referred to chapter 5. Chapter 6 and 7 provide respectively conclusions and a reflection on the project.

Acknowledgements

I would like to thank my graduating committee members; Zofia Lukzso who really helped me to continue the project at some critical points; Rik Luiten who always had time for me to discuss the project; Margot Weijnen and Leon Hermans for their valuable criticism during and in between the graduation meetings.

I want to thank my colleagues at Movares Energy. I really enjoyed our (sometimes pretty ethical) discussions at work, but also your substantial contributions on my project. I would also like to thank the people I met or interviewed at the municipalities, network operators and TU Delft.

Finally I would like to thank Bas my brother and parents for their time to read through and correct my report, and advices during the project. I would also like to my friends and family for their support and advices in finishing this project, and for the support and fun during my entire study.

EXECUTIVE SUMMARY

Due to environmental advantages on air quality and CO_2 reduction, local and national governments are stimulating the adoption of electric vehicles. In the coming decades, electric vehicles are expected to become widely adopted by consumers and companies. Electric vehicles charge via the electricity grid. Large scale electric vehicle adoption can significantly increase the electricity demand on the network. The existing grid capacity might no longer suffice to deal with the increased demand and will require reinforcements which is very costly. It is currently uncertain how and where this impact on the grid will occur. The potential costs for grid reinforcements are socialised. It is in societies' benefit to limit the social costs of electric mobility.

The allocation of the cost and benefits make it difficult to limit the costs. Municipalities are mainly faced with benefits of air quality and CO_2 reduction and some municipalities therefore actively stimulate electric mobility. Network operators deal with reduced grid reliability and costs for grid reinforcements but have limited insight and possibilities in charging station deployment, but a lot of interest to do so. Municipalities on the other hand have a role in charging station deployment, but no interest to thereby limit grid impact. There is thus a split incentive structure in limiting the social costs of electric mobility.

The main objective of this project is to deal with this split incentive structure by recommending a strategy for the two actors to limit the social costs of electric mobility. The main question to be answered in this thesis is therefore:

How can municipalities and network operators come to a strategy to limit social costs of electric mobility charging infrastructure?

The problem of the impact of electric mobility on the grid is identified as a socio-technical system. Grid impact of electric mobility on the grid is not only complex due to the complexity inherent to the network and electric mobility. The complexity is increased by the actors involved in the system and their formal and informal relations. The main question will therefore be answered by means of technical and actor analyses. Firstly, a system analysis further defines the problem by means of an analysis on technical system components and the relevant actors related to those components. Secondly, the grid impact of electric mobility is analysed quantitatively. Thirdly, an institutional analysis shows why municipalities and network operators act in a certain way and how they are affected by grid impact. Finally a possible strategy for the actors to deal with the grid impact will be presented.

System analysis

Electric vehicles charge via the existing grid and are thereby loads to the existing electricity system. Electric vehicles can be charged via a normal plug, connecting the vehicle to an existing grid connection, but in many cases also public charging stations are required. These public charging stations require new grid connections. The Dutch electricity grid is currently a very reliable network but faces several developments and challenges in the coming decades on changing demand and supply, and aging of the electricity network. Electric mobility is one of the developments that can possibly alter normal grid operation. When left to consumers' convenience it is expected that the peak of charging demand will occur at the same time as the normal electricity demand peak. Electric mobility can therefore harm the reliability of the grid.

Three actors are relevant when looking at the grid impact of electric mobility:

- Some *municipalities* actively stimulate electric mobility by deploying charging infrastructure. Municipalities also have a role in providing leasing rights for charging stations on public property.
- *Network operators* are responsible for operating and maintaining a reliable grid. The network operator will be faced with an increased electricity load. Network operators are initiating pilots in order to gain insights in charging behaviour of vehicle users.
- *Vehicle users* determine the adoption of electric vehicles and influence the grid by their charging behaviour. Users are in this thesis merely considered as passive actors, included in models by their charging behaviour and vehicle demand.

The main problem for limiting the grid impact lies in the interaction between the technical system and responsibilities and incentives of actors. Three interactions are uncertain and will be further detailed. The first interaction is the influence of the behaviour of a vehicle user on the electricity network. The second interaction is the influence network operators and municipalities have on the electricity grid and how these actors are affected by the grid impact. The third interaction is the interaction between network operators and municipalities to see how these actors can together limit the social costs of electric mobility. For these analyses, interviews, literature research and desk research was done.

Grid impact analysis

The grid impact of electric mobility is studied by using an existing grid model of a medium voltage sub-grid in Utrecht and supplementing it with a model which differentiates additional electric vehicle load per neighbourhood based on demographic characteristics. The following *differentiation formula* is used to calculate the expected number of electric vehicles in a certain neighbourhood:

$$EV_{\ i} = EV_{av} * Veh_i * \frac{HI_i}{HI_{av}} * \frac{VpH_i}{VpH_{av}} * \frac{PV_i}{PV_{av}}$$

Where:

EV_i	=	electric vehicle share in area i	VpH_i	=	number of vehicles per household in i
EV_{av}	=	average electric vehicle market in the municipality	VpH_a	=	average number of vehicles per household in the municipality
Veh_i	=	number of vehicles in i			
HI_i	=	percentage higher income in i	PV_i	=	property value in i
HI_{av}	=	average percentage higher income in the municipality	PV_{av}	=	average property value in the municipality

The calculations show that organic growth overloads 19% of grid components. Full adoption of electric vehicles causes 29% of the grid components to be overloaded.

An uncertainty analysis was done to see how different electric mobility deployment strategies influence the grid impact. This analysis shows that also for low electric mobility shares, an impact can be expected. It is also concluded that already critical components exist which will be overloaded either by organic growth or by electric mobility. Furthermore, it can be concluded that fast charging has a relatively large individual impact on the electricity grid. Finally, it can be concluded from the uncertainty analysis that smart charging significantly decreases the grid impact of charging stations.

Both smart charging and location assessment of high power charging stations limit grid impact. For assessing the location of high power charging stations based on grid capacity, charging stations can be located on other grid branches with sufficient capacity to deal with the charging station load, or located at the beginning of grid branches in order to limit the amount of reinforcements required.

Grid impact can be associated with reduced grid reliability or high socialised costs for grid reinforcements. A reduced grid reliability can have negative effects on business and living climate in the municipalities. Social costs could be associated with social inequality and reinforcements are also associated with road construction, which entails nuisance to residents and local transport. In order for network operators to prevent reduced grid reliability and be able to accurately plan reinforcements, it is important to know where impact can be expected. Network operators should therefore calculate the expected impact of municipal objectives for electric mobility and identify critical grid components. In order to calculate the impact, the electric mobility transition objectives need to be translated to additional load per grid node. This load should be based on the number of vehicles present in the neighbourhood and the differentiation formula.

Institutional analysis

The institutional analysis is used to analyse the underlying reasons for actions of the municipalities and network operators, how the technical system and the actors interact and where options lie within the institutional framework to deal with grid impact. To look into these aspects, the four layer model of institutions is used, which describes institutions in four layers: informal institutions, formal institutions, institutional arrangements and interaction between actors. In this model, also a role of technology is assigned. Technology is in the model located on the highest institutional level and thus deemed relatively stable.

On an *informal institutional* level a public value allocation conflict can be identified. While municipalities are faced with public value benefits on sustainability and liveability, network operators deal with reduced reliability and costs for grid reinforcements.

On a *formal institutional* level, different roles of institutions can be found. For municipalities, formal objectives and norms on air quality and CO_2 emissions drive them towards electric mobility. Network operators are by institutions bounded in their action to anticipate to electric mobility. The role of the network operator in the charging stations market model is still under discussion. The network operators' role can change if network operators can actively control electricity demand (the smart grid concept). The role of municipalities in electric mobility is expected to shift from a stimulating to a merely facilitating role.

Institutional arrangements entail formal interactions between municipalities and network operators. The most notable institutional arrangement is the fact that many municipalities are shareholders of network operators. This role is currently very passive, but an active shareholding role could increase the interest of municipalities in network operators' values for grid reliability and costs. Another institutional arrangement exists in cooperation on a public tender. Such a cooperation can increase awareness of each other's interests and provide possibilities to deal with grid impact.

Interaction between actors currently mainly focuses on pilot projects. Municipalities and network operators show a willingness to cooperate. Municipalities appear to be willing to take the network operators' interests on grid impact into account as long as it does not create too large barriers for charging station deployment. Possibilities for a process design exist. The main difficulty to be solved by the process is to deal with different knowledge bases and to create openness for other interests.

The role of *technology* differs for municipalities and network operators. While network operators perceive electric mobility mainly as a development on the electricity network, municipalities mainly focus on the vehicle and charging station technology. For municipalities the focus is more on short term technology development, while for network operators, the technology is associated with very long term developments.

From the institutional analysis, four institutional options are identified to limit grid impact. The first is to assign the role of the charging station owner in the market model discussion to network operators. The second is to include smart charging requirements in a combined tendering procedure of municipalities and network operators. The third option is for municipalities to have an active shareholding role in order to create an interest in the network operators' public values. The final option is to start a process where network operators are consulted on the location of charging stations.

The four layer model of institutions is largely deemed feasible for analysing the two actors' perspectives on the electric mobility case. A difference is however identified on the relatively stable role of technology in the model. In the municipalities' perspective the technology changes relatively fast. In addition, in contrast to the model, lower institutional levels are able to change technology. Therefore a revised institutional model is proposed (see figure A), where technology obtains a different role. Technology is as a technical system, which is rather stable. This system contains multiple sub-systems of which some are emerging or developing. In this case one could say that the electricity system (technical system) itself is rather stable. A new sub-system is emerging in the electricity system; electric mobility. Electric mobility is a separate technology, which causes changes to the technical system. A developing technology within the system is relatively unstable. In the electric mobility case, one can see that municipalities are mainly interested in the developing technology. Network operators were focused on the technical system. The stability of their perspective on technology thus differed.

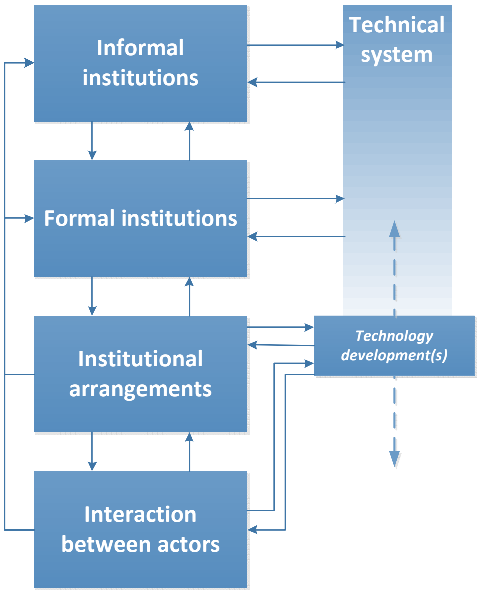

Figure A Proposition for revised four layer model of institutions, including a role for technology development.

Synthesis of strategy

As mentioned above, four institutional options to limit grid impact were derived from the institutional analysis which are able to apply one of the technical options presented, namely an ownership role of network operators, an active shareholding role, a combined tendering procedure and a consultation process. From the options, the consultation process in order to base their location on grid capacity is deemed most feasible. The other options require more research in order to study their feasibility and further detail them into strategies.

In order for the consultation process to be successful a low threshold set of requirements for municipalities to take grid impact into account should be created. This guideline has to allow for a comparison of grid feasibility with other objectives for charging station locations. It is therefore proposed for network operators to create a map for the municipalities where grid branches and the neighbourhoods in which they are located are assessed into categories which assign whether the grid will be able to cope with the additional demand.

The guideline (like the example in figure B) can be used in a process to create a strategic charging station location map. By means of the grid map, municipalities and network operators can evaluate whether locations for high power charging stations are feasible. By consulting network operators in this process, municipalities can be further informed on the consequences of installing charging stations at certain locations. The evaluation of location feasibility will include other location specific requirements. For some locations, a trade-off between requirements will have to be made. This trade-off can be made by translating all requirements to a nuisance factor to residents or electric vehicle users. The nuisance caused by grid reinforcements (road construction, reduced grid reliability and delay of charging station deployment) will then be compared to other requirements and constraints. By means of the creation of a strategic map, network operators are, in an early phase of deployment, informed on expected increases in load demand by electric vehicles and will thus have more information on which impact to anticipate to.

Figure B Hypothetical guideline to be created by network operators. Guideline shows capacity of grid branches to deal with additional load of charging stations, where 1. indicates no problems, 2. indicates that a limited capacity increase is possible and 3. indicates that reinforcements are required when installing charging stations.

Conclusions

Smart charging and assessment of charging station locations, based on grid capacity, can limit grid impact and thereby social costs of electric mobility. Institutions however create a skewed incentive structure which makes it difficult to apply those options. A strategy is therefore proposed which includes a process where municipalities consult on the network operators on grid impact of electric mobility. Municipalities appear to be willing to take network operators' interests into account as long as it does not entail a large barrier to charging station deployment. A process design which is focused on the creation of a low threshold guideline and a strategic feasibility map will allow municipalities to assess locations on the occurrence of grid impact and other location specific requirements. If municipalities decide to still locate charging stations on grid critical locations, network operators will be informed on potential grid limitations and can thereby anticipate to potential grid failure thereby reducing social costs by avoiding a reduced grid reliability. In case the consultation process leads to different locations of charging stations, social costs are avoided by reducing the need for grid reinforcements.

Recommendations

Municipalities and network operators are recommended to consider electric mobility from a broad perspective, from a technical point of view (relevance of other energy related developments) and an actor point of view (consider other parties' interests). A second recommendation is to calculate expected grid impact and thereby identify critical grid components based on municipal objectives. These critical grid components can be used to create the abovementioned guideline and initiate the consultation process for the feasibility of charging station locations. The most important aspect of the process is for municipalities and network operators to communicate on their objectives, strategies and expectations on electric mobility. Finally it is recommended to look into all institutional options to limit grid impact presented above. Especially combined tendering procedures can be very valuable for municipalities and network operators to together deal with grid impact.

For further research it is recommended to look into DANA, gaming and Agent-based modelling in order to include other actors in the analysis. In case one is interested in one specific municipality and network operator, one should look at those actors in more detail, as during the problem it was experienced that differences within actor groups existed. It is also recommended to further study the feasibility of the other institutional options. Finally some recommendations are made to further detail grid impact calculations, including the creation of energy and charging scenarios.

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ACRONYMS

EV	Electric Vehicle
PHEV	Plug in Hybrid Electric Vehicle
LV	Low Voltage
MV	Medium Voltage
HV	High Voltage
TSO	Transition System Operator
kV	Kilovolts
kVA	Kilovolts Ampère
HI	Higher Income
VpH	Vehicle per Household
PV	Property Value
GIS	Geographic Information System

1. INTRODUCTION

Depletion of oil, climate change and air quality are pushing many energy systems towards sustainability. Electric vehicles are meant to make mobility and the energy use of the future sustainable and green. Electric vehicles are greener than gasoline cars as they do not use fossil fuels themselves. The vehicles use electricity from the grid and their emissions are therefore dependent on the source of electricity production. With the current Dutch electricity sources, electric mobility limits the amount of CO_2 emitted to the air [Verzijlbergh, Lukszo, 2011]. If the share of renewable energy sources increases, CO_2 emission can be limited even further. Electric vehicles not only reduce CO_2 production, but also local emissions. Especially in urban areas, the Netherlands has had difficulty complying with European air quality standards. Road transportation is a large contributor to these local emissions [CBS Statline, 2011a]. Since electric vehicles have no emission and thus do not impact air quality on critical, busy roads. In addition power plants used for supplying energy to the vehicles are equipped with air cleaning devices and are thus relatively clean compared to the gasoline engines of conventional vehicles. Electric mobility can thus significantly reduce air pollution, especially in urban areas. In addition to emission reduction, electric mobility provides advantages of lower traffic noise and a lower dependency on oil.

Market potential studies and scenarios indicate a strong expected growth of electric vehicles in the coming decades. For instance a scenario study by ECN estimates a market share of 10% of electric mobility in 2020 and 45% in 2040 [Hanschke et.al., 2009]. A study by McKinsey looks into different scenarios and concludes that the market potential of electric vehicles lies between 2%-5% in 2020 and 15%-65% in 2050. Although there is a large spread in the expectations for these market potentials, the outcomes show that electric mobility will penetrate the market significantly. The differences in market potential show that there is still a lot of uncertainty involved with the break-through of electric vehicles. This uncertainty is related to technical and as social barriers which make it difficult for electric mobility, to penetrate the transport market.

In 2009, the Dutch government declared to put effort in increasing the amount of electric vehicles in the Netherlands. The Netherlands is meant to become a world player in electric vehicles and facilitate the transition to 200.000 electric vehicles in 2020 and about one million in 2025 [Rijksoverheid, 2011a]. To facilitate this transition, the Dutch ministry of Economic Affairs, Agriculture and Innovation, and the ministry of Infrastructure and Environment have set up a collaboration with Dutch municipalities, electricity network operators, energy companies and several players in the car industry. This organisation is called the Formula E-team and aims to realise a break-through in electric mobility infrastructure, batteries and availability [AgentschapNL, 2011]. Not only the national government, but also local governments in the Netherlands have shown interest in electric mobility.

1.1 PROBLEM STATEMENT

Some Dutch local governments initiated a stimulating policy for electric mobility due to the advantages of the technology; air quality improvements, CO_2 reduction, noise reduction, economic development of the region and city marketing [Gemeente Utrecht, 2011a; Gemeente Amsterdam, 2010]. Irrespective of stimulating policies, up to now only a limited amount of electric vehicles are on the Dutch roads. This limited adoption rate has several reasons. Firstly, although most car manufacturers recently announced to bring an electric vehicle to the market, only a limited number has been available to consumers or companies. A second reason is the high price of electric vehicles. Merely the batteries in the electric vehicles are almost as expensive as a conventional vehicle [Lehtinen, 2010]. A third reason is the fact that consumers fear that they will end up with an empty battery without possibility to charge the vehicle in time.

Electric vehicles cannot use the existing 'fuelling' system at gas stations. Electric vehicles require to be charged by the electricity network. In some cases, electric vehicle users will be able to charge at home or at work. Based on housing research in the Netherlands, only 14% of Dutch households has access to such a private parking spot and can thus easily charge at home [Datawonen.nl, 2009; Blijie et.al., 2009]. Public charging stations are thus required in order to allow people without that possibility to charge an electric vehicle. Some municipalities are therefore currently investing in the deployment of a charging station network.

These charging stations make use of the existing electricity network and thus do not require an entirely new infrastructure. An electric vehicle does however uses a relatively large amount of electricity. For comparison, a household uses on average about 10kWh per day [Nibud, 2011]. An electric vehicle (based on the current average travel distance per day) uses about 6kWh per day [Prud'Homme, 2010]. In addition, it is expected that, when left to consumers' convenience, this increased demand will occur mostly during peak demand hours. It is often assumed that electricity networks will be able to cope with energy developments like electric mobility, as the networks are designed with a large overcapacity to deal with years of demand growth. Electric mobility is however not the only changing energy system. Also other energy innovations, like renewable energy systems and heat pumps, are currently affecting electricity grid operation by increasing and changing the electricity demand and supply. The overcapacity of the networks might therefore no longer be sufficient to deal with increasing demand in the future [Hadley, 2006]. Dutch network operator Enexis states that around one million electric vehicles (the objective of the national government for 2025) will probably not be a real problem to the Dutch grid. However, above one million vehicles, the Dutch medium and low voltage grid will require reinforcements[1]. These reinforcements are associated with high costs. As the network operators are public, regulated organisations, the costs of network reinforcements will be socialised. It is thus in society's benefit to minimise costs for grid reinforcements.

The real impact of electric mobility is uncertain and difficult to predict, for instance because the market potential is, as said, uncertain. Policy makers are already taking measures to stimulate the energy innovations as they benefit from the sustainable character of energy innovations. Some municipalities have plans, or already started, to deploy an extensive charging infrastructure, while network operators do not yet know exactly which impact they have to prepare to.

Distribution network operators are responsible for electricity distribution. This responsibility obliges them to ensure sufficient network capacity to deal with the electricity demand and supply. There might be technical possibilities for the network operator to limit the impact of electric mobility on the grid, for instance by reallocating the electricity demand of charging stations to off peak hours by means of so called smart charging. Distribution network operators however have a very limited say in the charging station deployment. Municipalities on the other hand, have limited interest in reducing impact on the grid and thus in applying options to do so.

Problems, where the technical system is complicated by the acts of actors involved, seem to be inherent to infrastructure networks. Verwater-Lukszo and Bouwmans (2005) describe the complexity of networks by four components:

1. Networks are complex by the large numbers of technical components of the physical network;
2. The networks are complex by the actors involved in the network sector and the relations between the actors;
3. Actors and the physical network interact in a social-technical system. The actors shape the development of the physical network and the physical network affects actors' behaviour;
4. Complexity on networks is increased by interconnectedness between networks and their actors.

[1] Derived from the interview with Enexis.

The problem described above, where there is no incentive to apply options on electric vehicles to limit the impact of electric mobility on the network, seems to fit in the third matter of complexity. The problem describes how actors' behaviour (stimulation of electric mobility by the municipality) can shape the development of the infrastructure (grid reinforcements might be required to deal with the additional power demand). The complexity related to the impact on the electricity network is thus not only related to the physical components of the network but also to the actors involved and their interaction.

Several detailed studies have already been done on the technical impact of electric mobility to the electricity network. These studies for instance conclude that the impact is dependent on local network characteristics, is likely to be limited on a high voltage level, but is expected to occur at medium or low voltage networks [Karnama, 2009; NY ISO, 2009; Clement et.al., 2009; Green et.al., 2010; Hadley, Tsvetkova, 2008]. In addition to several technical studies, also several social aspects of electric mobility have been studied. Bunzeck, Feenstra and Paukovic (2011) for instance studied the charging preferences of potential electric vehicle users. Slater et.al. (2009) describe potential characteristics of electric vehicle users and existing policies for electric mobility around the world. Some social studies also look into potential impacts of electric mobility on the electricity grid. These studies thus look into how the acts of one actor (the vehicle user) can influence the technical electricity system in a one directional way. None of these studies, however, looks further into the interaction between the technical and social system. No research was found on how the impact of electric mobility to the grid influences actors (bidirectional relation between the technical and social system) or how the behaviour of different actors can be adjusted in order to limit the impact of electric vehicles on the grid. So although studies have been done on technical and social aspects of electric mobility. A knowledge gap appears to exist in the relation between the social and technical disciplines. This thesis will therefore look at the impact of electric mobility from the viewpoint of the interaction of the technical and social system and combine those disciplines.

The following main question will therefore be answered in this thesis:

How can municipalities and network operators come to a strategy to limit social costs of electric mobility charging infrastructure?

To answer this question, first the social costs will be analysed. As will be discussed in the next chapter, impact on the electricity network is not the only social cost aspect of electric mobility. This thesis will however focus on the social costs associated with grid impact, as these currently seem to encompass the largest social costs of charging infrastructure. After the analysis of the social costs, the perspectives of network operators and municipalities on electric mobility will be described and compared. From this description, objectives and constraints for both actors will be distracted, which will be the starting point of recommendations on how to come to a combined strategy. In this strategy possible technical options to limit the impact on the grid are proposed based on their social feasibility. Further elaboration on the strategy will be provided in the concerned chapter.

1.2 RESEARCH DELINEATION

This section will describe the framework used to answer the main research question, followed by the research goals and sub-questions. Finally the relevance of the research will be discussed.

1.2.1 RESEARCH FRAMEWORK

Infrastructure sectors are associated with a lot of complexity. One component of the complexity lies in the interaction between the physical network and the actor network. Actors are involved via economic, social, legal or institutional interests. These actors are related to different technical components and to each other, increasing the complexity of the infrastructure network [Verwater-Lukszo, Bouwmans, 2005].

To illustrate the relations within and between the technical and actor systems, first a system diagram will be presented. A system diagram originates from systems engineering theory. Systems engineering perspective entails a broad perspective of a certain development or problem. As stated by Sage and Armstrong (2000): "*systems engineers not only examine the specifics of the problem under consideration but also investigate relevant factors in the surrounding environment*". A systems engineering perspective is used throughout this thesis in order to describe the problem of social costs of electric mobility. A system diagram is a means of presenting a system and will be used to present the system by the corresponding technical aspects of electric mobility, related factors and relevant actors operating in the field of electric mobility.

An additional framework will be used to look in more detail into the interaction between technology and actors' behaviour. Koppenjan and Groenewegen (2005) describe this social aspects of technology development by means of institutions. As will be explained in chapter 5, different definitions of institutions exist. Institutions are in general described as underlying reasons why actors act in a certain way towards each other or a (technical) system. These institutions can thus describe the interaction and relationships between actors related to a technical system. Williamson (1998) developed a framework for institutions, describing the types and interactions between institutions and actors. An adjusted version of this four layer model is displayed below.

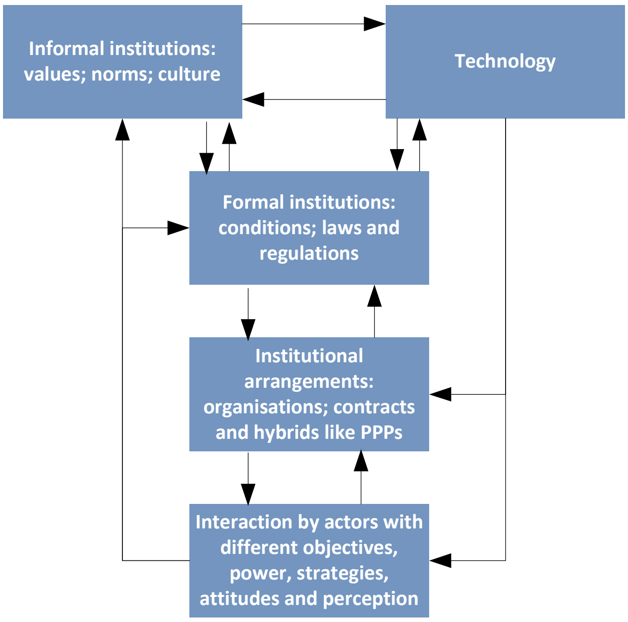


Figure 1 Four layer model of institutions describing the interaction between types of institutions, interaction by actors and technology [Koppenjan, Groenewegen, 2009].

The model contains for layers:

1. *Informal institutions* refer to unwritten norms and values which underlie people's behaviour. On the right to informal institutions is *technology*. Here lies a difference between Williamson and Koppenjan and Groenewegen. Where Williamson sees technology as a given factor, Koppenjan and Groenewegen identify a bilateral relation between technology and institutions. Technology developments can require for new interactions between actors and new sorts of institutional arrangements between parties involved. In addition, technology paradigm shifts can cause informal institutions to change;
2. *Formal institutions* are written down legislation and regulation;

3. *Institutional arrangements* are the operationalization of formal institutions. Examples of institutional arrangements are contracts and public private partnerships;
4. *Interaction by actors* describes the fact that actors are part of a network and act according to their preferences.

The model will be used as a framework to identify the underlying values and reasons for actions of municipalities and network operators. After using the framework to describe the actors' behaviour, the model will also be assessed for its feasibility to the case of electric mobility. As this thesis looks at a technology development (electric mobility) and the consequences for the actors, the feasibility assessment of the framework will especially focus on the role of technology in the four layer model.

1.2.2 RESEARCH GOALS

As mentioned in the problem statement, electric mobility is related to complexity on both the technical and the actor system. This thesis is meant to provide insight in the relation between the actors and the technical system, by means of an institutional and a system analysis. In addition this thesis will compare the perspectives of both the municipalities and distribution network operators and will provide insight in the benefits and consequences of electric mobility.

The goals of this thesis are thus:

1. Provide insight in the technical and actor system related to electric mobility;
2. Provide insight in the way municipalities stimulate electric mobility;
3. Provide insight in the impact of electric mobility on the electricity grid;
4. Provide technical and institutional options to limit grid impact;
5. Recommend how municipalities and network operators can limit social costs of electric vehicle charging infrastructure deployment.

1.2.3 RESEARCH QUESTIONS

The main research question (as presented in the problem description) to be answered in this thesis is:

How can municipalities and network operators come to a strategy to limit social costs of electric mobility charging infrastructure?

This question will be answered by means of the following sub-questions:

1. What does the electric mobility system look like?
2. How will electric mobility impact the electricity system and how can the impact be determined?
3. What is the institutional environment of the municipality and network operator related to electric mobility?
4. How can institutions be arranged in order to limit social costs of electric mobility?

1.2.4 RESEARCH RELEVANCE

The practical and societal relevance of this thesis lies in the need for a sustainable transition of mobility. The current mobility system, based on fossil fuels, causes CO_2 emissions (and thereby climate change), air pollution, noise nuisance and dependency on depleting oil. A transition to a more sustainable mobility system like electric mobility can help to reduce these downsides. However, the implementation of the sustainable transport transition is expected to entail societal costs. This thesis will provide insight in how to support the transition to a sustainable system while minimising the social costs.

At the faculty of Technology Policy and Management, the interaction between technology and policy in complex decision making is often emphasised. Such an interface between policy and technology is visible when looking at the socio-technical system of electric mobility, the expected impact on the electricity grid and the associated actors. A difficulty in dealing with socio-technical system lies in the association of different disciplines. While the technical aspects of a socio-technical system are analysed and dealt with by engineers, the social aspects are dealt with by policy makers. Several frameworks are proposed to deal with these different disciplines. A first tool is to analyse the system by its technical components and the relevant actors associated with this technical system. This thesis will analyse electric mobility and the corresponding impact on the electricity grid by means of such a system analysis. A second tool to look into the interaction between technology and actors' behaviour is the above described framework of institutions. This model will be used to analyse institutions and the role of technology for the actors. It is valuable to see how two different tools, to combine technology and actors, are applied to the same case. The system analysis is used to see the problem based on technical components and actor behaviour and to identify the environment which influences the system. The institutional analysis will be used to detail the actors' behaviour. As said above, this thesis will also look into the feasibility of the institutional framework for the electric mobility case.

1.3 APPROACH

In this section first the project steps are described. These project steps describe the pathway to which the combined strategy will be designed and which outcomes each step has. The methods used during the project steps are presented afterwards.

1.3.1 RESEARCH STEPS

This thesis project consists of several research steps. The figure below graphically displays these steps. As can be seen the first step is the problem analysis, followed by a system analysis in which the problem is further analysed by means of its technical components and the related actors. The system analysis allows to identify uncertainties and unknown relations in the system. This research step is displayed by a thicker line. This line emphasises as it describes the identification of uncertainties and unknown relations to be researched in the remainder of the project. As will be explained in the system analysis chapter, these uncertainties and unknown relations lead to a definition of following project steps, namely grid impact analysis and institutional analysis. All research steps are combined to a synthesis of a combined strategy.

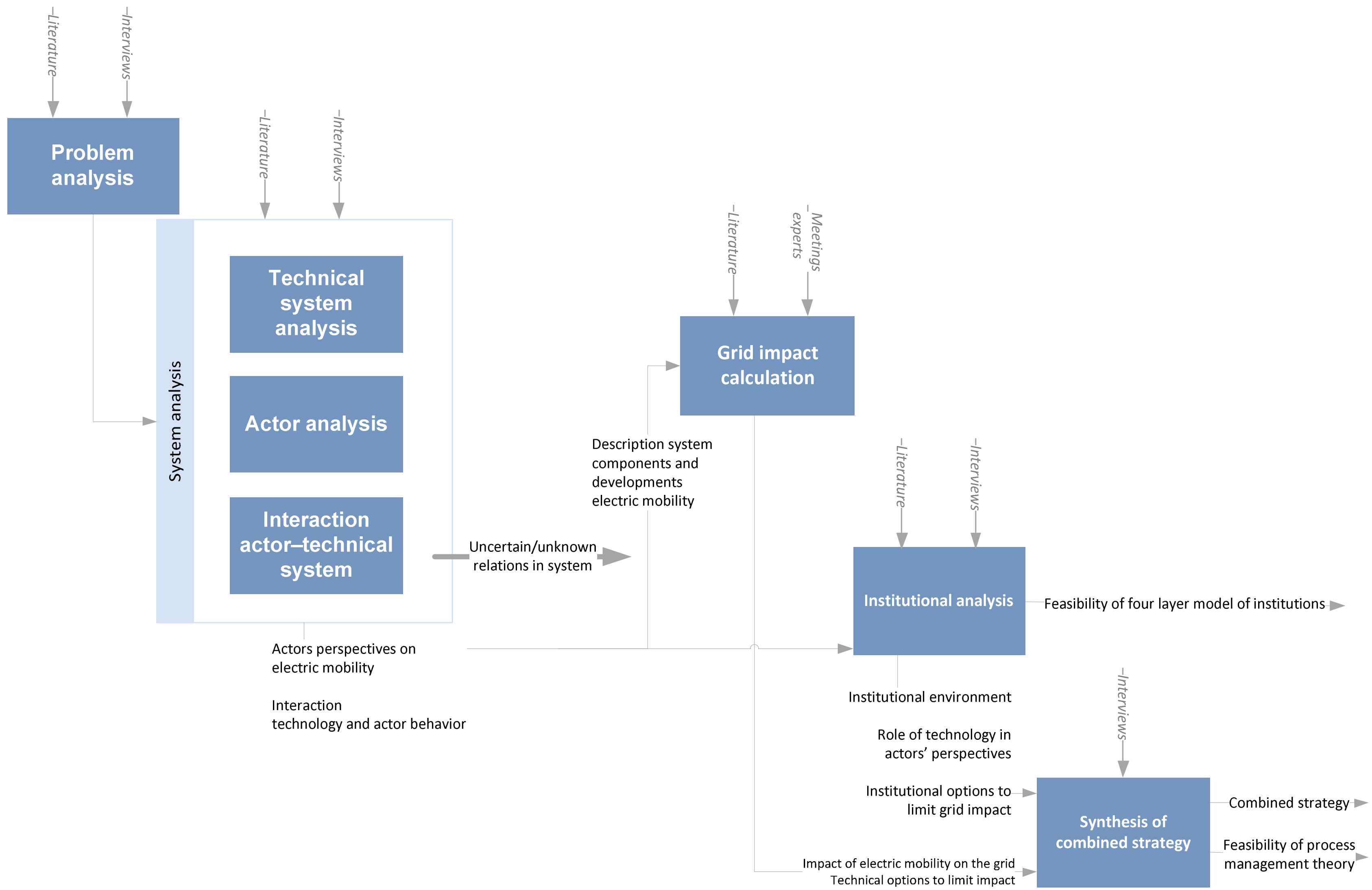


Figure 2 Research steps of graduation project. The blocks describe the research steps, the arrows coming out of the boxes display the outcomes of the research steps. The incoming arrows display research methods.

1.3.2 RESEARCH METHODS

The figure above, displaying the research steps of this thesis shows three main research methods, namely literature research, interviews and meetings with experts. This section will elaborate on the research methods and explain the role of the methods in the thesis project. Additional research methods used for the grid impact analysis will be explained in chapter 3.

Literature study

A large variety of literature is used to support this thesis. Literature on scenarios and roadmaps are used for background information on electric mobility and the actors involved. Scientific papers are used for research on the technical systems and the expectations of grid impact. For the institutional environment, policy documents of municipalities are studied. Dutch electricity regulation is studied for insight in the formal institutional environment of network operators and municipalities. At the end of this thesis a list of references is provided. This list shows two separate lists for legislation and regulation, and for interviews.

Interviews and meetings with experts

Throughout the project, interviews are held to gain more detail information on actors' perspectives or to specify and validate certain conclusions. Interviews with the municipalities of Amsterdam, Rotterdam and Utrecht help to analyse the problems associated with electric mobility in municipalities. From the interviews also a more detailed view on the system considered is defined. The questions the interviews with the municipalities refer to their goals and objectives of electric mobility and whether or not they identified possibilities to cooperate with other parties, like the network operators.

In addition, meetings are held with network operators Liander and Stedin which provide insight in the network operators' point of view. Network operator Stedin is also involved in the project by providing data and knowledge needed for grid calculations. During the grid impact calculation, additional meetings are held with experts at Movares Energy and the Delft University of Technology. These objectives of these meetings are twofold. Firstly they allow to further specify the approach, secondly they are meant to validate early research results.

In a later research phase, a meeting with network operator Enexis is conducted. This meeting is used to further specify the network operators' perspective and to validate the recommendations presented in this thesis. In addition, to check the validity of the proposed recommendations to municipalities, other than Amsterdam, Rotterdam and Utrecht, also interviews are conducted with two other municipalities.

Some interviews took place during face-to-face meetings, the others via telephone. All interviews are summarised in a report which is sent to the interviewees. The list of interviews can be found in the reference list. The summaries of the interviews can be obtained digitally by contacting the author of this thesis.

In addition to the meetings and interviews, regular meetings were held at Movares Energy, the commissioner of the project. Employees at Movares Energy helped in finding the contacts for the other meetings and in carrying out the grid impact calculations.

1.4 OUTLINE OF THESIS

This thesis contains six chapters, of which the first is this introduction. Note that the project scope is not yet described in this chapter. The scope will be defined throughout the next chapter. The reason for placing the scope definition in the next chapter is the fact that the scope definition requires explanation of certain aspects of electric mobility. The system analysis in the next chapter explains these aspects.

Chapter 2 describes the system considered in this thesis. The system description will look into the technical aspects of electric mobility and the relevant actors associated to it. Furthermore, the system description will look into the interaction of the technical system components and the relevant actor system.

Chapter 3 will analyse the impact of electric mobility to the grid. This chapter provides a technical analysis of the effect of increased electricity demand by electric mobility, by means of a grid model. The chapter will describe which method is used for calculating grid impact, the results of the calculation and the implication of grid impact.

Chapter 4 will use the framework of the four layer model of institutions to describe the acts and constraints of municipalities and network operators. Each section of the institutional framework will relate the institution to the actors and will discuss the differences between those.

Chapter 5 will use this institutional framework and the impact analysis to look into options for technology and institutions to deal with grid impact. Chapter 5 will also provide a possible strategy for dealing with the impact of electric mobility on the grid involving both municipalities and network operators.

Chapter 6 will conclude the thesis and provide recommendations for the main actors and for further research.

The figure below displays the six chapters. The large blocks link the chapters to the research steps presented in figure 3.

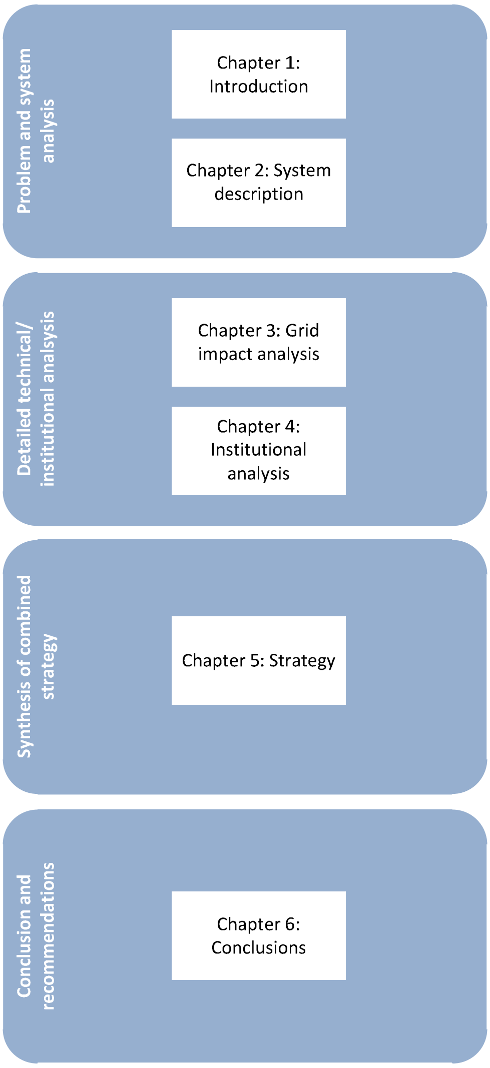


Figure 3 Thesis chapters and corresponding research steps.

2. SYSTEM DESCRIPTION

As explained in the introduction of this thesis, electric mobility is seen as a socio-technical system. A socio-technical system consists of a technical system and a network of relevant actors surrounding this technical system, interacting with each other. In this chapter a system analysis will identify technical aspects relating to, and the actors involved in electric mobility. System analysis entails a broad perspective of a problem or issue. A technology is defined by its components (sub-systems), relations between these sub-systems and its environment [Sage, Armstrong, 2000].

Several aspects of electric mobility influence the impact on the electricity grid. In addition, electric mobility is not the only energy development impacting the grid. The 'sub-systems' and 'environment' of electric mobility cause uncertainty for the expected impact. Furthermore, the uncertainty related to electric mobility and grid impact is increased by the involvement of actors. It is valuable to include these aspects and uncertainties when analysing the problem of grid impact as it provides insight in the extent of the impact and the effect of the impact on relevant actors.

System analysis helps to transform an ill-defined, complex problem, like the one presented above, into a structured model which can help to analyse certain aspects of the problem. In the end of this chapter, the system analysis will be summarised in a system diagram. A system diagram is a (communication) tool to describe a systems' components and environment [Enserink et. al., 2008]. A system diagram can be composed in many ways. As the problem considered is defined as a socio-technical problem, a system diagram will be made which specifically looks into the interaction between a technical and social system. This method is often used by research institute Next Generation Infrastructures [NextGenerationInfrastructures, 2011].

When looking at electric mobility, one can identify it as part of an existing system. Electric vehicles can for instance be seen as part of a mobility system. Electric mobility can also be seen as a development to the electricity network, since the electric vehicles will become loads to the electricity network. The system to consider normally depends on the perspective of the problem owner [Enserink et. al., 2008]. However, in this thesis, not merely one problem owner will be defined. The choice for a systems' view therefore needs to be based on other aspects. As this thesis focuses on the social costs of impact of electric mobility, the electricity grid forms an important aspect of the system considered. Therefore electric mobility will be considered as a development of the electricity system. The system analysis will however use a very broad view of electric mobility and will therefore also touch upon other aspects of the system, which are not directly related to the electricity system. By means of this broad perspective, the researcher intends to include other system perspectives into the analysis. This chapter will thus provide a general description of electric mobility, with a focus on the electric mobility system.

The following figure graphically displays the general components of the system.

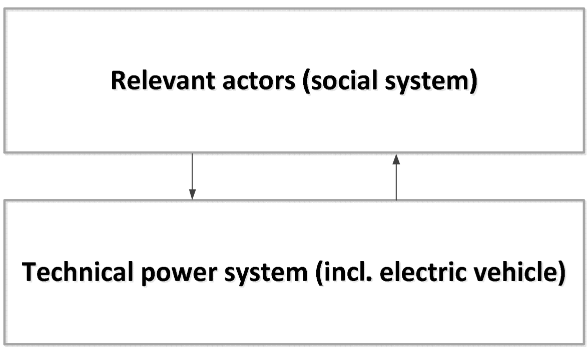


Figure 4 System components in socio-technical system: technical system and its relevant actors.

The figure displays the two components of the socio-technical system of the considered electric mobility system. The social system relates to the relevant actors of the power system and electric mobility. The actor and technical system blocks will be decomposed in the end of this chapter in a system diagram. The decomposition is based on technical and the actor analysis and provides insight in the interactions between the technical system and the actor network. The figure below shows the different paragraphs in this chapter and how they relate.

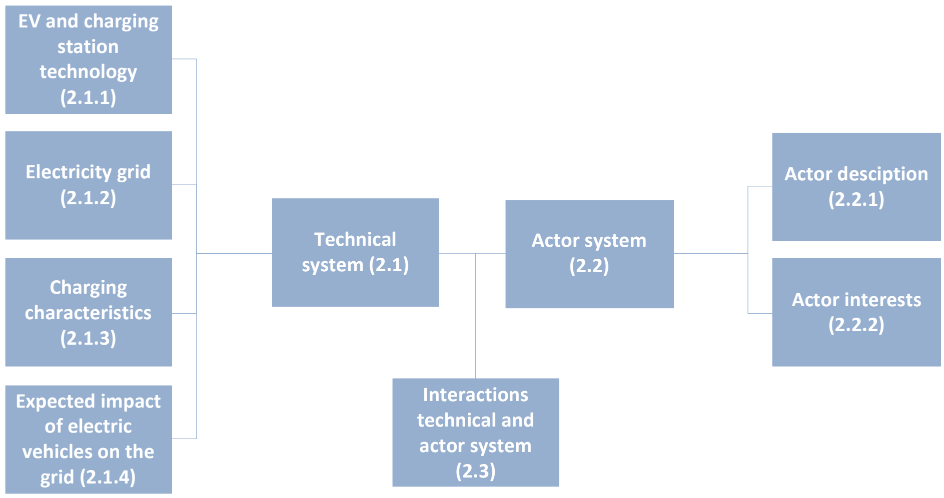


Figure 5 System description – chapter structure.

2.1 TECHNICAL SYSTEM

When looking at the current electricity system, one can identify several electricity producers and loads. Electric vehicles charge via the existing electricity grid and are thereby electricity loads. This section will provide insight in electric mobility and the electricity grid to which electric vehicles are connected. Firstly a description will be provided on electric vehicle and charging station technology followed by a description on the characteristics of the electricity grid and the developments occurring on the grid. Finally the effect of electric vehicles on the grid will briefly be discussed. The latter will be further detailed in the next chapter.

2.1.1 ELECTRIC VEHICLE AND CHARGING STATION TECHNOLOGY

This section will describe the technological developments of electric vehicles and the charging stations required for electric vehicles. Appendix I provides an overview of experiences with and expectations for development of electric mobility.

2.1.1.1 ELECTRIC VEHICLE TECHNOLOGY

Electric vehicles were firstly introduced in the 19th century, at about the same time as the internal combustion engine (ICE) vehicle. In the beginning of the 20th century, due to the invention of the starting engine, mass market production for ICE vehicles and inconvenient battery characteristics, the electric vehicle almost vanished from the scene and the ICE vehicle became the leading technology. Since the 1930s, electric vehicle technology however has had several boosts, mainly caused by high oil prices and environmental concerns [Hussain, 2011; p.2].

In 1997 the Toyota Prius, a hybrid electric vehicle, was introduced. Hybrid electric vehicles (HEV) have both a combustion and a battery driven engine but can only be fuelled with fossil fuels and not by the electricity grid [Chan, 2002]. The hybrid vehicle was, and still is, a popular vehicle. Although it is not possible to charge the vehicle via the electricity network, the hybrid vehicle opened doors for car manufacturers to introduce a plug-in electric (PHEV) or full electric vehicle. Several car manufacturing companies have introduced either a full electric or plug-in electric vehicle, for example the Toyota Prius (which can now be converted to a PHEV), the Cooper Mini E, the Nissan Leaf and the Tesla Roadster [Green et.al., 2011].

Scope definition electric vehicles and electric mobility
electric vehicles can either be purely electric, or equipped with a combustion engine, called hybrid electric vehicles. It is expected that a plug in hybrid electric vehicle will play an important role in the transition to electric mobility. However in the long run, these hybrid electric vehicles will mainly act as a transition technology and be phased out at the expense of full electric vehicles [Nemry, Brons, 2010]. Therefore in this thesis (plug in) hybrid electric vehicles will not be taken into account as a separate vehicle type.

Literally the term electric mobility and electric vehicles cover several types of transport systems, from electric bikes to busses. In this thesis however, electric mobility and electric vehicles refer to electric cars, vans, busses and trucks. Scooters and bikes can also have a valuable contribution to reduce air pollution, but these vehicles have a different business case from cars, vans and busses. In addition, these vehicles only require a limited amount of public charging facilities as the driving distance and the battery capacity (meaning that they will charge faster) is much lower. Therefore, in this thesis, electric scooters and bikes will not be taken into account when referred to electric vehicles (only when stated differently).

Battery technology
One of the technical barriers for electric vehicle adoption in the past has been the battery technology. Lead acid batteries (which is still the standard vehicle battery) are heavy, have a low capacity and therefore a limited driving range. Due to an increasing demand of laptop computer and mobile phone batteries, battery technology improved and lithium-ion batteries have penetrated the market. Lithium-ion batteries have a higher energy density, are lighter and have a low self-discharge rate. However, the energy density and life time of the batteries are still limited and the batteries are expensive [Tatsumi, 2010].

To make electric vehicles economically viable, battery development faces several challenges, namely the costs[2], storage capacity and resistance to extreme weather conditions [Lehtinen, 2010]. Current energy densities of batteries are 140-170Wh/kg, corresponding to about a 100-150km driving range. For comparing purposes: gasoline has an energy density of 13.000Wh/kg [Lehtinen, 2010]. It is expected that batteries will develop towards a driving range of about 200-300 km in the long term [Valentine-Urbschatt, Bernhard, 2009;].

Battery life time is influenced by weather conditions, the number of charging cycles, and the charging pattern (whether or not the battery is fully charged or discharged). Depending on the battery type, incomplete, or so called shallow charging affects battery lifetime. Also the power by which batteries are charged is expected to affect the life time of the batteries [Axsen et.al., 2008].

After the expiration of the battery life time, the batteries are not useless. The batteries still have storage capacity although it significantly decreases. Disposition of ‘expired’ batteries could entail environmental damage as the batteries contain dangerous chemicals. Recycling of the battery components can avoid social

[2] The costs of a Lithium-ion battery are currently around 960€/kWh and expected to decrease and lowered to 400€/kWh in distant future [van Vliet et.al., 2011]. According to a study by Roland Berger, these costs could be lowered to even 200€/kWh in 2020 [Valentine-Urbschat, Bernhart, 2009]. Different types of batteries and different assumptions thus result in a wide range of expectations.

costs of such an environmental damage. Another option to avoid environmental damage is to use the remaining storage capacity for other purposes, for instance as a stationary backup storage capacity to the electricity grid [Cready et.al., 2003].

Scope definition social costs – Batteries

Although this thesis looks into social costs of electric mobility, the social costs associated with battery life time will not be further taken into account. Firstly, experimentations on battery lifetime are still occurring, thus detailed information on the expectations and effect of charging cycles is not yet available. The life expectancy of a battery is about 10 to 15 years, thus experimentation of battery life time and the effect of charging takes many years. A second reason to not take these social costs into account is the fact that these social costs focus on a different technology. The issues of battery life time and the environmental effect of batteries after their life time expiration focus on the battery and corresponding chemical technology. This thesis looks into electric mobility from a charging infrastructure and grid perspective. The chemical composition and thus the development of the technology is here defined as outside the power systems scope.

Electric vehicle efficiency and emission reduction potential

Like for conventional vehicles, the efficiency of electric vehicles is strongly dependent on the type of vehicle (size, acceleration etc.). On average, the energy use of a small electric vehicle is expected to be about 20kWh/100km. The energy use of a conventional gasoline vehicle is 60kWh/100km [Lehtinen, 2010]. The efficiency of a conventional vehicle is thus a lot lower than the efficiency of an electric vehicle. However, these efficiencies are difficult to compare, as they do not use the same energy input. Electric vehicles require an additional energy conversion step; electricity production. In order to compare the efficiencies of an average ICE vehicle with an electric vehicle, previous conversion steps therefore need to be taken into account. This efficiency is called Well-to-Wheel (WTW) efficiency. The precise efficiency depends on the type of power plants used for electricity generation. The picture below shows an estimation by Enexis of the WTW efficiencies of both ICE and EV based on the Dutch electricity mix [Knigge, 2011].

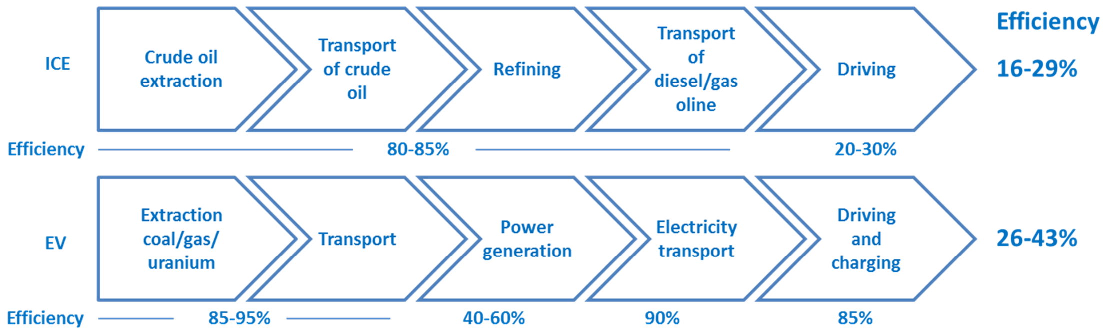


Figure 6 Well-to-wheel efficiency of ICE and electric vehicle [Knigge, 2011].

The main drivers for governments to stimulate electric mobility are emission reduction. The CO_2 emission of the energy chain of EVs is dependent on the above mentioned efficiency, but is not easily determined. The emissions are dependent on the type of power plant required for the additional electricity demand for EV charging. When a gas plant is required to operate, the CO_2 emissions are lower than when a coal fired power plant is required to increase its output. The latter could be the case during night time charging. Verzijlberg and Lukszo (2011) calculated that for the Dutch energy portfolio the CO_2 emission of charging an electric vehicle is between 0,4 and 1,4 kg/kWh.

NO_2, SO_2, CO and PM_{10} emissions, which are causes of local air quality problems, have a much more local effect than CO_2. The dispersion of these emissions is lower. In open areas, emission of NO_2, SO_2, CO and dust can still easily be dispersed by the wind, reducing the concentration of the emissions. In build-up urban areas, like large municipalities, the emissions linger between the buildings, which cause higher concentrations of these emissions [Nicolescu et.al., 2008]. In large Dutch municipalities NO_2 emission is currently the most problematic emission [Passier et.al., 2009, p.35].

Electric vehicles do not emit local emissions themselves. Electric vehicles therefore do not emit in urban (air quality critical) city environment. Emissions can thus more easily disperse. The power plants used for supplying power to electric vehicles do emit local emissions, however, electricity production is cleaner than gasoline vehicles. Exhaust gasses of electricity production plants are required to be cleaned [EnergieNed, 2003]. As road transportation causes about 40% of the NO_2 emission [CBS Statline, 2011a], electric vehicles can significantly contribute to air quality improvements.

Scope definition social benefits
This thesis looks into social costs of electric mobility. The counterpart of social costs are social benefits. Local and CO_2 emission reduction are social benefits of electric mobility and are for governments drivers to stimulate electric mobility. This thesis mainly focuses on social costs aspects which are difficult to reduce due to actor involvement and responsibilities. For emission reduction such a problem does not occur, as the actor impacting the reduction, namely (local) governments also have tools to do so (incentives for cleaner technology). Emission reduction will however not be completely left out of scope due to the importance of emission reduction as a driver for governments to stimulate electric mobility.

2.1.1.2 CHARGING INFRASTRUCTURE TECHNOLOGY

Electric vehicles can in some cases be charged at home in a normal electricity socket. Most vehicle owners, especially in urban areas, however, have no private parking spot or garage and have therefore no possibility to charge at home. In addition, a vehicle might not be at home when it requires charging or require fast charging. Charging at other locations, for instance on public streets is therefore expected to be required for a successful deployment of electric mobility [Bunzeck et.al., 2011]. Chargers outside household property however require more advanced technology to for instance identify (and later on remunerate) the customer. These public charging facilities thus not only entail a socket, but also entail an identification system (like RFID). In addition, on some locations (for instance on public streets), charging stations are also required to be vandalism proof [Reitsma et.al., 2010].

Fast and slow charging
The currently existing charging stations can be classified as either being slow or fast. This classification can be divided into sub-categories as well. The table below shows the characteristics of two charging stations in order to provide insight in the power demand and charging time for electric vehicles.

Table 1 Characteristics of slow and fast charging stations [Lehtinen, 2010, p.30,34].

	Maximum current (A)	Voltage (V)	Power (kW)	Charging time (h)[3]
Slow	16	230	3,7	10-12
Fast	70	690	50	<1

Currently, charging station, especially fast charging, technology is still being developed. Research and development mainly focuses on limiting charging times and guaranteeing safety. Fast charging time is estimated to have the potential to be about five minutes in the future, with powers above 250kW. Fast

[3] Based on a 30kWh battery pack, which corresponds to approximately 150km and one phase charging. In case of a three phase connection, the charging time would be three times as short.

chargers however still face some technical problems, like the heat produced during charging. In addition, as the current battery technology is relatively new and many battery types currently exist, it is uncertain what the impact of fast charging will be on battery lifetime [Smokers, 2010; Nemry, Brons, 2010]. For instance, the currently most promising battery technology, the Lithium-ion battery, faces problems of lithium plating formation on one of the battery components, thereby increasing battery loss. Lithium-ion battery technology is still being developed in order to resolve this problem [Zaghib et.al., 2010].

Battery swapping is another option for recharging electric vehicles. Instead of charging the battery, the batteries are exchanged at special switching stations. A company called 'Better Place' developed switching stations that use robotic machines to replace an empty battery with a full one in a few minutes [Betterplace.com, 2011]. Almost none of the planned vehicles[4], are currently build for switching stations. In addition, no standard battery type exists [Valentine-Urbschat, Bernhart, 2009]. Switching stations would thus have to store a large stock of all types of batteries to be able to supply every customer.

Conductive and inductive charging
Most currently available charging stations are designed as conductive chargers, meaning that they charge by a direct wire connection, like a traditional electricity plug. The conductive charging hardware can be located inside the car (on-board charging), or at the plug which allows for higher power levels.

Another type of charging is inductive charging. Inductive charging uses magnetic coupling (induction) to transport power. Inductive charging systems can be installed below the parking or road surface. Inductive charging uses less space (as the system does not need a charging station above the surface), but is associated with high electricity losses.

Standardisation charging station technology
As the technology for electric mobility is still in an early development phase, many different versions of technology exist. Standards for electric mobility technologies do not yet exist. Especially the lack of standards for charging stations is impeding the development of electric mobility. When deploying charging infrastructure, choices for charging station technology might become outdated when standards are set. At the same time setting standards chooses one technology over another, thereby creating a monopoly position for one technology developer. Standardisation is thus a very difficult process in innovative sectors [Blind, 2009].

The problem of a lack of standards for charging station technology was experienced by the municipality of Amsterdam, which was one of the first municipalities to invest in electric vehicle charging infrastructure. Ideally international or European standards exist to enable low barrier cross border transport and mobility. However, European standards are not yet available. Therefore a Dutch normalisation committee is installed under the NEN (the Dutch normalisation committee), in which several different types of market and governmental parties takes place (car manufacturers, municipalities, network operators, electricity companies etc.). This committee came to an agreement on charging station meters and plugs. This standard was set to make it easier for investors to choose between certain technologies. However, still many aspects of charging stations are not yet decided upon, for instance payment methods and authentication of customers, and uniformity of maximum power demand [van den Akker, 2010; Normcommissie 364 069, 2011].

2.1.2 ELECTRICITY GRID

In 2006, Dutch energy companies were obliged by law[5] to unbundle production and delivery of electricity from the electricity network. This separation was meant to enable competition in the electricity sector, as production and delivery were seen as market activities for which competition was possible and transport as a

[4] Only Renault electric vehicles are equipped with switchable batteries [Renault.com, 2011]
[5] Independent Network Operation Act, supplement to the Electricity Act 1998

public task and monopoly. The figure below displays the roles and relations of parties within the Dutch electricity sector. In the figure the elements are separated in an economic, institutional and physical layer. The physical layer describes the steps between electricity generation and load. The institutional, economic layer shows the roles of the parties involved, from generation to electricity use and the markets these parties are involved in.

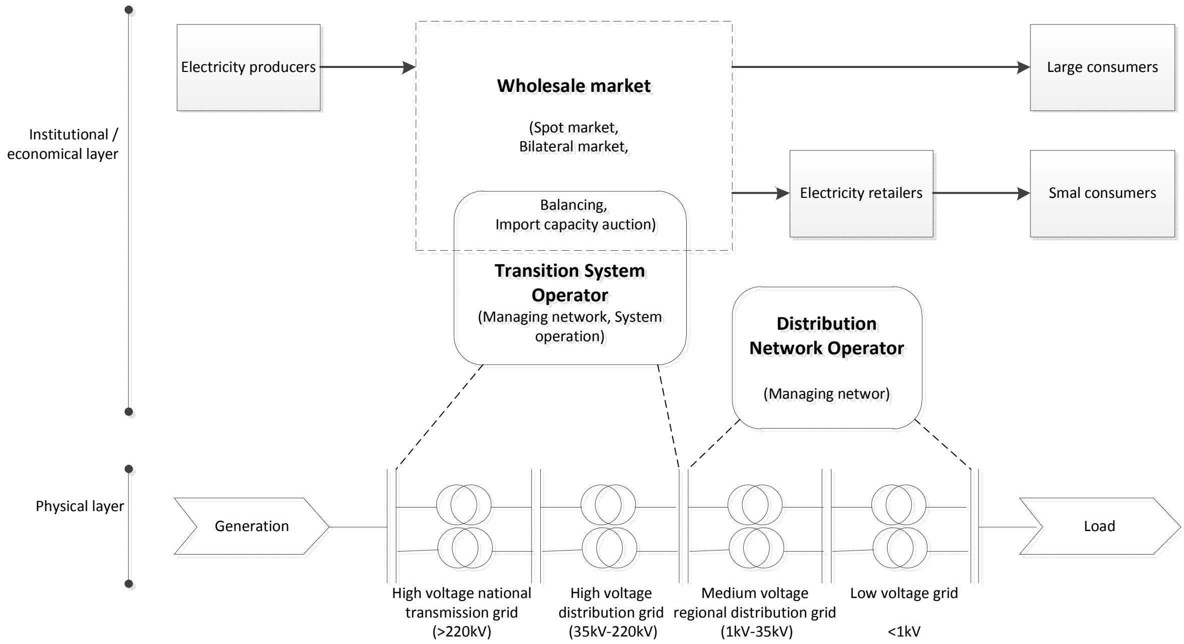


Figure 7 The Dutch power system, displaying the physical electricity grid with generation and load, and the institutions and markets involved in the electricity system [based on de Vries et.al., 2009; Karatay et.al., 2010].

The purpose of an electricity grid is to connect producers and consumers of electricity. The grid consists of high voltage, medium voltage and low voltage networks, where high voltage is used for longer distance electricity transport and lower voltage networks for regional distribution of electricity. The figure below shows a simplified grid configuration, where power is fed into the grid at high voltage grid level and load is connected at the low voltage grid.

The electricity grid mainly consists of overhead lines (in the Netherlands used almost only in high voltage grid), underground cables and transformers. Transformers convert electricity to a different voltage level with a very high efficiency. The figure below shows a schematic representation of the structure of a network from high voltage to low voltage, showing the different grid levels.

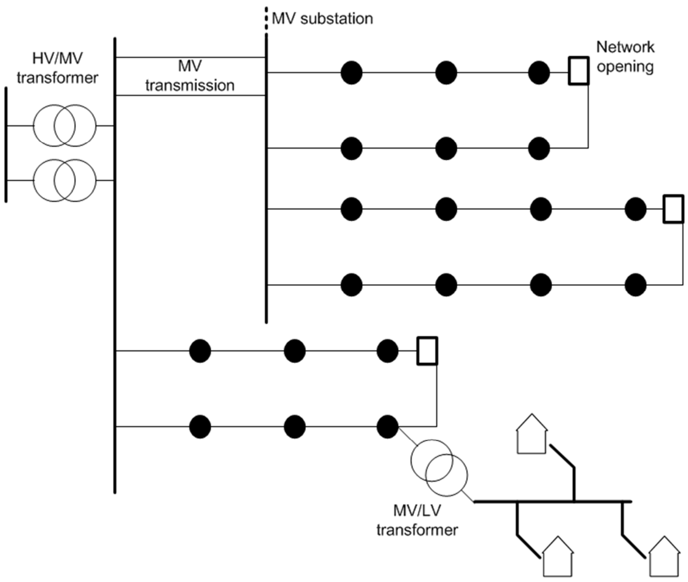


Figure 8 Network structure, showing a grid from a high voltage to medium voltage transformer to a low voltage household network [Adjusted from Grond, 2011].

Figure 8 describes the grid from a high to medium voltage transformer to a low voltage grid. The high to medium voltage transformer is linked to either a transmission or a distribution grid. This distinction will be described in the next section. The blocks in the figure represent a network opening, this grid element will be discussed in section 2.1.2.1.

Medium voltage networks

Medium voltage (MV) networks are either transmission, or distribution networks. The MV transmission network transmits electricity over longer distances from high voltage to medium voltage (HV/MV) transformers to medium voltage distribution transformers. Medium voltage transmission grids mostly consist of 10kV, 20kV or 30kV grid components. A medium voltage distribution grid distributes electricity either from a high to medium voltage transformer or from a medium voltage (transmission) to medium voltage (distribution) transformer. Medium voltage distribution grids have a voltage of 10kV and distribute either via a transformer station to low voltage networks or directly to (business) consumers [Grond, 2011].

Low voltage networks

Low voltage networks are designed to distribute electricity to consumers. Low voltage grids are mainly loaded by connections for small consumers, entailing for instance connections to households of 1x25A, but also small or medium sized companies with a connection up to 3x80A. Larger electricity consumers can also be connected to the low voltage grid. Large consumers have connections from 3x80A to 250A. Finally public lighting is connected to low voltage grids. Low voltage networks have a voltage level of 400V (three phase) [Grond, 2011].

Scope definition voltage levels

High voltage networks are designed to transport a large amount of electricity for longer distances. High voltage networks transport from large production plants to lower voltage grids, or between distribution grids and have voltages above 35kV. The effect of electric mobility is in literature however expected to be limited on a high voltage level [Karnama, 2009; NY ISO, 2009; Green et.al., 2010; Hadley, Tsvetkova, 2008]. Therefore, high voltage grids will be outside this thesis scope.

2.1.2.1 GRID RELIABILITY

The Dutch electricity network has a relatively reliable network compared to other European networks [Karatay et.al., 2010]. Figure 9 displays outage time in 2009 for high voltage (regional high voltage: red, national high voltage: orange), medium voltage (blue) and low voltage (green) networks.

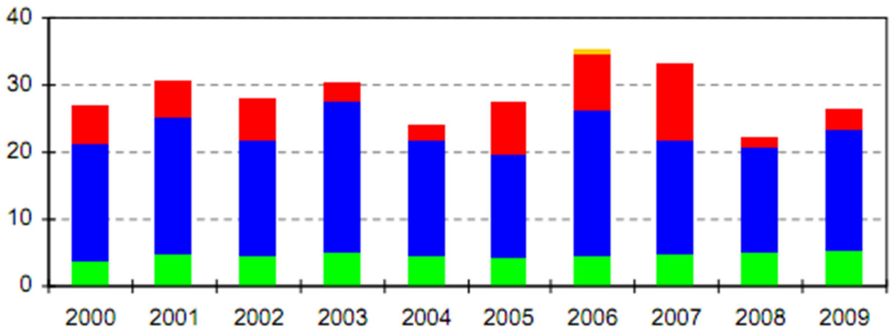


Figure 9 Yearly outage minutes (minutes/year). Most outages are caused at medium voltage level [Karatay et.al., 2010].

The numbers in the table show that most outages are caused on a medium voltage level. These outages are mostly caused by excavation activities, where lines and cables are damaged. To deal with outages and keep outage duration as low as possible, most high and medium voltage network components are designed with n-1 characteristics. This network planning rule means that the system should be able to withstand grid failure of one component by using redundant infrastructure to take over transport.

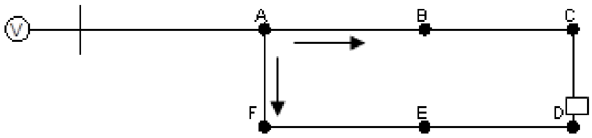


Figure 10 Illustration n-1 - normal operation.

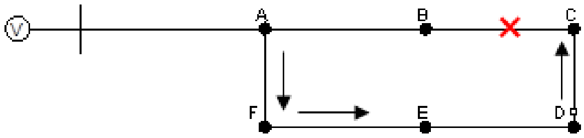


Figure 11 Illustration n-1 rule - grid failure.

Figure 10 and 11 display a simple illustration of the n-1 rule. The block between C and D in figure 10 represents a network opening. During normal operation, load C is fed via A and B, Load E and D via A and F. In case of a grid failure between for instance B and C (as is shown in figure 11), the opening can be closed (done by hand), feeding C via A and F. The outage time is thereby limited to the response time to close the network opening instead of time until the grid failure is resolved. In the Netherlands, the n-1 rule is obligated for 380kV/220kV and 110kV/150kV (thus high voltage) networks via the Net code Electricity[6]. Most medium voltage networks with a large number of consumers are also planned according to the n-1 rule to minimise outage time. Most low voltage networks are not planned according to the n-1 rule, as the number of customers in a low voltage network and thus the scale of an outage is limited [van Beek, 2010].

Most medium voltage distribution grids have a meshed grid topology, meaning that different configurations exist within the grid and that multiple grid branches are connected to each other. As can be seen in figure 8, medium voltage distribution networks are operated with a network opening. They are thus operated with a radial grid topology, meaning that in normal operation the loads are fed via only one cable [EnergieNed, 1996, p.21-22].

[6] Net code Electricity §4.1.4.5-§4.1.4.6

2.1.2.2 GRID CAPACITY

Network components are planned to suffice for several decades. Life time of components lie between 50-70 years [Liander, 2009; p.38] and as infrastructure investments mostly consist of sunk costs, a long operation of network components is most cost effective. Network capacity is therefore planned to deal with an expected organic growth of demand (about 1,5% per year [Stedin, 2010a; Essent Netwerk B.V., 2007]) for several decades. Energy saving is however stimulated and electrical devices are more and more energy efficient, thus organic demand growth could be lower than expected during grid planning [Essent Netwerk B.V., 2007].

Simultaneity

Electricity demand is strongly time dependent. During night hours, demand is low, during the day demand is higher and peaks at several moments a day. Diversity in loads and their profile exists. The figure below shows (normalised) weakly demand profiles for households in urban and rural areas and industry. These profiles do not only differ per hour, but also per day, week, month or year. The networks need to be able to deal with the maximum capacity and are thus based on the peak demands.

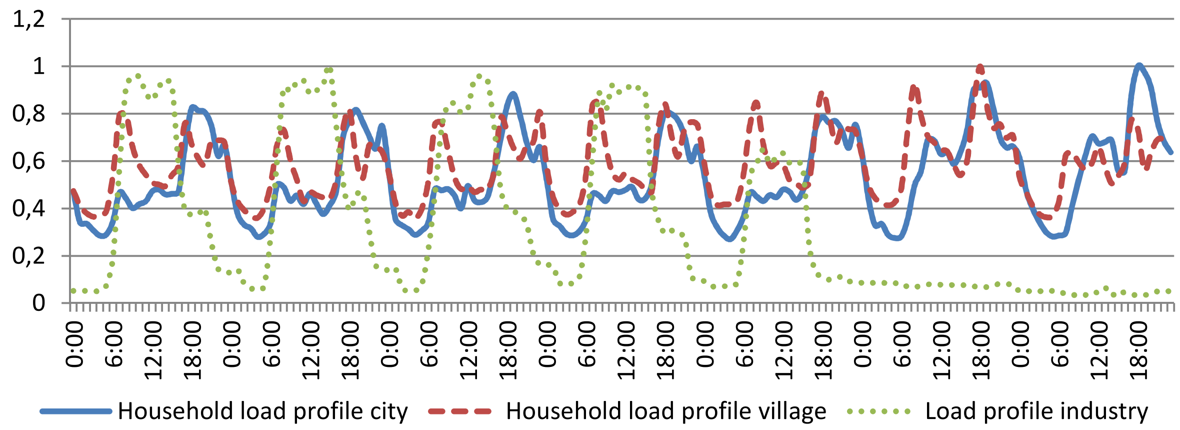


Figure 12 An average load profile of a household in a city or village, and an average load profile for industry [Vision network analysis, 2011].

Not all individual peaks occur at the same time and not all peaks have the same height. The individual load to consider per household (or company) is lower than the sum of all maximum loads. The total capacity of a household connection is about 8kW (assuming a connection of 1x35A and 230V). At medium voltage level, a network operator however considers an individual load of around 1kW per household[7]. The factor describing the difference between the maximum load a network operator has to take into account and the sum of the maximum loads is called the simultaneity factor, or coincidence factor.

$$simultaneity\ factor = \frac{total\ maximum\ load}{\sum maximum\ individual\ loads}$$

Capacity

For network planning, total load to a network node needs to be determined. This load is determined by multiplying the simultaneity loads by the number of loads on the node. These loads are than corrected for expected demand growth for 50-70 years. However, as mentioned above, the network also has a significant redundancy to deal with outages. This redundant capacity added to an overcapacity to deal with organic growth and peak demand results in a capacity which is much larger than average electricity demand. Unexpected developments to the electricity grid might however impact the utilisation of network capacity and thereby network planning.

[7] Stedin considers a household simultaneous load of 1,4kVA [Stedin, 2010a], corresponding to about 1,3kW (where: Q(kVA)=P(kW)*cosϕ, and cosϕ= 0,9-0,95).

2.1.2.3 GRID PARAMETERS

When looking at developments on the electricity grid like electric mobility, three grid parameters are important to take into account for network planning: thermal load of cables and transformers, voltage deviations and energy losses [Clement, 2008; Verzijlbergh et.al., 2011a; Peças Lopes, 2009].

Thermal load
A components' (thermal) load can be calculated to see whether the capacity of the grid is sufficient to deal with the load and is measured by the ratio between the current flowing through the grid component and the nominal current (the maximal current which can flow through the component, based on components materials and thickness). When looking at thermal load of grid components, simply looking at a maximum of 100% grid load does not suffice. First, due to the required redundancy of the grid, 100% capacity utilisation would not be able to cope with calamity situations. Second, network capacity is not limited to a 100% thermal load. For short periods of time (during peak hours) it is possible to overload components to about 120% or more. The extent to which cables can be overloaded above 100% depends on the cooling down capacity of the surrounding soil and component characteristics. Overloading does however impact the life expectancy of components. In addition, the grid, when overloaded, requires time to cool down again. Slootweg et.al. (2007) came up with a guideline which takes into account thermal characteristics of the environment and the cable, and the average number of parallel cable. Applying this guideline, medium voltage distribution cables, can be loaded up to 120% for 72 hours [Goud, 2011].

Voltage deviation
Another indicator for system operation is voltage deviation. As mentioned above, the Dutch electricity system has several voltage levels. These levels can deviate a little due to sudden (unexpected) increases or decreases of load and supply. These deviations however need to be limited as electrical devices might flicker, break, or age faster. Voltage deviations are therefore not allowed to be 10% above or below their standard voltage levels[8]. Voltage deviations are dependent on (among other things): network configuration, cable length and characteristics of the load [Goud, 2011].

Power losses
Power losses are a result of resistance in grid components and are dependent on the type of grid component, the grid configuration, the peak load and the peak duration of the grid component. In grid cables, power losses are also dependent on the cable length [EnergieNed, 1996]. Power losses are required to be limited as they reduce the efficiency of the electricity system.

2.1.2.4 DEVELOPMENTS INFLUENCING NETWORK OPERATION

Several developments are expected to influence grid operation in the coming decades, both from a production, demand and network perspective.

Changing supply
Electricity production used to be centralised and was produced in large power plants, with sufficient capacity to feed a large number of customers and companies. Electricity was fed into the grid at a high or medium (in case of smaller combined heat and power plants) voltage level. It is however expected that an increasing share of renewable distributed energy sources will be fed into the lower voltage grid, meaning that the low voltage grid no longer has a one-directional flow from production plant to consumer. The distributed energy sources will in many cases be fed into the grid by consumers. The role of electricity consumers thus changes to both a role of electricity consumer and producer (so called 'prosumer'). Decentralised production requires a more flexible

[8] Net code Electricity §3.2.1

grid, where electricity is both consumed and produced. This flexibility is meant to be provided by smart grids. This concept will be explained in the next section.

Changing demand

Electricity load is also changing. On the one hand, normal 'organic' electricity growth associated with an increasing amount of electrical devices leads to a growing demand. As mentioned before, the development of organic growth is uncertain and additional demand is expected from an upcoming amount of electric vehicles and electric heating devices [Liander, 2009; p.54-55]. Network planning is currently based on organic growth expectations of 1,5%. Electric mobility and heating increases electricity demand by a significant amount.

Component aging

Another development is inherent to the infrastructure itself, namely the aging of grid components. A bulk of grid components is installed between 1950 and 1980, which is shown for medium voltage transformers in figure 13[9]. As the life expectancy of most components lie between 50 and 70 years, a significant number of components might have to be replaced in the coming decades. Network operators however indicate that age alone is no reason to replace grid components and that they base replacement decisions on risks assessments, which include failure data and capacity availability [Liander, 2009; Stedin, 2010a].

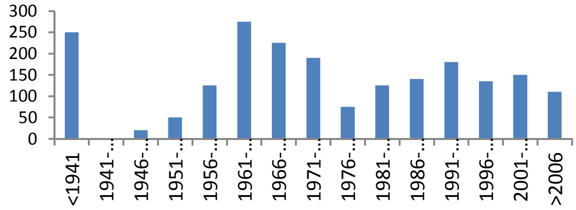


Figure 13 Age distribution 50 kV cables Liander (total length) showing the fact that a large share of grid components require to be replaced in the coming years [Liander, 2009].

2.1.2.5 DEALING WITH GROWING DEMAND

Additional power demand in combination with organic demand growth and redundancy requirements, might lead to insufficient grid capacity. The conventional approach to deal with insufficient capacity was to increase grid capacity. Tan (2011) calculated for grid operator Enexis the required costs for grid replacement due to developments of on the one hand energy production and load developments and on the other hand component replacement requirements. She concluded that to facilitate future environment, Enexis would have to invest at minimum €4,5 billion and at maximum €31,9 billion, with an average of €13,5 billion up to 2040. These numbers show a great variety, indicating that there is a lot of uncertainty related to the impact the future developments will have on the grid. According to Tan, more detailed study on the expected energy transition is therefore required to be able to anticipate to future developments.

Current tariff regulation is however focused on cost efficiency. Tariffs will not always be sufficient to recover costs of grid reinforcements in case investments are anticipating on uncertain developments like electric mobility. In addition, as the Dutch grid is mainly located beneath surface, grid replacement is very costly, difficult and can take a long time to plan and arrange.

In case grid replacement is still required due to decreasing reliability associated with component age, reinforcement might be the most favourable option. In other cases different options to deal with a growing demand can be favourable to this conventional approach.

[9] Note that this figure is merely an indication of the problem, the ages of components strongly differs per component type and per network operator. Note also that the first time bar represents a larger time scale than the other bars, which explains the large amount of cables installed in that time frame.

Smart grids and demand side management
One of the options to deal with a capacity limitation is to have a more flexible, smarter network. A so called 'Smart Grid' is a combination of several technologies to involve multiple stakeholders in the electricity system in a way to make the use of the electricity network more efficient.

The Dutch government, who assigned a Taskforce Smart Grids to come up with a strategy to deal with Smart Grid developments, identified the following characteristics of Smart Grids [Taskforce Intelligente Netten; 2010]:

- Enable and activate consumer interaction;
- Accommodate generation and storage in a more efficient way;
- Develop new products, services and markets;
- Increase the flexibility of the electricity system;
- Limit or postpone required infrastructure replacements;
- Secure the reliability of electricity supply.

For network operators, responsible for balancing demand and supply on the electricity network, the importance of smart grids lie in the possibility to control electricity demand. Two types of control can be identified: demand control and load control. Demand control uses financial incentives to stimulate customers to switch off their load. Load control allows network operators to directly switch load on or off. Also options in between demand and load control exist where customers are incentivised by tariff structures to allow network operators to switch off load, but still retain the choice on beforehand to allow the network operator to do so.

One of the enablers of smart grids is the smart meter. In the coming years, smart meters will replace the existing electricity meters in Dutch households [Rijksoverheid, 2011b]. Smart meters can provide both consumers and network operators with more detailed information on consumers' demand and thereby enable demand control.

Currently smart grids are in an early development phase and deployment will take decades. However, as smart grids are a very broad concept, entailing many different changes to the electricity network, the concept is not something one can deploy in a few large steps. The development of smart grids will be associated with many small steps, constantly increasing the participation of stakeholders. One of these steps is electric mobility. There is thus a certain synergy between electric mobility and smart grids. For network operators, electric mobility is a component and enabler of the smart grid concept [NetbeheerNederland, 2010].

The smart grid concept will demand an active participation in electricity demand of consumers. Such an active participation is not always evident, especially when consumers are accustomed to the luxury of having access to electricity wherever and whenever they want. Electric mobility can play a transition role, as vehicle charging is new and customs are not yet embedded in consumer behaviour. When consumers are not used to charging, they do not yet have a reference point. When directly applying smart devices to charging stations, consumers could thus get accustomed to smart charging. When consumers would first become accustomed to 'dumb' charging, they might not be willing to change their behaviour[10].

A smarter operation of the electricity grids can thus be an option for network operators to avoid network reinforcements. Smart grids are however in a early development phase and it is uncertain how exactly the system will function. In addition, it is not certain whether smart grids will actually reduce costs, as smart grids increase electricity losses [Tan, 2011]. Pilots, supported by a national subsidy scheme, which are meant to look into those uncertainties in practice, were initiated in June 2011 [Verhagen, 2011].

[10] Financial incentives could still convince consumers. See section 2.1.3.3

2.1.3 CHARGING CHARACTERISTICS

This section will describe characteristics of vehicle charging via the electricity grid. The section will first describe the daily demand of an electric vehicle, followed by a comparison of this demand to normal household load. The latter provides insight in the effect of home charging on a household connection. Finally, this section will go into smart charging and possible charging concepts.

2.1.3.1 CHARGING DEMAND

The average daily Dutch driving distance is approximately 30km, corresponding to 6kWh per day [Prud'Homme, 2010]. As is mentioned in section 2.1.1, the driving range of near-term expected available battery packs is about 30kWh. The daily driving range is thus much smaller than the battery capacity, meaning that vehicles do not require full charging. Using a 3,7kW (1 phase) charger, charging an entire battery to full capacity takes approximately eight hours. Charging a partially empty battery takes one to two hours[11].

As mentioned before, electricity loads are corrected by a simultaneity factor. Based on estimated aggregated load profiles, Verzijlbergh et.al. (2011b) and Taylor et.al. (2010) estimate the simultaneity load of an electric vehicle at around 0,7kW. The simultaneity factor is thus around 20-30%.

2.1.3.2 CHARGING PROFILES COMPARED TO NORMAL LOAD

Where possible, vehicles can charge via an existing household connection. This section will provide insight in the demand of an electric vehicle relative to other electrical devices in a household.

Household connections are generally designed to handle normal household load (taking simultaneity of electric vehicles into account), with a small overcapacity to deal with organic demand growth. A standard household has a 1x35 ampere, a larger household a 3x35 ampere connection [Stedin, 2009a]. As the power is equal to voltage times current (P=V*I), a connection of 1x35A with a voltage level of 230V means the power of the connection is about 8,1kW. Three phase connection (3x25A) equals 17,3kW.

The table below shows an overview of the power demand of a few household devices[12].

Table 2 Power demand of household connection and devices.

	Power demand
Connection	8,1kW (1 phase) or 17,3kW (3 phases)
Tumble dryer	3,7kW [Siemens, 2011a]
Washing machine	2,3kW [Siemens, 2011b]
Oven	2,3kW [Siemens, 2011c]
Kettle	2,4kW [Philips, 2011]
Charging station electric vehicle	*3,7kW(1-phase) or 11,1kW (3-phase)*

Between electrical devices in a household there is simultaneity as most devices are not used at the same time. A connection can also deal with a thermal overload for a limited time frame before it switches off. A connection is therefore able to deal with these power demands, even when the connection capacity is lower than the cumulative demands of the devices.

[11] Note that shallow or incomplete charging does impact the life time of the battery in terms of the total number of kilometers driven on the battery [Axsen et.al., 2008, p.10].

[12] As only one household is considered, there is no simultaneity between household load or in charging station load. Therefore charging station load is, when looking at a single household, the entire power demand of 3,7kW and 8,1kW are considered.

From the table it can be concluded that electric vehicle charging takes a significant share of total connection capacity. This share increases by the fact that charging takes a couple of hours of this high capacity, while the household devices only require a maximum capacity for a limited time (for example a washing machine uses the maximum capacity only during the water heating process).

As mentioned before, electricity demand is highly time dependent. To see whether electric vehicles actually increase demand at peak hours, it is important to look at the load profiles of housholds and electric vehicle charging. Because no data on electric vehicle charging is yet available, no empirical charging profiles yet exist. Verzijlbergh et.al. (2011b) created an aggregated load profile for vehicle charging. This aggregated charging profile is based on mobility data of Dutch vehicle drivers [Ministry of Transport, Public Works and Water management, 2010]. The figure below shows these normalised charging profiles for one day. As can be seen, the load of uncontrolled charging peaks at about the same time as the household peak. Vehicle owners are expected to plug in their vehicle whenever they arrive at home, at the same time when lights and other electrical devices are switched on. The peak thereby increases with about a third.

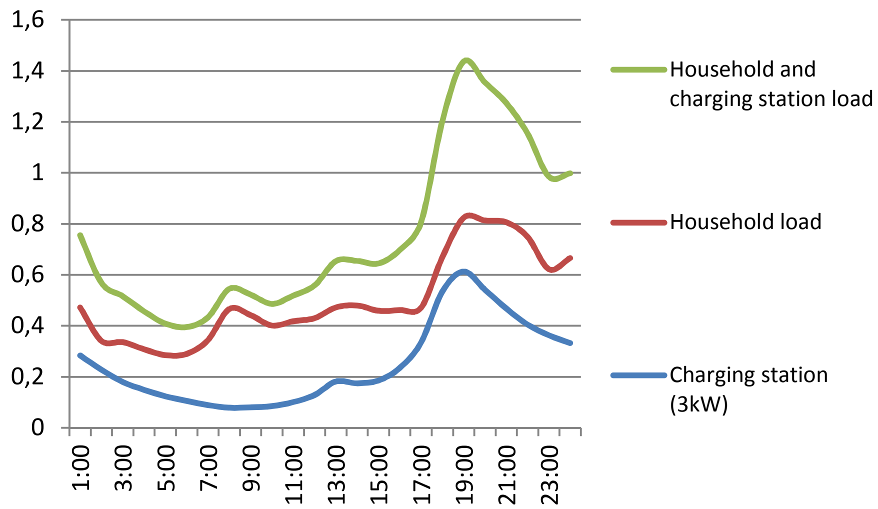


Figure 14 Charging and household load, individual and combined profiles for an average day. The load peaks occur at about the same time [Verzijlbergh, 2011].

A charging station thus increases the peak demand by about a third and demands almost half of the total connection capacity for a couple of hours. Charging stations might therefore require households to increase their connection capacity [van der Sluijs, 2009]. A connection reinforcement to 3x25A costs a household almost €570-€858 [Stedin, 2009b]. Households can, however, also choose to use smart devices to limit their peak demand.

2.1.3.3SMART CHARGING

The charging profile in figure 14 is based on current mobility data and is thus merely based on an estimation of when vehicle drivers park their vehicles and are able to charge. It is however uncertain when exactly the drivers will charge their vehicles, this depends on the availability and location of charging stations. For the network, the night, when the electricity demand is low, is the optimum time for vehicle charging. Vehicle owners might however prefer to charge whenever they arrive at home, as they want to have certainty that their vehicle is charged whenever they want to use it again [Hadley, 2008].

Smart charging makes use of the underutilisation of the grid during low demand hours and thereby avoids extra investments for network reinforcement [Hadley, 2008]. Smart charging can occur via price incentives or automatic devices. No matter what smart charging system will become established, the principle is generally the same, although the extent to which it will have effect might differ. The figure below shows how load peaks can be ‘shaved’ by smart charging. The peak load will be displaced to an off-peak moment.

Except for a case where charging stations are fully automatically switched off during overcapacity, it is expected that not all charging load will be displaced. Always some consumers will want their vehicle to be charged during or right after the peak.

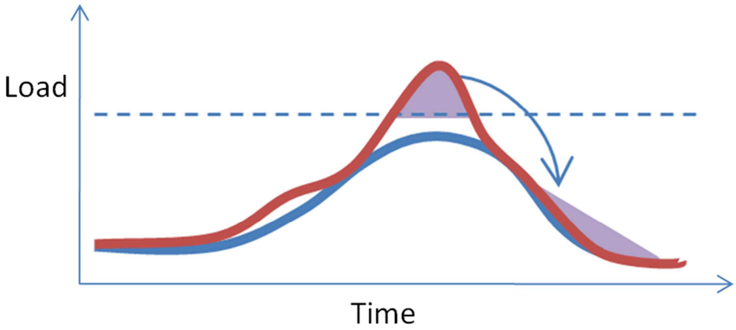


Figure 15 Load shaving showing the smart charging concept. Load at the peak can be displaced to off-peak demand hours.

There are several options to incentivise customers to charge at night. One example is differing pricing schemes, based on high and low demand. Dual pricing schemes are currently used for household loads, where for most contracts, electricity is cheaper after 11PM. In the current electricity system, this dual pricing would thus also apply to home charging. The effect of dual pricing for electric vehicles is that if most users would plug in (or switch on by means of a timer) their vehicle more or less simultaneously around 11PM, it could cause a peak demand around 11PM [Peças Lopes et.al., 2011]. If vehicles are actually all plugged around 11PM (or via a timer at exactly 11PM), due to financial incentives, there is limited natural spread of load. The additional power of the charging stations at medium voltage would thus be almost the full charging station power, instead of about 20%-30% simultaneity. This is different for vehicles compared to other household devices. Other household devices are often not as time independent (not always possible to delay) as a vehicle. Consumers for instance do not want to delay their computer or television. In addition, electric vehicles have a much larger power and energy demand. When looking at the flexibility of shifting loads of a household, including an electric vehicle, the vehicle is expected to provide more than half of the flexibility[13].

A more preferred option of smart charging is to use devices which regulate total load in a grid node. Smart chargers are not yet widely available on the market, but there are options being developed. More information on possible devices will be provided later in this thesis.

2.1.3.4 CHARGING CONCEPTS

Charging behaviour depends on vehicle demand, possible charging profiles, the possibilities of smart charging and the location of charging. Charging at work will occur at different time frames than charging at home, and charging or a supermarket. In addition, different locations require different types of charging stations. The combination of charging station location and type is here referred to as *charging concept*.

Lehtinen (2010) looks at charging concepts based on their access points, and thereby identifies six charging concepts:

- *Charging at home*: electric vehicles can be charged at home, using the normal electricity socket. Due to the longer available time for charging and the limitations of a household connection (see section

[13] This knowledge is based on the interview at Enexis.

2.1.3.2), only slow charging is available here. Home charging is only possible for those people who have a parking spot on private property.

- *Charging at workplace*: basically workplace chargers can be similar to home chargers, as the parking time is relatively long[14].
- *Charging in park-and-ride areas*: in park-and-ride areas vehicles are parked for a long time. Therefore also in this charging concept, slow charging would be most applicable.
- *Charging in parking garages*: charging in parking garages can both be fast or slow, depending on the location and parking purposes of the garage. If the garage is for instance utilised for residents, slow charging could be favourable. If the garage is located near a supermarket, fast charging will be favourable. Charging in parking garages has the advantage that it does not use the often limited public space on the street. In addition, a grid connection is already available in a garage. This grid connection will in most cases however not be suitable for fast chargers or for a large number of slow chargers.
- *Charging on public streets*: charging in public streets is required for those people who have no private parking spot or garage. In addition, charging stations can be located in public streets near shopping areas. A disadvantage of street charging is that it needs to be able to withstand vandalism.
- *Fast charging:* the majority of charging stations will in the future be slow chargers. Fast charging will only be required for longer distances or sudden occasions.

Valentine-Urbschat and Bernhart (2009) looked at the charging concepts from a different perspective and designed three charging concept models, which combine types and locations of charging into three scenarios. In model 1 electric vehicles use their existing (or upgraded) electricity connection to charge at home overnight. Model 2 describes a superfast charging infrastructure, where electric vehicles are charged at high power stations, similar to the current gas station fuelling infrastructure. These charging stations could thus also be located at the current fuel stations. The third model describes a system where an almost infinite number of charging points can be found and vehicles can be charged everywhere they are parked.

The Valentine-Urbschat and Bernhart concepts and the charging access points identified by Lehtinen are in most aspects not contradictory. The charging points of Lehtinen describe the types and location of charging used in the Valentine-Urbschat concepts. Valentine-Urbschat and Bernhart, and Lehtinen however have a different perspective on fast charging stations. While Lehtinen describes fast charging as having a limited contribution to total vehicle charging, Valentine-Urbschat and Bernhart see a fast charging network as a possible alternative to slow charging at home and at work. They are not the only ones to identify a possible key role for fast chargers. TNO and Innopay [Boekema et.al., 2010] also describe a possible scenario where fast charging is becoming increasingly important. The figure below shows this scenario, where the emergence of fast chargers boosts the electric vehicle market and reduces the need for slow chargers. In this case fast charging is identified as most convenient and thus most promising for consumer preferences.

[14] Note that vehicles used for company purposes (like pool vehicles) might require fast chargers as those vehicles are parked for shorter time periods.

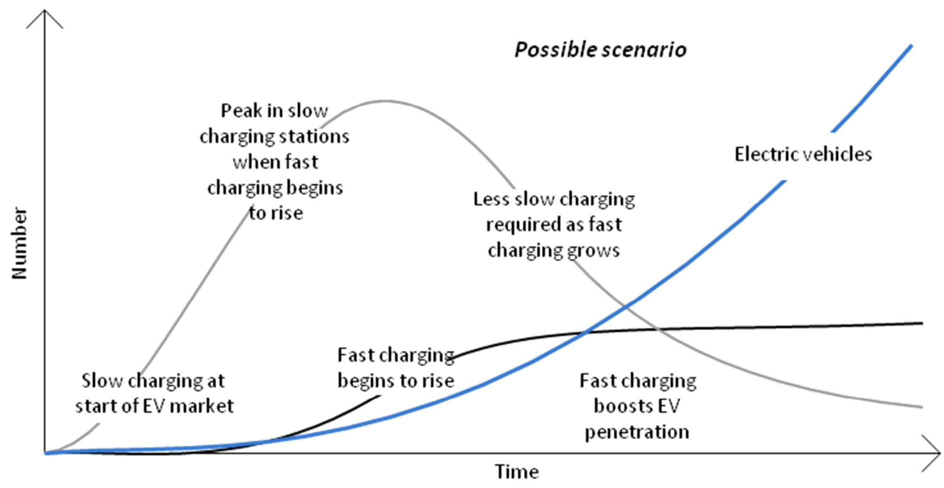


Figure 16 A possible charging scenario of TNO and Innopay, where fast charging becomes the main charging facility [Boekema et.al., 2010]. The scenario merely describes the concept, not the time frame or expected number of vehicles, thus scales the axes in the figure are undefined.

The lists below displays the combined concepts of Lehtinen, Roland Berger and Boekema et.al., where the first charging scenario describes a case where everyone is able to charge at, or near home. This means that everyone will have either a charging possibility at home, or can charge on public street in front of their home. In the second scenario, fast charging is considered to be the main charging option, only people who are able to charge at private property will charge at home (the TNO, Innopay and Valentine-Urbschat, Bernhart fast charging scenario). The third scenario considers fast charging as an additional charging concept (next to slow chargers everywhere one parks), only used for occasional purposes or long distance travellers (the Lehtinen concept).

Charge at home overnight
- Charging at home
- Charging on public street

Superfast charging infrastructure
- Charging at home
- Fast charging

Charging everywhere
- Charging at home
- Charging at workplace
- Charging in park and ride
- Charging in parking garages
- Charging on public street
- Fast charging

Which charging concept will become the standard is uncertain. Both technical and social factors influence the deployment of the concepts. Firstly, technology developments strongly influence whether or not fast charging will be applicable and widely available to electric mobility. Technology development applies to the speeds (and thus the power) for which fast chargers will become available and the capacity of the batteries of electric vehicles. If vehicles will be equipped with batteries which can easily suffice for the driving distance of a few days, fast chargers will only be required for long distances, or unplanned trips when the battery is empty. If large battery capacities appear not to be possible, a (super)fast charging network is required. Another technology development is the impact of fast charging on battery lifetime. A decreased lifetime of batteries might be so disadvantageous to consumers that they will avoid the use fast charging stations. The true impact and the extent of this impact on batteries is however yet to show.

In addition to technical developments, social factors play a role in charging concept deployment. Consumers are currently locked into their vehicle customs, fuelling the vehicle, only when the tank is empty is one of these customs [Cowan, Hutlén, 1996]. When using a slow charger, a vehicle is charged whenever it is not used, not only when it is completely empty, as it would take too much time to charge an entire vehicle when the owner will want to use it again. So next to technology development, the question whether or not consumers will get accustomed to slow charging determines which charging concept will deploy. Another influential factor is based on the price difference which can be appointed to slow and fast charging, thereby assigning an incentive to consumers to choose for slow charging and thereby possibly changing their behaviour. A final influential factor for the deployment of a charging concept is based on investment strategies. Currently mostly governmental parties are deploying infrastructure (mostly slow, but in some cases also fast). By making consumers accustomed to these charging stations, governments can create a new lock in effect for charging concepts.

To summarise, fast charging might sound like the most convenient charging concept to consumers, as it enables them to continue their current ‘fuelling’ behaviour (fuel when empty) and does not require custom changes. There are, however, also several factors (like battery lifetime) disadvantageous to fast charging. Technology developments, as well as social and economic factors, make it very uncertain which charging concept will deploy.

2.1.4 EXPECTED IMPACT ON ELECTRICITY GRID

The electricity grid has a certain power capacity, which is dimensioned for maximum peak demand. The additional demand caused by electric vehicles, possibly makes the existing capacity insufficient. This section will look into the possible impact of electric mobility on the grid. A literature review is described, where some literature studies on grid impact are discussed. The section will also describe another side of electric mobility, namely a concept where vehicles are used as a backup facility to the electricity grid, vehicle to grid.

2.1.4.1 LITERATURE ON GRID IMPACT ELECTRIC MOBILITY

The impact of electric vehicle charging on the grid and the electricity demand will heavily depend upon the time and duration at which consumers charge their vehicles and the location of charging [Hadley, 2006]. In addition, the impact of electric vehicles in densely populated urban areas are expected to be higher than the impact in rural grids, due to the concentration of people and thus of load and future vehicles load [Karnama, 2009; Pieltain Fernández, 2011].

Many grid impact studies have already been done for several different impact aspects. Below a short overview of the results will be provided for four grid impact studies. In appendix II an overview of the underlying assumptions and characteristics of these studies can be found. The list is not meant to be exhaustive, but mainly to provide an overview of the different outcomes and different types of studies.

Table 3 Summary of four grid impact literature cases.

Author	**Verzijlbergh et.al. (2011a)**
Grid	Low voltage grid of Enexis (North- and South-Eastern part of the Netherlands)
Parameters	Percentage of transformer (1) or cable reinforcements due to overloading (2a) or voltage deviations (2b)
Results	• Required grid reinforcements due to organic demand growth: 1) 19,1%, 2a) 2,8%, 2b) 2,1% • Required grid reinforcements in case of 3kW chargers for 75% EV: 1) 41,2%, 2a) 9%, 2b) 2% • Required grid reinforcements in case of smart charging for 75% EV: 1) 21%, 2a) 4,8%, 2b) 2,5%.

Author	**Peças Lopes et.al. (2009)**
Grid	Low voltage grid in Portugal
Parameters	Grid capacity is taken as a constraint, calculating the possible share of EVs for dumb and smart charging.
Results	• ‘Dumb’ charging: 11% EVs • Smart charging 61% EVs For higher electric vehicle market penetrations, grid reinforcements are required.

Author	Pieltain Fernández et.al. (2011)
Grid	Medium and low voltage grid in Spain
Parameters	Uses three scenarios (including scenarios with smart charging and vehicle to grid) to calculate required network reinforcements, based on grid component loads.
Results	• Grid reinforcements up to 19% of actual network costs (in case of 62% EV) • Smart charging can avoid 5-35%

Author	Clement et.al. (2008)
Grid	Low voltage grid in Belgium
Parameters	Looks at ratio of power losses (1) and percentages of voltage deviations (2) for four percentage of electric vehicle adoption (0%, 10%, 50%, 100%), applied to two load scenarios, (high and low load) combined with summer and winter load profiles. The extremes will be shown below (low scenario – summer and high scenario – winter).
Results	• 0% electric vehicles: 1) 2,6% - 4,1%, 2) 4,2% - 7,5% • 10% electric vehicles:1) 3,4% - 5,0%, 2) 7,3% - 10,4% • 50% electric vehicles: 1) 8,8% - 10,8%, 2) 20,8% - 26,5% • 100% electric vehicles: 1) 28,5% - 29,7%, 2) 63,1% - 65,1%

The first case shows that grid reinforcement is also required without electric mobility. With merely the organic growth of electricity demand, grids will become overloaded and network reinforcements will be required. Electric mobility will add to these requirements, especially for transformers. The majority of grid reinforcements is required by overloads, only a limited impact is caused by voltage deviations.

The second case takes grid capacity as a constraint and calculates which electric vehicle adoption is possible. The case shows that full adoption of electric vehicles is not possible with the current grid capacity. Grid reinforcements are thus required to avoid grid overloads. These reinforcements are limited in case of smart charging. The latter is a conclusion which can be drawn from all cases. Grid reinforcement requirements due to electric mobility can be significantly limited by applying smart charging.

The last case shows a significant impact on voltage deviation and power losses in case of electric mobility. The first case also looked into voltage deviation and identified a far lower impact on voltage deviation. This difference implies that the outcome of a grid impact calculation can strongly depend on grid characteristics (differences between the Belgium and Dutch low voltage grid) and applied assumptions. One of these differences is that the Belgium case only looked into a grid with 35 nodes, while the Verzijlbergh case looked at a numerous number of grid nodes. Due to the small number of electric vehicles considered in the Belgium case, no simultaneity of loads is applied. Clement takes the full 2,5kW of the considered charging stations into account, against a 0,7kW simultaneous power considered in the Verzijlbergh case.

Organic growth

The Verzijlbergh case shows a relatively large impact of normal organic growth to the electricity grid compared to electric mobility. This conclusion is also supported by several other grid development studies. Grond (2011) looks at different energy scenarios to see the impact on the grid, thereby applying organic growth factors of 1% and 2%. From the calculations, Grond concludes that organic growth is the dominant impact factor which damps out effects of other energy developments. It is also concluded that the percentages of 1% and 2% are merely standard organic growth numbers used for network planning. Research on actual growth figures is required.

Uncertainties and assumptions

The cases described above show different types of network impact studies. Their outcomes strongly differ, not only in number but also in approach, parameters, network characteristics and underlying assumptions. It is however unclear what the impact of these different assumptions is on the expected impact on the grid. The next chapter will therefore go into these uncertainties and describe how network impact calculations are done and what the impact of underlying assumptions is on the outcome of impact calculations.

2.1.4.2 VEHICLE TO GRID

Electric mobility not only forms a threat to the electricity grid. In the long term electric vehicles can also provide storage capacity to the grid. The so called Vehicle-to-Grid (V2G) concept is a system where electric vehicles provide power to the grid when they are parked, basically acting as a storage system within the grid.

The Dutch car fleet currently owns over 7,6 million private cars [CBS, 2010a]. Parked electric vehicles do not use their battery capacity most hours of the day [Brooks 2002] and can, when plugged in, provide a large battery back-up capacity for the electricity grid. As each car can roughly provide 10 kW to the grid [Brooks 2001], this storage can theoretically provide up to 76 GW. As comparison: the total installed capacity of all power plants in the Netherlands is about 25 GW [CBS Statline, 2011b]. Vehicles thus provide an enormous capacity to the grid. However, as said the 76 GW is a theoretical number, as vehicles will not always be plugged into the grid, the vehicles will expectedly not be completely full at peak demand hours, and vehicle owners will not want their vehicle to be completely emptied by the grid operator to balance the grid, as they will then not be able to use it for transport purposes.

By acting as a backup electricity supply, electric vehicles can increase the reliability of the electricity grid. Especially an increasing share of intermittent renewable energy sources with unpredictable electricity supply, requires some sort of backup or storage capacity. Consumers could also use the storage facility on a smaller scale, for instance to balance the solar energy production of their own solar energy system. As the vehicle is in that case not used as a storage device for the grid, but merely for the home, this concept is called Vehicle to Home (V2H) [Botsford, Szczepanek, 2009].

The V2G concept is, however, under debate. As stated by the interviewee of Enexis, technically, the concept is possible. From an energy perspective, vehicle to grid can provide a large electricity backup potential to the electricity grid. Most of the studies on vehicle to grid do however not take into account the cost of the system [Ingvar, Persson, 2010]. These costs can however be considerable. Network operators will be required to compensate for the discomfort of consumers who provide the storage capacity to the grid[15]. This discomfort is increased by the fact that this partial discharging might have an impact on the life time of the vehicle battery [Axsen et.al., 2008, p.10]. This discomfort does not only apply to compensation costs, but also to whether or not consumers will be willing to displace the battery of the vehicle to the network operators' disposal. In addition, to actually have a significant energy storage capacity, the batteries would be required to recharge very fast. To do so, the cables connecting the vehicle to the grid would have to have a high capacity and would in many cases have to be reinforced. This reinforcement limits the need for vehicle to grid, as a grid with a high capacity will be able to cope with an increasing demand of electricity itself and would not require storage capacity[16]. In addition, such a fast recharger could affect battery lifetime and thus increase the inconvenience of the consumer.

Scope definition Vehicle to Grid
Technically, Vehicle to Grid can be valuable to grid operation. As explained above, the feasibility of the concept is however debatable, due to cost considerations and potential unwillingness of consumers to cooperate. Therefore this concept will not be further included in the thesis scope.

[15] Note that these costs will potentially have to be traded off against reinforcement costs or costs for compensating grid outages.
[16] This knowledge is based on the interview at Enexis

2.1.5 CONCLUSION TECHNICAL SYSTEM ANALYSIS

This section described the technical components of electric mobility. This thesis considers electric mobility from a power system perspective. Electric vehicles are, via charging stations, loads to the electricity system. Based on the type of charging station and the charging behaviour, this load can greatly impact the electricity grid. This impact can reduce grid reliability. Failing grid components, or grid components where insufficient capacity can be expected, will have to be reinforced in order to retain the reliability of the electricity grid. A reduced reliability and the requirement of grid reinforcements come with high social costs. Electric mobility is thus associated with social costs to the electricity network.

Electric mobility is in an early development stage. This early stage is associated with a lot of uncertainties. A first uncertainty is related to technology development. Especially for batteries and charging stations, it is uncertain how technology will develop. This development is however very determining for, on the one hand, adoption of electric vehicles, but also for the impact of the vehicles to the grid. An important factor on charging station technology development is the emergence of (super) fast charging stations. Fast charging stations can provide a fast way to recharge battery (for instance for long distance travelling), but it has a relatively large individual impact on the electricity grid. In addition, fast charging can reduce battery life.

Another uncertainty is related to the adoption rate of electric vehicles. Depending on the attractiveness of electric vehicle technology to vehicle users, electric vehicles will be adopted in the coming decades. The time frame of such an adoption and the final adoption rate are currently however very uncertain. The rates depend on technology developments, price developments of alternatives, and governmental incentives.

The impact of electric mobility on the grid depends on the charging behaviour of consumers. The time and duration of charging can be determining for grid impact (charging during peak hours affects the grid much more than during off peak hours). In addition, the development of a possible smart grid can change the time when loads are demanding power and thus limit the impact on the grid.

The technical analysis shows that electric mobility is still emerging and comes with a great deal of uncertainties. These uncertainties are however only partially related to the technical system. Also involvement of actors comes with uncertainty, for instance the electric vehicle adoption of users, the influence of governmental incentives on consumers, or choices made for adapting the grid. This relation between the technical system and actor environment is inherent to a socio-technical system. In order to describe also the social perspective of the system, an actor analysis is done.

2.2 ACTOR ANALYSIS

Below an overview will be provided on the actors playing a role in electric mobility and the relations between these actors. The list of actors is mainly based on the roadmap and scenario studies referred to in appendix I. Appendix III provides more information on the actors presented below. Some actors are added to the list derived from the scenarios and roadmaps or slightly adjusted to the Dutch situation as they apply specifically to the Dutch actor environment. Other references of these additional actors can be found in appendix III.

2.2.1 DESCIPTION OF ACTORS

The actors are categorised based on their role in electric mobility, in this case policy makers, actors related to the electricity system, vehicle users and other actors. Note that the role of the actors described here is very dynamic. The actors are still searching for their role to play in the evolving electric mobility system.

2.2.1.1 POLICY MAKERS

The Dutch **Ministries** of Transport and Environment and Economic Affairs, Innovation and Agriculture wrote a plan of action for electric mobility. This plan of action entailed the formation of a cooperation organisation to support a breakthrough both from the private and public sector. This organisation is called the **Formula E-team**. The ministries, Dutch municipalities, network operators, energy companies and several players in the car industry are affiliated with the Formula E-team. **Provinces** also play a role in electric mobility. The provinces of Brabant and Utrecht are currently cooperating with municipalities on stimulating electric mobility [Provincie Brabant, 2011; Provincie Utrecht, 2011]. **Municipalities** benefit from air quality, and a reduction of noise and CO_2 emission. Some large Dutch municipalities have therefore initiated a stimulating electric mobility policy. Besides this stimulating role, all municipalities have a facilitating role. As public charging stations will be located at public ground, municipalities have a formal role in lease rights for locations of charging stations.

2.2.1.2 ELECTRICITY SECTOR

Electricity for electric vehicles will be drawn from the existing electricity grid. The actors involved in the electricity sector will thus also be related to electric mobility. **Network operators** are responsible for maintaining and operating a reliable grid and thus have to deal with changes due to electric mobility. Network operators might thus be required to reinforce the grid. As the network operators are public, regulated organisations, these costs are socialised. Most distribution network operators are cooperating in Stichting E-laad to facilitate the transition to electric mobility and gain knowledge on the impact on the grid [E-laad, 2010]. **Energy companies** (producers and retailers) will sell additional electricity, electric mobility might thus create a possible new business case. In addition, a new role is created; that of the **service provider** on a charging station. This actor is the link between the vehicle owner and the electricity provider. The charging station service provider can for instance arrange the transaction between consumers and electricity retailers. The exact role of the service provider and who to fulfill this role is however not yet defined. Charging services are defined as a combination of transactions between charging providers and customers. Service providers, like energy companies, electricity network operators, installers and lease companies can support providers and customers [Boekema et.al., 2010].

2.2.1.3 VEHICLE USERS

Governmental policies are aimed at convincing **consumers** and **companies** to switch to electric vehicles. In the end, users are essential to electric vehicle adoption. Currently electric vehicles do not seem to have much added value to consumers compared to conventional vehicles. The cost of an electric vehicle is high, the driving range limited and there is almost no charging infrastructure available, which causes users to be afraid to strand with an empty battery [Valentine-Urbschat, Bernhart, 2009, p.56]. As stated in an interview with the BAM Group, for companies, electric vehicles might already have some added value, as the purchase of an electric vehicle can provide companies with a green image. In addition, the vehicles can for instance be used for short distance mobility requirements. Vehicle users thus a have a key role in the deployment of electric mobility. However, as consumers do not yet know what to expect from electric vehicles (most consumers have no experience yet), market potential is difficult to study. It is thus uncertain how consumer behaviour will develop.

2.2.1.4 OTHER ACTORS

Other actors are **media, technology developers** and **oil companies**. Media are involved by influencing the public perception of potential vehicle users. Other social factors, like behaviour of friends and family can also influence the behaviour of potential users. When referring to media, also these social influences should be considered. **Technology developers** entail charging station and battery developers, as well as car manufactures and research institutes. These actors play an important role in electric mobility as technology development is still required to make electric mobility attractive to consumers. **Oil companies** and the corresponding fuelling stations will no longer be needed for providing energy to vehicles[17]. Oil companies might thus be opposed to electric mobility.

2.2.2 INTERESTS OF ACTORS

The list of actors presented above is based on scenario and roadmap studies on electric mobility. However, as said, this thesis looks specifically into electric mobility from a social cost perspective. This section will therefore look into the actors' interest in the impact of electric mobility on the electricity grid. This impact can either be based on the fact that the actor can influence the impact on the grid, or the fact that the actor is influenced by the impact on the grid. The table below describes the interest of the actors on the impact to the grid and indicates whether the actor influences or is influenced (affected). In the table a relative interest of the actor is indicated by a number between 1 and 5, where 5 reflects the largest interest and 1 reflects the lowest interest. Note that this number merely provides a general indication of actor involvement. Also note that these numbers are based on the researcher's perspective and that each individual number is scored relative to the other actors.

Table 4 Actor interest and influence on grid impact of electric mobility.

Actor	Interest	Influence or affected	Relative interest (1-5)
	Policy makers		
National government	• Stimulates consumers to switch, thus indirectly increases impact of electric mobility to the grid; • Regulates the operation of the electricity grid.	Influence	3
Provinces	• Stimulates consumers to switch, thus indirectly increases impact of electric mobility to the grid.	Influence	2
Municipalities	• Stimulates consumers to switch, thus indirectly increases impact of electric mobility to the grid; • Deploys charging infrastructure; • Owner of public property, on which public charging stations will be located (leasing rights required for other parties to install charging stations).	Influence	4
Formule E-team	• By stimulating electric mobility, the Formule E-team indirectly increases impact on the electricity grid.	Influence	2
	Electricity sector		
Distribution network operator	• Owner and operator of distribution grid and responsible for balancing load (including electric mobility) and supply. • Most network operators cooperate in Stichting E-laad which installs and operates charging stations.	Affected	5
Electricity companies	• Increasing power demand due to electric mobility can create business opportunities for electricity retailers and producers. Some electricity companies are therefore already investing in charging stations	Affected/ influence	3
Charging station provider	*This role is yet to be defined, so no definite interest can be identified*		
	Vehicle users		
Consumers	• In large numbers consumers can significantly increase	Influence	4

[17] Fuel stations might still play some role in fast charging or battery swapping.

		electricity demand by charging their vehicle.		
Companies	•	See 'consumers'	Influence	4
		Other actors		
Media	•	Influence the adoption of electric vehicles by consumers (in a positive or negative way).	Influence	2
Technology developers	•	The technology of charging stations can have an impact on the grid.	Influence	3
Oil companies	•	Some fuel stations plan to install charging stations.	Influence	2

The table above provides insight in the relative interest or influence of actors in the impact of electric mobility on the electricity grid. Network operators are rated as most affected by impact of electric mobility on the grid. Municipalities and users (consumers as well as companies) strongly affect electric mobility. In the next section these interests will be further explained.

Scope definition Actors

From the relative interests, three main actors can be selected. The first actor is the network operator, who is strongly affected by the impact of electric mobility on the electricity grid. The second key actor is the municipality, which has a role in local electric mobility charging infrastructure deployment. The third actor is the vehicle user. The user is the key actor for electric vehicle adoption. However, as will be explained below, the user will in this thesis be taken into consideration in another manner than the first two actors.

2.2.3 DESCRIPTION SELECTED ACTORS

Based on the actor analysis above, three key actors are selected. Below a description will be provided on the involvement of these actors. First, the involvement of municipalities in electric mobility will be described, including their electric mobility objectives and measures. Second, the network operators will be described. This description entails a short introduction on the involvement of network operators in electric mobility. More detailed information on the perspectives of these two actors in electric mobility can be found in the institutional analysis. Finally a description will be provided on vehicle users. As mentioned in the scope definition above, vehicle users will be considered in another manner than the other two actors.

2.2.3.1 GENERAL DESCRIPTION MUNICIPALITIES

As said before, municipalities have a role in leasing rights of charging station locations. Municipalities will thus be confronted with a demand for charging infrastructure deployment and a role in electric mobility. However, not all municipalities will merely be confronted by electric mobility. In 2009, Amsterdam was the first Dutch city to stimulate electric mobility [Gemeente Amsterdam, 2010]. Currently also the municipalities of Utrecht and Rotterdam have an active policy on electric mobility. These municipalities stimulate electric mobility as a means to reduce air pollution. In addition, electric mobility contributes to the reduction of CO_2 emission, for which these municipalities have set objectives, reduction of noise and to economic development of the region [Gemeente Amsterdam, 2010; Gemeente Utrecht, 2011a]. Other smaller municipalities follow suit. For instance Zaanstad (near Amsterdam) installed charging stations [Zaanstad.nl, 2010], and in the province of Brabant several municipalities have shown interest to do the same [Wieringa, van Beek, 2010]. These municipalities do not only show a passive role to facilitate the installation of charging stations on public property, but also try to accelerate the adoption of electric mobility in their region.

Scope definition Municipalities

As this thesis looks into the impact of municipal policy on the electricity grid, only those municipalities with an active electric mobility policy will be considered. In addition, only large municipalities are considered as they seem to have both the means (financially, as well as administratively) and motivation to actually make a difference in the adoption of electric vehicles. Based on this selection on the existence of an active policy and size of the municipality, **Amsterdam, Rotterdam and Utrecht** will be considered in detail. The reason to select a limited number of municipalities is to have a comparable and workable number of actors. This selection does exclude other local governments who might have an interest in electric mobility. In the end of this thesis lessons will be drawn which might also be applicable to the excluded municipalities and provinces.

The three large municipalities considered have all set objectives for electric mobility. The information for the descriptions below was gathered via several interviews with municipal officials from Amsterdam, Rotterdam and Utrecht and the owner of EV consult who (amongst other things) represents the *Vereniging Nederlandse Gemeenten* (Association of Dutch Municipalities)[18] on electric mobility. Additional information sources are referred to in the text.

Electric mobility policy Amsterdam

Amsterdam was one of the first municipalities to stimulate electric mobility in Europe and has become a frontrunner in electric vehicles and charging infrastructure [Gemeente Amsterdam, 2010].

Amsterdam wrote a plan where detailed actions and expectations are specified. Their expectations for electric mobility are to have 200 electric vehicles in the period between 2009 and 2012 and 200.000 electric vehicles (or all kilometres driven in Amsterdam emission free) in 2040. Amsterdam has set the objective to have 20% of the total car fleet electric in 2015.

Amsterdam started with a broad approach: to stimulate electric vehicles to every consumer and company. The municipality is now shifting towards a more focused approach where mainly high potential sectors are stimulated. These high potential sectors are those sectors driving a lot of inner-city kilometres, like taxi companies and city transport services. Another high potential sector is inner city public transport (here refers to busses, as trams, metros and trains are already electric). Public transport vehicles drive a lot of inner-city kilometres. Using clean vehicles can thus significantly improve air quality. Amsterdam is therefore also looking into whether or not it is possible to have electric busses [Gemeente Amsterdam, 2010].

Currently about 250 charging stations are located in Amsterdam, of which about 100 are public. In addition, two fast chargers are installed and a pilot is initiated to locate a battery swapping station near Schiphol in 2012. The public charging stations are procured via a European procurement procedure. Recently a new procurement for 1000 charging stations is won by Nuon, Heijmans and Essent [Nuon, 2011][19]. Amsterdam collects data from the public charging stations on the location, duration and utilisation of charging and charging stations to gain insight in charging behaviour.

In addition to public charging, Amsterdam stimulates semi-public charging stations at companies with a semi-public parking spot like Ikea, Praxis and Q-park, by partially subsidizing companies who are willing to install those charging stations.

[18] See list of interviewees in reference list.
[19] Contract awarded in March 2011 [Aanbestedingskalender.nl, 2011]

Amsterdam already learned a lot on communication to vehicle users. As everything about electric mobility is new to consumers, people often assume that services are or will become a standard. For instance Amsterdam experienced difficulties with communication to people about free parking spots. People assumed that when they received a free parking spot they were able to keep it for as long as they owned an electric vehicle. Now Amsterdam tries to make clear that this measure only will be maintained until the end of 2012. Another example of miscommunication is related to the location of the charging station. At first Amsterdam assured requestors that they would receive a charging station in front of their homes. Such a promise was however not always possible to keep, as sometimes parking spots were unavailable or the location was too far from an electricity grid connection. Therefore Amsterdam now assures charging stations requestors that a charging stations will be installed within 300 metres of their homes.

Electric mobility policy Rotterdam

Rotterdam initiated a program called *Stroomstoot* (Surge) to become a frontrunner in electric mobility. The objective of Rotterdam is to have 1.000 electric vehicles in Rotterdam within 5 years and 200.000 electric vehicles in 2025. The *Stroomstoot* program financially supports the installation of 1.000 charging stations for consumers and companies who want to purchase an electric vehicle. This subsidy is only directed to consumers and companies with a private parking spot [RCI, 2011a]. These consumers and companies can request for a €1.000 subsidy for purchasing a charging station in the first year, and in the second year for €450 for green electricity to charge the vehicle. The subsidy scheme was initiated in September 2010. The municipality of Rotterdam however experienced a low demand for the subsidy. It is expected that the reason for this low demand is the fact that there is only a limited number of electric vehicles available.

Rotterdam is currently working on a procurement procedure for public charging stations, possibly in cooperation with Stichting E-laad[20]. In parallel with the procurement procedure, Rotterdam is also working on the definition of 'search areas'. These areas are meant to define whether or not charging stations will be installed or allowed. The areas represent the potential of electric mobility based on mobility figures, permit requirements and procedures, and grid connection possibilities (charging stations should be located within 20 meters of the grid). To define these search areas, Rotterdam considers involving other stakeholders like city boroughs, municipality officials on mobility and permits and possibly external parties like the network operator.

Finally, Rotterdam is involved in pilots for electric mobility. One is related to the municipal car fleet. After depreciation, some municipal vehicles will be replaced by electric vehicles. In the pilot, Rotterdam cooperates with network operator Stedin and electricity company Eneco to install charging stations for these electric vehicles in the municipality car fleet.

Electric mobility policy Utrecht

In 2014, Utrecht expects to have 5000 electric vehicles. In a detailed plan of action, the municipality of Utrecht sets targets, ambitions, a detailed approach and planning for electric mobility [Gemeente Utrecht, 2011a]. One of the first actions from the plan is a pilot to install fifteen public charging stations in 2011. In June 2011, the first charging stations were installed. The pilot is meant to provide insight in the possible technologies for charging stations, required licenses, spatial integration of charging stations and an assessment framework for requirements and criteria for installing public charging stations.

In the end of 2012, the objective is to have 200 charging stations and electric vehicles[21]. Of these 200 charging stations, 150 are to be public. The other stations are required to be installed in park and ride parking spots, parking garages and next to hospitals and large companies. Utrecht wants to cooperate with companies who

[20] Publish date of procurement unknown

[21] Utrecht includes scooters in this number, as the municipality believes scooters can have a symbolic meaning for electric mobility.

are willing to install charging stations on their parking spaces. The municipality believes that companies will be willing to do so for a sustainable image. In the period 2013-2014, Utrecht wants to achieve 800 charging stations throughout the city [Gemeente Utrecht, 2011a]. Utrecht will co-finance the charging stations with Stichting E-laad. Utrecht also recently installed two fast charging stations.

Comparing municipality policies
The table below displays the objectives of the three municipalities for electric mobility:

Table 5 Electric mobility objectives of Amsterdam, Rotterdam and Utrecht.

Municipality	Objective	Number of vehicles[22]
Amsterdam	10.000 EVs in 2015; Long term expectations are: • 2015-2020 40.000 EVs; • 2020-2040 200.000 EVs	218.000
Rotterdam	1.000 EVs in 5 years Long term ambitions: • 200.000 in 2025	202.000
Utrecht	200 EVs in 2012 5.000 EVs in 2014	129.000

During the interviews it was perceived that, Amsterdam is seen as an example to other municipalities. As a front runner in electric mobility, Amsterdam gained a lot of experience and those experiences are shared among the municipalities. However, still some differences in approach can be identified. Amsterdam started with a very broad approach, stimulating companies and consumers in different ways (including subsidising vehicle purchase and free parking spots). Their reason to do so was to kick start electric mobility in the city and to become a front runner in the technology. Now Amsterdam is shifting to a more focused approach in stimulating high potential sectors. Utrecht and Rotterdam appear to start with a focused approach.

Municipality measures
The high initial costs of electric vehicles are currently the largest barrier for EV adoption. However, financial or fiscal benefits for vehicle purchase basically not lie within the municipality resources[23] and are currently offered by national governments. Municipalities do have several other means to stimulate electric vehicles, like providing free parking spots, access to environmental zones and cheap accessibility to charging infrastructure [Wiederer, Philip, 2010, p.62]. The following measures are applied in the three large cities considered:

Table 6 List of measures applies in Amsterdam, Rotterdam and Utrecht.

Measure	Amsterdam[24]	Rotterdam[25]	Utrecht[26]
Installation or financial support for charging stations	X	X	X
Charging station infrastructure plan	X	-[27]	-
Free parking spots	X	X	X
Access to environmental zones	X	X	X
Financial incentive EV purchase	X	-	-
Cooperating with businesses	X	X	X
Stimulate high potential sectors (taxi companies, city transport services)[28]	X	X	X
Electrify municipal car fleet	X	X	X

[22] Derived from Dutch statistic center database CBS [CBS Statline, 2010b].
[23] Unlike other cities, Amsterdam did stimulate vehicle purchase [Gemeente Amsterdam, 2010].
[24] Gemeente Amsterdam (2010). *Amsterdam Elektrisch: Het Plan*.
[25] Based on the interview with John Akkerhuis – Gemeentewerken Rotterdam
[26] Gemeente Utrecht (2011a). *Actieplan schoon vervoer 2010-2014*
[27] Is planned to be created before the end of 2011
[28] Refers to sectors which drive a large number of inner-city kilometers, like taxi and city transport services.

Stimulate R&D for battery and charging station technology development	X	-	X
Promote/communicate	X	X	X

When looking at current infrastructure-related policy of large municipalities, mainly two types of measures can be identified, namely: stimulating private charging and stimulating public charging.

For instance, Berlin initiated pilots to facilitate the private sector to install charging stations [Wiederer, Philip, 2010]. Also the Rotterdam policy mainly focuses on private charging stations. In London and Amsterdam, both seen as leading cities in infrastructure roll-out [Wiederer, Philip, 2010], most measures were focused on installing public charging stations throughout the city.

Currently the selected Dutch municipality are investing in charging infrastructure. Rotterdam and Utrecht made an agreement with Stichting E-laad to co-finance public charging stations. A public tender procedure will be initiated in 2011[29].

2.2.3.2 GENERAL DESCRIPTION NETWORK OPERATORS

Network operators are obliged to maintain and operate a reliable electricity grid. As explained in section 2.1.2.4 distribution network operators are confronted with a changing energy system. The cooperating organisation of network operators, Netbeheer Nederland, describes this changing system as being confronted with [Netbeheer Nederland, 2009]:

- An increasing share of small scale decentralised electricity production;
- An increasing share of heat pumps in buildings;
- An increasing share of electric mobility;
- Demand for efficient facilitation of a growing and changing electricity demand.

Network operators are thus confronted with a changing environment. Electric mobility increases the total electricity load. This additional load requires additional grid capacity. The extent of the impact of electric mobility in the future is for network operators currently still uncertain. Therefore network operators are starting pilots to measure consumer behaviour and to be able to estimate the impact of electric mobility on their grid. Below these pilots will be discussed. The information on the network operators is mostly based on the meetings with the network operators. Additional references are made when applicable.

As can be seen in figure 17, network operators are fixed to certain regions. Three large network operators can be identified, namely Enexis (in the north-east and southern parts of the Netherlands), Liander (in the north-west and mid-eastern part of the Netherlands) and Stedin (in mid-western part of the Netherlands). These three operators are also the ones who actively deal with electric mobility.

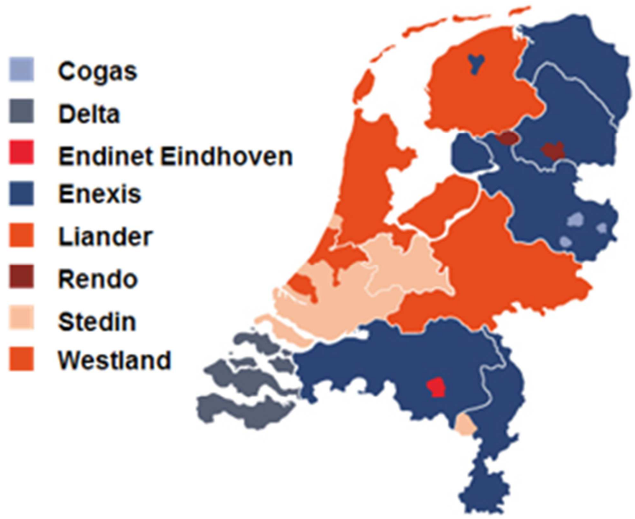


Figure 17 Location network operators, the three largest are Stedin, Liander and Enexis [Microwatt, 2011].

[29] Publish date unknown

Scope definition Network operators
There are two types of network operators. One is the operator of the high voltage network, in the Netherlands TenneT. TenneT operates and maintains the entire Dutch high voltage network. On a medium and low voltage level, distribution network operators maintain and operate the networks. In the Netherlands there are several distribution network operators. This thesis focuses on a regional scale and looks into the interaction between network operators and local governments. In addition, as mentioned before, it is expected that electric mobility will have only a limited impact on high voltage networks. Therefore, only the distribution network operators will be considered when talking about network operators. In the Netherlands, eight distribution network operators exist, of which three large ones. Only the three large distribution network operators are discussed, as these are the only ones currently involved in electric mobility.

Electric mobility involvement Liander
As network operator in the Amsterdam region, Liander was the first to be confronted with electric mobility. In 2009, Liander and Nuon gained a concession to realise a hundred public charging stations throughout Amsterdam. For the next thousand charging stations, for which the concession is granted to Nuon, Heijmans and Essent, Liander will realise the connection of the charging stations to the grid. In addition, Liander is involved in a number of pilots:

- Liander is involved in Stichting E-laad to realise 10.000 charging stations;
- Liander owns twenty electric vehicles to monitor the charging patterns and investigate how charging can be steered;
- Liander is involved in an initiative by the New Motion to realise a network of twenty-five fast charging stations throughout the Netherlands [Liander, 2011];

Electric mobility involvement Stedin
Stedin believes in an approach which starts with small pilots and measures the effects of the electric vehicles on the local grid [Stedin, 2009b]. Stedin is therefore involved in several pilots, supported by the subsidy scheme of the national government.

- Together with Eneco and the municipality of Rotterdam, Stedin purchased 75 EVs for pooling purposes;
- Stedin is involved in a pilot of Prestige Greencab in Utrecht. In this pilot Stedin connects charging stations required for the taxis, advices on the required grid connection and gets insight into the data on charging behaviour acquired from the charging stations [PrestigeGreencab, 2011];

Electric mobility involvement Enexis
Enexis is involved in studies on the impact of electric mobility on the electricity grid [Verzijlbergh et.al., 2011a]. In addition to grid impact research, Enexis is involved in the following pilots and initiatives [Enexis, 2011a]:

- Enexis is involved in Stichting E-laad to realise 10.000 charging stations;
- Enexis signed a memorandum of understanding (MoU) with the province of Brabant, Den Bosch, Essent, car sharing organisation Greenwheels and public transport organisation Arriva to set up pilots for electric mobility [Essent, 2011];
- Enexis is working on a mobile smart grid concept, including a smart charging pilot [Enexis, 2011b].

Comparing network operators
The network operators agree that it is important to gain knowledge on charging behaviour and thereby grid impact. To do so, they are all involved in pilots in their region. Due to the front runner role of Amsterdam,

Liander got involved in electric mobility first and thereby currently has the most experience in dealing with it. Liander is also focusing more on a market facilitating role. Enexis is focusing on grid impact estimations and future concepts to facilitate electric mobility. Stedin focuses mostly on small scale pilots, which is illustrated by their involvement in three subsidised pilots.

Cooperation of network operators

In general matters, network operators are represented by Netbeheer Nederland. This association represents the interests of national and regional network operators towards national and international decision makers. More recently most network operators founded Stichting E-laad, a foundation to stimulate electric mobility and monitor the impact of electric mobility to the electricity network. All network operators except for Stedin are involved in Stichting E-laad. E-laad installs publicly accessible charging stations on request throughout the Netherlands to gain insight in the effects of electric mobility on the electricity grid. Based on the *Elektriciteitswet 1998* (Electricity Act) network operators are however not allowed to invest in competitive activities. Stedin does not agree with the approach to install charging stations throughout the Netherlands and is therefore not cooperating in E-laad. Stedin believes in an approach which starts with small pilots and measures the effects of the electric vehicles on the local grid. Despite their different approaches, all network operators agree about the need for knowledge on the effects of electric mobility on the electricity grid [Stedin, 2009b].

2.2.3.3 GENERAL DESCRIPTION VEHICLE USER

The vehicle user (both consumer and company) is a key actor to electric mobility adoption. Users increase electricity load possibly during peak demand.

Currently, only a very limited number of vehicle owners purchased an electric vehicle. Most of the limited number of electric vehicles driving around in the Netherlands are company owned. In order for electric mobility to actually become widely utilised, companies and consumers would prefer lower purchase costs, shorter charging time and universal access to a network of charging stations. It is difficult to estimate when the barriers to adopt will decrease and when vehicle users will switch to an electric vehicle. Due to the low current adoption rate, it is also still unknown how vehicle owners will use and charge their electric vehicles.

Scope definition Vehicle user

Although user behaviour is an important aspect to grid impact, the user will be considered as a 'passive' actor, responding to incentives of governments and acting according to certain behavioural patterns. The behaviour will be used as input factors for further thesis steps but is not studied itself. The reason for excluding this specific user behaviour is the questionable value of a research on charging behaviour. Most vehicle owners currently do not yet have experience with electric mobility. As electric vehicle charging is a completely new activity, users do not yet have a reference point and will have difficulty to estimate how and when charging will occur. Interviews or surveys might thus have limited value as behaviour might be completely different when users have experienced electric vehicles and charging. In this thesis project it was not possible to include experiences for consumers in electric vehicle driving and charging in a survey. In addition, no data was available on current users of electric vehicles, thus those users could not be interviewed. Therefore users are considered to be 'passive' actors, not by themselves included in the research, but responding to municipalities incentives and acting according to certain behavioural patterns. For more detailed information on the impact to the grid, more research is required on expected user behaviour. As said, to do so, it is important to either do surveys under current electric vehicle users, or to allow users to experience electric vehicle driving and charging before doing interviews or surveys.

Vehicle users are thus only taken into account by three behavioural characteristics which are important for the impact of electric mobility to the electricity grid. The first characteristic is whether or not the user uses an electric vehicle. This characteristic is influenced by governmental incentives, but also by technology developments (costs of the vehicle, battery capacity and life time etc.). This characteristic will be taken into account as general adoption rate of electric vehicles. The adoption rate determines the additional load of electric mobility on the electricity grid. The second characteristic is the daily use of a vehicle. As mentioned above, the current daily travel distance by car is about 30 kilometres, corresponding to about 6kWh. Although it is uncertain whether this distance will also apply to electric mobility (users might only use the electric vehicle for shorter distances), it is here assumed that the 30 kilometres also accounts for daily electric vehicle use. The third and final characteristic is charging behaviour. As discussed in the previous chapter, there is not yet empirical data available on charging behaviour. Therefore, this thesis will use the charging patterns of Verzijlbergh (2011) as presented in section 2.1.3.2 which are based on mobility data.

2.2.4 CONCLUSION ACTOR ANALYSIS

Electric mobility is an emerging system. Actors are thus still searching for their role to play. Four actor categories are identified: governments, actors related to the energy sector, potential electric vehicle users and other actors.

Governments are currently stimulating electric mobility for sustainability reasons. In charging infrastructure, municipalities play an important role as they in some cases install charging stations, and in all cases have a role in leasing rights for charging station property. The energy sectordeals with an increasing electricity demand. To energy producers and retailers such an increasing demand entails a new business opportunity. To network operators this increasing demand can reduce the reliability of the electricity grid and demand for grid reinforcements. Most potential electric vehicle users currently seem to be indifferent to electric mobility. Technology improvements or governmental incentives might change this indifference. Other actors involved are technology developers, media and oil companies.

When looking at the specific interest of the actors in the impact of electric mobility to the grid, three actors are identified as either having an influence, or being affected by the impact of electric mobility on the grid. Actors having an important influence on the grid impact are: municipalities and users (both consumers and companies). Only the network operators are really affected by the impact on the grid.

Municipalities have a role in the deployment of charging infrastructure. Firstly, municipalities are owners of the public property on which many charging stations will be located. Secondly, some large municipalities stimulate electric mobility by deploying charging infrastructure themselves. The main reasons for municipalities to stimulate electric mobility are air quality improvements and CO_2 emission reduction.

Network operators are responsible for operating and maintaining a reliable network. In this role, the network operators are confronted with the development of electric mobility as this increases electricity demand, possibly at current peak demand hours. Electric mobility however also provides opportunities for network operators as electric vehicle charging provides flexibility to the grid.

Vehicle users are key actors in electric mobility deployment. By their behavior, vehicle users will cause an impact to the electricity grid. Relevant behavior of consumers entails the adoption to an electric vehicle, the daily electric vehicle use and the charging behaviour.

2.3 INTERACTIONS TECHNICAL AND ACTOR SYSTEM

The technical system describes how electric vehicles connect to the power system and provides an insight in the possible impact of electric vehicles on the electricity grid. The actor analysis shows which actors are involved in electric mobility. This section will look into the interactions between the technical, and actor system. These interactions will be illustrated by means of a system diagram.

2.3.1 SYSTEM DIAGRAM

The following figure displays the interactions between the technical and actor system, which system components are taken into account in this thesis and how the next steps of this thesis correspond to system components.

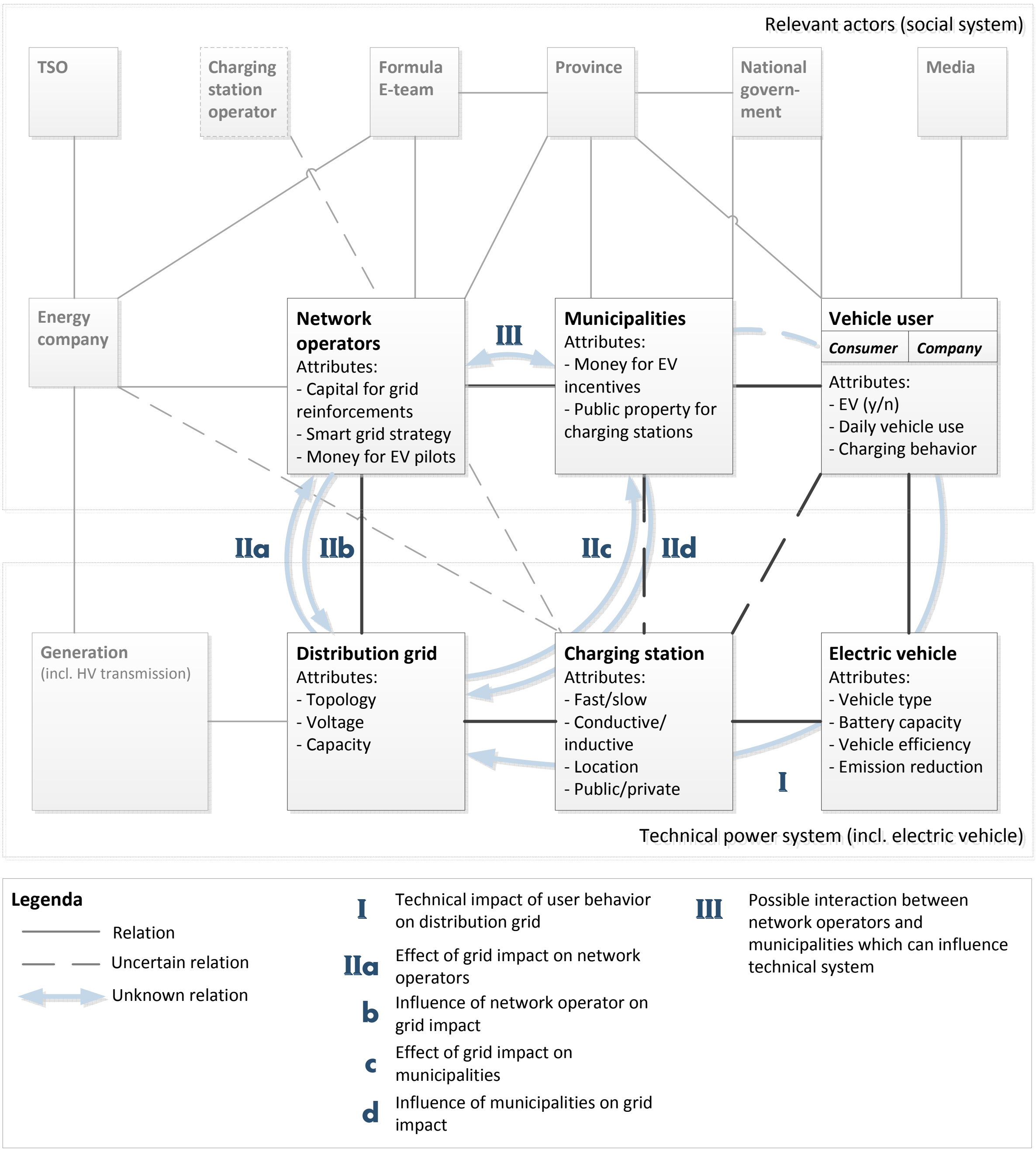


Figure 18 System diagram displaying the decomposition of the technical power system and the relevant actors. The colour of the blocks and arrows display whether the component is in (black) or outside (grey) the project scope.

The system diagram divides the system in the 'Technical power system' in which electric vehicles are included as an electricity load, and the relevant actors. The lines indicate a relation. Such a relation can refer to both ownership of an actor to a technical component (vehicle user is the owner of an electric vehicle) and a relation between actors (both formal and informal). Dashed lines and blocks indicate that the interaction (or role of the actor) is still uncertain. This uncertainty is mostly related to ownership and operation of charging stations as this role is still undecided. Note that, in contrast to the actor analysis, technology developers are not included as actors. The technology which the developers create is included as attributes to the system components, so charging stations can either be fast or slow and vehicles have a specific type and battery capacity. An additional change to the actor system is the identification of two types of network operators. The TSO (transmission system operator) is in the system diagram indicated as a separate actor from (distribution) network operators.

2.3.2 TECHNICAL AND ACTOR SYSTEM BOUNDARIES

When looking at the technical power system, one system component is left out of scope. Power generation, and high voltage transmission is not included in the system scope. High voltage transmission networks are not considered as the impact of electric mobility to the grid is expected to be limited on this voltage level. Power generation is left out of the system scope as impact of electric mobility is not expected to be a problem. The increase in electricity demand is considered as a new business opportunity for producers and retailers. Impact of electric mobility on power generation is thus not considered as social cost but as a business opportunity.

When looking at the actor system, three actors are specified. Firstly the network operator, which are responsible for grid operation and balancing demand and supply. As mentioned in the system description, the grid capacity will not always be sufficient to deal with this increasing demand. As owner and operator of the distribution network, network operators are directly involved to the grid impact.

A second specified actor is the municipality. Some large Dutch municipalities have initiated an active policy to stimulate vehicle users to electric mobility. By stimulating vehicle users to switch to electric mobility, municipalities thus indirectly increase the electricity demand of electric vehicles. In addition, municipalities play a stimulating and facilitating role in charging station deployment.

The third actor specified in the system diagram is the vehicle user. By their behaviour (electric vehicle adoption rate, daily vehicle use and charging pattern), users increase electricity load, depending on the charging pattern, during peak demand. As said above, the vehicle users will merely be taken into account by their behavioural characteristics.

2.3.3 FURTHER PROJECT STEPS

The system analysis looked into a broad perspective of electric mobility and allowed to look into electric mobility by means of the relevant components, actors and relations. By looking into electric mobility from a system perspective, it was possible to see where the main uncertainties in electric mobility lie. In addition, not all relations are already specified or studied. The system analysis showed which aspects or relations in the electric mobility system are uncertain or unknown. As indicated in the previous chapter, especially relations between technical aspects and actors are unknown. These relations are indicated in the system diagrams by the grey thick arrows, numbered by I, II and III. These interactions underline the further project steps in this thesis and will be described below.

- **Interaction I** is mostly located in the technical system, where user behaviour (as said, defined by its attributes) is translated into impact on the electricity grid. This relation includes three sub-relations. The first is the ownership of the user of the vehicle. Via this ownership, users translate their behaviour (daily use and charging pattern) to the vehicle. Vehicle characteristics again convert charging behaviour to a certain demand of energy on a specific time. Electric vehicles are, when charging, connected to charging stations, where time and duration of charging depends on the behaviour, but also on the configuration of the charging station (smart charger, fast or slow charger etc.). The charging station is connected to the electricity grid, where it demands a certain capacity of the grid. Based on the power, duration and time of charging, the charging station causes an impact to the grid. The next chapter of this thesis will look into this interaction of user behaviour to the technical power system.

- **Interaction IIa - IId** in the system diagram look into the translation of the impact on the technical level to the actor level. To do so, institutions are identified which describe the way actors act and are involved in a (technical) system. An institutional analysis will thus be done to describe the interaction between actors in the actor layer and a component of the technical system. More specifically, the institutional analysis will describe how the impact of electric mobility on the distribution grid affects actors' behaviour (IIa and IIc) and vice versa how actors can influence the impact on the grid (IIb and IId). As explained above, municipalities have an indirect influence on the impact of electric mobility to the grid, by actively stimulating vehicle users to adopt an electric vehicle, by actively installing charging stations and by facilitating charging station deployment due to public property ownership. Network operators are directly involved in the impact of electric mobility on the distribution grid, as they are responsible for operating the grid in a reliable way. The institutional analysis will therefore look into these two actors and describe their acts and relations by means of different types of institutions.

- **Interaction III** will look into possibilities in the interaction between municipalities and network operators by which impact of electric mobility and the corresponding social costs on the distribution grid can be minimised. This research step will use the technical and institutional analysis from interaction I and II to identify the possibilities and describe how the interaction between the network operators and municipalities can be arranged in order to come to options to limit social costs of grid impact. Note that this interaction is (in contrast to the other relations) bidirectional. This interaction looks into a bilateral interaction between the two actors and thus not into the relation of one actor on the other.

In other words, the final step in this thesis describes what **(III)** (interaction between network operators and municipalities) looks like, to provide an option to limit **(I)** (impact of electric mobility on the distribution grid and corresponding social costs), taking into account **(II)** (institutions of network operators and municipalities).

3. GRID IMPACT OF ELECTRIC MOBILITY

The system analysis in the previous chapter provided insight in the developments of electric mobility and the electricity system. As the system analysis studied the broad spectrum of technical and social aspects of electric mobility, it was possible to identify several uncertainties and unknown interactions between the components of the technical and actor system. The first uncertain interaction was the impact behavioural characteristics of vehicle users on the electricity grid. This section will therefore look into this interaction.

The previous chapter already provided an overview of literature on grid impact. Results from this literature shows that grid reinforcement is required, partially due to organic growth of electricity demand and partially due to electric mobility. The cases from literature also showed a large difference in assumptions and parameters used in the calculation. It is not completely clear what the impact of different assumptions is on the outcome of grid impact calculations. In addition, the cases do not look into local (demographical) characteristics which will influence the additional load of electric vehicles. This section will therefore provide an additional impact calculation in a small city grid. This calculation will make use of existing grid models and uses a new model to determine additional load of electric vehicles, based on local demographic characteristics.

The reason for doing a technical grid impact analysis is the fact that the source of the social cost problem lies in technical constraints of an existing network. The calculations use the characteristics of an existing network and will identify how constraints determine social costs and which consequences these constraints have on relevant actors. The case is not meant to provide exact data on the number of grid components with insufficient capacity. Instead the case is merely meant to show whether or not reinforcement is required in case electric mobility is stimulated and to show how local grid characteristics can be included in grid impact calculations. Below an explanation of the approach is provided. Further explanation on the approach, the grid considered, and more detailed results of the case can be found in appendix IV and V.

The following sections will first describe the approach of the calculation, after which results will be presented. The method and results are evaluated through verification and validation. The implications of such an impact will be discussed afterwards. In addition, options will be presented to limit the grid impact of electric mobility.

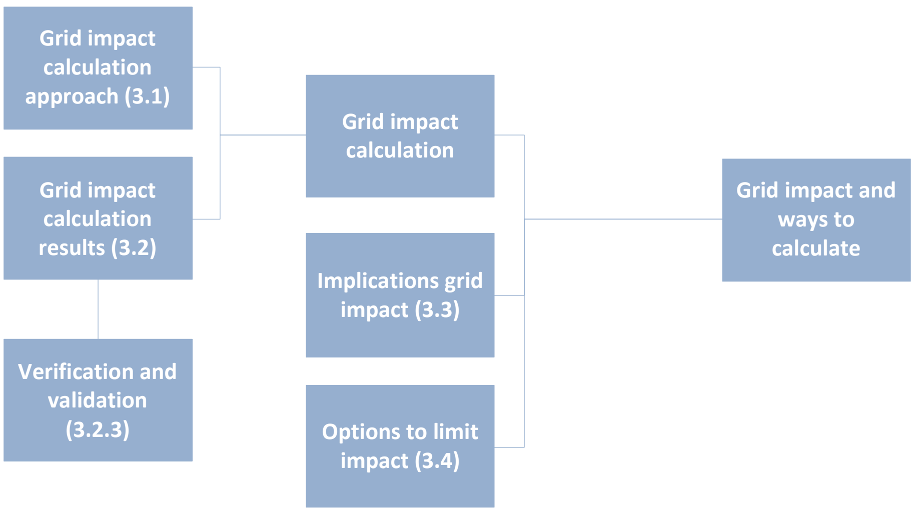


Figure 19 Impact analysis – chapter structure.

3.1 GRID IMPACT CALCULATION APPROACH

In this chapter a grid impact calculation will provide insight in the impact of electric mobility on the grid. The calculation will build on the existing knowledge from the literature cases presented in section 2.1.4.1. The calculations will however also include a new aspect. As this thesis looks into municipalities specifically, the calculation will look into local aspects of the grid and the loads connected to the grid. The calculation will use an existing grid model with actual data on grid assets in a sub-grid in the municipality of Utrecht. The additional aspects of the calculation entails the fact that also the load of electric vehicles will be based on local characteristics. The approach to do so will be explained below.

Note that the grid impact calculation only looks at a medium voltage network. Low voltage grids are also expected to face impact from electric mobility. Urban low voltage grids are mainly designed for dealing with household and small company loads. On the low voltage grid, the variety of household loads is limited. It is therefore expected that impact of electric mobility will occur at low voltage level. However, there was only a limited amount of data available on low voltage grids during this thesis project. In addition, the data which was available could not be used in the designated software tool. Therefore a calculation is only done on a medium voltage grid. However, as stated at one of the meetings with network operator Stedin, it is expected that on the low voltage grid, the impact is similar or larger than on the medium voltage grid. In addition, the proposed approach of calculating grid impact, based on grid and load characteristics, is also applicable to low voltage grids.

This section will describe the approach of the network calculations. Firstly the software tool used will be described, followed by the explanation and definition of parameters used in the calculation. Next, a reference case and the steps taken in the calculation are discussed, followed by a description of the uncertainties in the assumptions of the case. For more information on the considered grid, one is referred to appendix IV.

Software, grid model and parameters
In network planning, network operators often do several analyses, including load flow and short circuit analysis. These analyses are often done in the software program “Vision network analysis”. The Vision software can do load flow, short circuit and reliability or fault analysis. The software uses available data on grid components and assumptions on load in a graphical editor to allow for fast calculation of for instance loads and voltages on grid components [Phase to Phase, 2011].

Vision can do several different calculations. For network planning, load flow analysis provides valuable information on the steady-state behaviour of the network. Load flow analysis indicates voltages, currents and power flows of network components. Each node in a model has several parameters, some specified, others unspecified. In load flow analysis multiple unknown parameters have to be calculated (power flow, current etc.). Vision Network Analysis therefore uses an iterative method, the *Newton-Raphson,* to solve these unknown values in the load flow analysis[30] [Grond, 2011].

As an input to the load flow analysis, an existing grid model is used. A model of a sub-grid of Utrecht was made available by Stedin. This model included the grid topology and characteristics of grid components. No transformers are included in the grid model. Therefore grid components in this case only relate to medium voltage (10,5kV) cables.

As mentioned in section 2.1.2.3, three output parameters are important to take into account when looking at electric mobility: thermal load of cables and transformers, voltage deviations and energy losses. In this grid impact calculation the focus will be on thermal load. The calculation will also shortly look into voltage deviations.

[30] For more information on the Newton-Raphson method, see [Phase to Phase, 2001]

As also explained in 2.1.2.3, grid cables can be overloaded up to 120% for 72 hours. A maximum load of 120% would however not take into account whether or not the cable requires redundant capacity to take over additional load in case of grid failure. In addition, the cables do require time to cool down after the overload and can thus not always be overloaded. Goud (2011) uses the guideline for component loads to do grid load flow calculations in a software tool related to Vision for different energy scenarios. Goud notes that it is not possible for the software tool to take into account the fact that the 120% load can only take 72 hours. He therefore uses a factor of 0,5 to correct for this difference in load. The grid components in the grid calculations are thus overloaded in case they exceed 60% of the load. This assumption will be adopted in this case, as it is also not possible in Vision itself to include such an advanced maximum overload.

The calculation will also shortly examine the impact on voltage deviation of cables to whether or not this is influenced by electric mobility. It is assumed that it will at the most have a very limited impact as voltage deviation is directly dependent on cable length and in urban areas the length of cables is relatively short [EnergieNed, 1996]. When this assumption will be confirmed by the first calculations, the voltage deviations will further be left out of scope.

3.1.1 STEPS FOR GRID IMPACT CALCULATION

The following steps are taken for calculating grid impact:

1. In Vision, the city grid is divided into geographical neighbourhood;
2. The number of electric vehicles per grid node is determined;
3. In Vision a load flow calculation is done for 29 years (until 2040);
4. The results are exported to Excel, where they are identified as being loaded below or above 60%.

In step 2, the number of electric vehicles to be included in the grid has to be determined. As said, other researchers did not yet include a differentiation on local characteristics to determine additional electric vehicle load. Such a differentiation will however provide a more detailed insight in local grid impact which is more relevant when looking at a local scale. The impact of electric vehicles on the electricity grid is expected to depend on both local grid characteristics and expected electric vehicle share. The electricity grid in a large municipality contains several grid branches. As the impact on the grid is expected to differ based on grid characteristics, it is relevant to look into the scale of these grid branches. The grid branches are more or less on a neighbourhood scale. The case will therefore look into the number of electric vehicles within a neighbourhood.

It is expected that electric vehicles will, especially in the early market development phase, mostly be bought by higher educated people, with affinity to sustainability. In addition, it is expected that early adopters of electric vehicles will be people with a relatively high income (as electric vehicles are still relatively expensive), and people who own more than one car (as an electric vehicle might especially be applicable as second or third car. Stedin commissioned a market research for the number of electric vehicles in a city district or neighbourhood [Stedin 2010b]. Neighbourhoods with high property value, high household income and a relatively large number of vehicles per household are expected to have the largest share of electric vehicles. They conclude that the number of electric vehicles in area x can be determined by the following *differentiation formula*:

$$EV_{\ x} = EV_{av} * Veh_x * \frac{HI_x}{HI_{av}} * \frac{VpH_x}{VpH_{av}} * \frac{PV_x}{PV_{av}}$$

Where:

EV_x = electric vehicle share in area x
EV_{av} = average electric vehicle market in the municipality
Veh_x = number of vehicles in x
HI_x = percentage higher income in x
HI_{av} = average percentage higher income in the municipality
VpH_x = vehicle per household in x
VpH_{av} = average vehicle per household in the municipality
PV_x = property value in x
PV_{av} = average property value in the municipality

This formula can be used to identify high potential electric vehicle locations. Stedin emphasises that this formula does not accurately predict the number of vehicles in a certain year, but merely provides insight in the locations where a large share can be expected and in differences in expected share between city districts. In this grid calculation, the formula will however be used to estimate the number of vehicles in a neighbourhood. Due to the potential questionability of the role of the formula, a sensitivity analysis will be done where the formula will be excluded to see what the impact on the outcome of the calculation is.

The formula above is already slightly changed for the calculations. As the formula corrects the number of vehicles in the area to higher income, vehicle per household and property value, it is possible that the formula exceeds the number of total vehicles in the area in case the factors are higher than the average value. The formula used in the grid calculations is therefore corrected for a higher number of electric vehicles than the total number of vehicles (by applying a maximisation function in the Excel database). Result of this maximisation is that some neighbourhoods can reach 100% electric mobility adoption at lower total shares, in case the correction factors caused a faster increase of electric vehicles in that area.

An Excel model is created to calculate the number of electric vehicles in each city neighbourhood in the existing Vision model. The data used for filling in the formula is collected from the Dutch statistic centre CBS [CBS Statline, 2011c]. The data file can be found in appendix V.

For inserting the electric vehicles in the grid, the number of vehicles per grid node needs to be determined. As said, the grids are divided into neighbourhoods and the number of grid nodes per neighbourhood is counted. This number of nodes per neighbourhood is included in the Excel file, enabling the number of electric vehicles per neighbourhood to be divided by the number of grid nodes. The resulting number of electric vehicles per grid node is multiplied by the simultaneous power of a charging station (0,7kW), thereby resulting in the additional power to a grid node due to electric mobility. The figure below displays the steps.

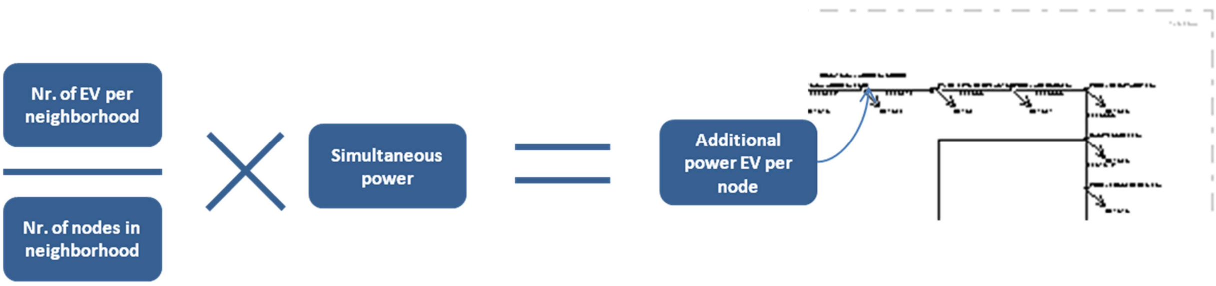


Figure 20 Steps for determining the additional power due to electric mobility. This additional power is included in the grid model.

First a reference case will be calculated. The reference case relates to the grid operation in case of no electric mobility. One can, however, not simply use the existing grid, as network operators always assume organic growth of electricity demand. Therefore the existing grid loads are assigned with a demand growth profile of 1,5% [Stedin, 2010a]. The loads resulting from the reference case will be compared to different shares of electric mobility.

Next to the reference case, a 'worst case' will be presented, where every vehicle in the neighbourhood is electric. This 'worst case' is chosen to see what the maximum load which will have to be supplemented into the grid in case of electric mobility. This case assumes that all vehicles use slow chargers of 3,7kW (simultaneity power 0,7kW).

3.1.2 UNCERTAINTY ANALYSIS APPROACH

The system diagram in section 2.3.1 described the fact that vehicle users influences the electricity grid. The behaviour of these users is described by the adoption rate of electric vehicles, the daily vehicle use and the charging behaviour. The user behaviour on vehicle adoption and charging concepts is influenced by municipal policy. Municipalities for instance provide incentives for vehicle users to switch to electric vehicles. In addition, by deploying infrastructure in a certain way (deploying fast or slow charging), municipalities influence the charging behaviour of consumers. For network operators, these aspects cause uncertainty on what impact to expect on the grid. This section will look into these aspects caused by user and municipal actions and influencing the impact of electric mobility on the grid. These influences will be analysed by means of sensitivity analysis. The calculations will go into the effect of changing one of the underlying assumptions or input factors.

Based on the meetings with Stedin and Enexis and on the impact calculations presented in literature (section 2.1.3.1), it appeared that also other underlying assumptions or input factors for grid impact calculations are subject to uncertainty. Therefore a list of five main uncertainties (including those aspects influenced by vehicle users and municipalities) is identified for the impact of electric mobility on the electricity grid:

- **Share** of electric mobility penetration (adoption rate);
- Development of the **total number of vehicles**;
- Development of **organic growth**;
- Possibilities for **smart charging**;
- The **charging concept**.

Explanations of the approach of the different uncertainty analyses can be found in appendix IV.2. As smart charging and charging concepts both change the load of an individual charging station, smart charging will be included in the charging concept analysis.

3.1.3 OVERVIEW GRID IMPACT CALCULATIONS

The table below shortly summarises the analyses. The first two calculations are respectively the reference case, without electric vehicles, and a 'worst case', where all vehicles in the district are electric. Cases 3 to 6 refer to the uncertainty analysis cases, where one of the assumptions is changed. The table shows the assumptions on all different analyses and, in case of the uncertainty analysis, which assumption is changed.

Table 7 Overview analyses grid impact calculation

	Assumptions / *Cases*	EV market share	Growth total vehicle fleet	Organic electricity demand growth	Charging concepts
1	Reference case	0%	0%	1,5%	slow
2	Full EV adoption	100%	0%	1,5%	slow
			Uncertainty analysis		
3	Varying market share	0-100%	0%	1,5%	slow
4	Varying total vehicle fleet	100%	-10% – 50%	1,5%	slow
5	Varying organic electricity demand growth	100%	0%	-1 – 2%	slow
6	Varying charging concept	100%	0%	1,5%	Slow/mixed/fast/ smart

In the remainder of the chapter, the cases will be referred to by their number in the table.

3.1.4 ASSUMPTIONS IN GRID IMPACT CALCULATION

The electricity system is a very complex system. For the model to be valuable to gain insight in the impact of electric mobility on the grid, assumptions are made.

Firstly, although load and charging profiles are available (see section 2.1.2.2 and 2.1.3.2), this case will make use of the more simplified approach of simultaneity loads. Simultaneity loads describe the maximum power demand. For network planning purposes (like estimating whether capacity is sufficient to deal with expected developments), peak load is the most significant parameter. This case will therefore look at the peak in the aggregated demand profile and thus use simultaneity factors for household loads and peak demand for charging loads. The simultaneity loads of households and charging stations are already discussed in the previous chapter. The simultaneity load of charging stations to be included in the grid model is 0,7kW. The household loads are already included in the existing grid model and equal 1,4kVa.

As network operators usually plan according to an increasing demand of about 1,5% [Stedin, 2010a], the calculation takes this organic growth into account. There is however a lot of uncertainty how the electricity system will develop in the coming decades. Electricity demand might even be decreased due to energy saving measures. The sensitivity analysis studies the effect of other organic growth scenarios. More study is however required to see the impact of different energy scenarios, for instance also the impact of other energy developments (renewable electricity and electric heating).

As explained at the beginning of this section, a maximum load of 60% is assumed for the grid cables. This 60% limitation however not completely reflects reality. It is merely an assumption to take into account half of the total grid load. This assumption disregards the fact that grid topology is not ring structured. In case of a grid failure, not simply one cable can take over the additional load, but multiple cables can cover for failing components. The 60% might thus be not accurate for single cables, but is merely an average value. A cable with a load above 60% would actually only be overloaded for a limited time frame. Only in case of a grid failure would the cable use its redundant capacity and only in case of peak demands would the cable be fully utilised. In addition, the cables require to be cooled after an overload. The actual amount of overload is thus dependent on the load profile. If the load profile shows a large peak, followed by a low demand, the cables can easily cool down. However, when the load is mostly constant, cooling down is more difficult. The assumption of 60% is however justifiable by the fact that the case is merely meant to compare different electric mobility cases and in all cases the same assumption is applied. The case is thus merely meant to show the impact of different electric mobility cases, not to give exact figures on grid impact.

3.2 GRID IMPACT CALCULATION RESULTS

This section will show the results of the case study on the impact of electric mobility on a sub-grid in the municipality of Utrecht. Firstly the results will be presented of cases 1 and 2. After that section, the uncertainty analysis will present case 3-6.

3.2.1 RESULTS REFERENCE AND WORST CASE

The above described calculations 1 and 2 result in the following outcomes:

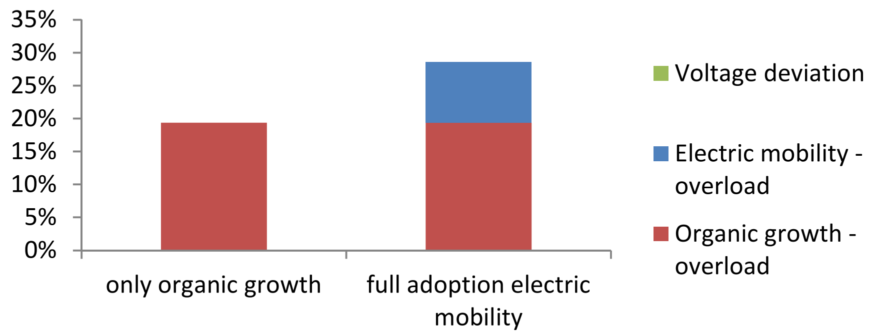


Figure 21 Case 1 and 2: These calculations show that organic growth causes 19% and full adoption of electric mobility 29%.

The impact on the grid is fully caused by cable overloading, no components were impacted by voltage deviation. The total load of electric mobility compared to total existing load of the district in 2040 is 15% in case of full adoption of electric vehicles. This 15% load increase causes 10% of the cables to be overloaded (100% EV causes 10% more cables to be overloaded than in only organic growth). The percentage of required grid reinforcements due to electric mobility is about 10% more than the organic growth scenario. There is no requirement for grid reinforcements due to voltage deviation.

The results are similar to the Verzijlbergh case from literature (see section 2.1.4.1), although the numbers of cable reinforcements are higher (note that one should only look at the required cable reinforcement as the considered Utrecht grid did not contain transformers). Causes for this relatively high impact can be found in the fact that the electric vehicle share of this case is higher than the Verzijlbergh case (100% against 75%). Other differences between the cases can be found in grid specific characteristics; this specific grid might have a relatively low cable capacity to handle increasing electricity demand. In addition, the differentiation formula used as an input value based on CBS data file can cause different impacts. From this data it can for instance be concluded that the households in this grid have a relatively low number of vehicles per household (the average in the Netherlands is 1,0, the average in Utrecht is 0,8 and the average in the considered grid is 0,5). This low number of vehicles can be explained by the fact that the grid is located in the city centre of Utrecht, where parking spots are rare. As the formula used for assigning a number of vehicles to a neighbourhood corrects the number of electric vehicles for the number of vehicles per household, this correction factor lowers the grid impact in the sub-grid.

There is no impact on the grid caused by voltage deviation (no components exceed the norm of 10%). The Verzijlbergh case does show a limited impact on voltage deviations. This difference can be explained by the dependency of voltage level on the length of the cable [EnergieNed, 1996]. The Verzijlbergh case studied rural areas with larger distances between nodes than the city district of the Utrecht case study. As mentioned in section 3.1.1, voltage deviation will be left out of scope in case of a limited impact. As the 100% electric mobility adoption already looked into one of the highest possible additional loads, for the further calculations voltage deviation is left out of scope. The further calculations will only look into thermal loading of cables.

Vision network analysis also allows for visual representation of grid impact. The figure below shows a screenshot of the Utrecht sub-grid after a load flow calculation.

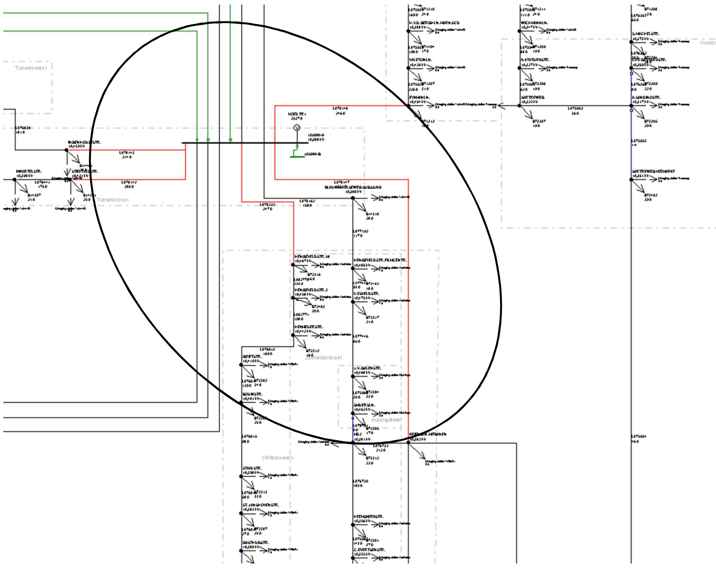


Figure 22 Screenshot of Utrecht sub-model after grid impact calculations for case 2. The red lines in the circle show the cables which are loaded above 100%. These overloaded cables are located at the beginning of branches.

The thicker horizontal line represents a grid bar, distributing energy to different branches. The red lines in the circle are overloaded, most of them are located at the beginning of grid branches. The load on a cable depends on the location in the grid, in the beginning of a branch or at the end of a branch. Cables at the beginning of a grid branch are impacted more as these cables deal with the increasing demand of the entire branch. Cables at the end of the branch only deal with the load on their grid node. Some cables at the beginning of the branch are thus overloaded already at low electric vehicle shares as they deal with large number of electric vehicles already. Cables further along the branch deal with a lower number of electric vehicles and are thus not overloaded. Cables at the beginning of branches have a larger capacity than at the end as, also in normal situations, they deal with a larger demand. However, the 'spare' capacity of these cables in this case appears to be relatively lower than the spare capacity of cables at the end of the branches.

Critical cables in a grid can thus be identified. The identification of critical grid components can help network operators in network planning. Based on electric vehicle objectives in their region, network operators can calculate the expected impact of these objectives.

As mentioned before, several uncertainties exist in electric vehicle deployment. The impact is expected to be different in case of a different number of electric vehicles, a different organic growth or in case of other charging concepts. Therefore the next section will look into the effect of changing these factors in the grid calculation.

3.2.2 UNCERTAINTY ANALYSIS RESULTS

As mentioned before, the behaviour of vehicle users and municipalities, together with other factors, are expected to influence the grid impact. A scenario analysis is therefore done to see which developments can significantly change the expected impact. First different electric vehicle market penetration shares will be studied, followed by a scenario for the total number of vehicles in the district. Next, an analysis is done for electricity market (changing the organic growth). Finally scenarios are tested for different charging concepts.

Varying shares

The results of case 2 are based a 100% adoption of electric vehicles. The true market potential of electric vehicles is however dependent on the willingness of consumers to switch to an electric vehicle, partially influenced by municipal incentive policies. In addition, in the transition towards the maximum electric mobility potential, other market penetration shares will occur. The figure below shows the impact of electric vehicles on the grid for other adoption scenarios.

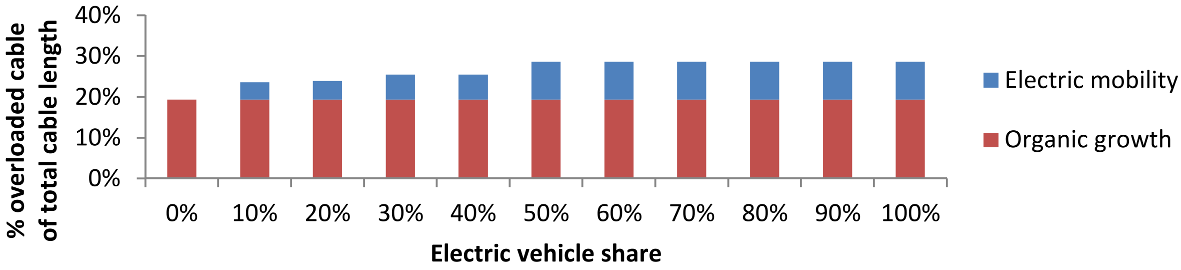


Figure 23 Case 3: Impact of different shares of electric mobility on the Utrecht sub-grid. The graph shows limited additional impact for higher shares of electric mobility market penetration.

The graph shows a flattening line of impact percentages. This flattening line implies that there is a large number of cables with a large overcapacity which will be able to deal with even a 100% electric mobility. Other grid components are overloaded by either organic growth or additional electric vehicles. Between 20% and 30%, and 40% and 50%, 'steps' in increase can be identified. These steps can be explained by the scale of the model. Due to a limited number of grid components, a few cable overloadings is directly visible in the graph. However, in a local grid, these few cables could still cause problems. When a number of grid component reach a critical capacity, addition of a limited number of electric vehicles could overload these critical components. A certain amount of overloading cables at more or less the same time might be misleading to network operators and policy makers. At first, electric mobility will not seem to cause any grid problems. Above a certain limit, the impact could however suddenly occur in several grid components.

This sensitivity analysis also shows that already a low amount of electric vehicles (10%) impacts the grid. When looking at the aforementioned electric mobility objective of the municipality of Utrecht in which this grid is located, about 4% of the total vehicle fleet (5.000 electric vehicles), one could expect at least some impact of electric mobility. This impact will not require large scale reinforcements throughout the municipality, but locally the impact can cause some nuisance of reinforcement construction. As the vehicle adoption is expected to be stronger in certain city districts (in the rich neighbourhoods), these local effect will especially show in these areas.

Additional vehicles

The time frame of the calculations is 2040. In cases 1 and 2 it is assumed that the number of vehicles in a city district will remain stable. It is however not unthinkable that until 2040 the total number of vehicles in a city district will change. Therefore the figure below show the results of a grid calculation of 10% less, 10% and 50% more vehicles than the current amount of vehicles, where an adoption of 100% electric vehicles is considered. The 10% more case thus looks into 110% electric vehicles.

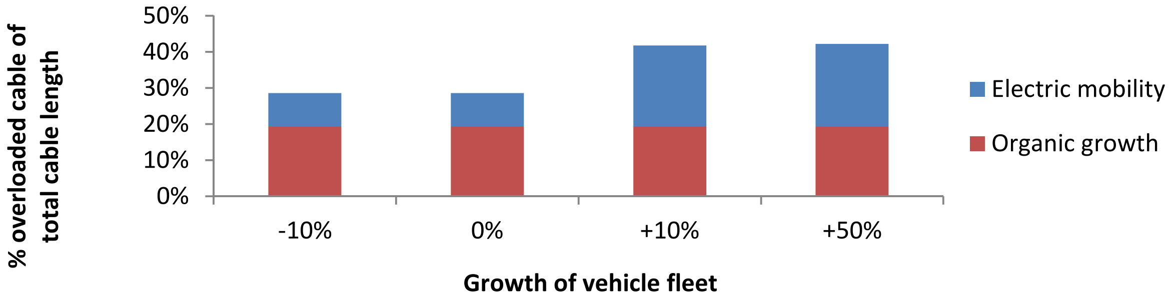


Figure 24 Case 4: Impact of a smaller or larger total vehicle fleet, assuming 100% electric vehicle adoption. A small increase of 10% of the total vehicle fleet shows a large increase in overloaded grid components.

The results of case 4 show that a decrease of the number of vehicles has no effect. An additional amount of vehicles has a significant impact on the grid, already at a 10% increase. The additional increase of 50% compared to 10% is again limited. These results imply that there is a certain threshold value in the spare capacity of a number of components of the grid, which is overloaded in case of an additional 10% of vehicles. This large difference can however also again be explained by the limited number of grid components.

Organic growth

Case 1 shows a significant impact of organic growth on the grid. The impact of energy savings and at the same time more electric devices make the cause uncertainty to organic growth. Case 5 will therefore look into the impact of different organic growth shares.

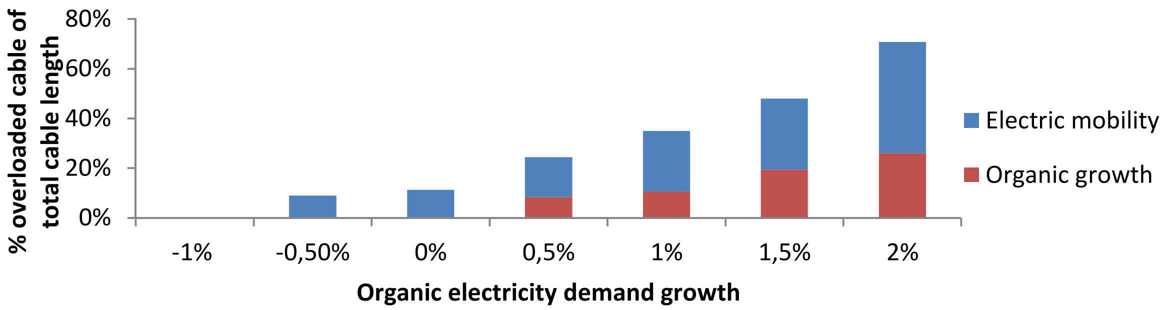


Figure 25 Case 5: Impact of different organic electricity demand growth. The graph shows a continuous increase in overloaded cables due to organic growth.

As can be expected, the analysis shows an increasing number of overloaded cables for an increasing organic growth. Note that a decreasing demand of 1% can compensate for the increasing demand due to electric mobility. A decrease by 0,5% can partially compensate for a electric mobility. In addition, the figure shows that the relative impact of electric mobility in the 1% organic growth case is larger than in the 1,5% or 0,5% organic growth case. This difference can be explained by the fact that certain cables are already critical before an increasing load, regardless whether that increasing load only entails organic growth, electric mobility, or both.

This sensitivity analysis shows that the development of organic growth significantly influences the required grid reinforcements in this grid in 2040. Firstly, if demand was to decrease instead of increase, the additional load of the electric vehicles in this grid can almost be compensated. Secondly the relative impact of electric mobility in different organic growth cases differ, suggesting that a number of cables is critical and will be overloaded also in case of a low additional load. The development of the electricity system thus affects the expected impact of electric mobility. However, organic demand growth is not the only development occurring in the system. As mentioned in the previous chapter, load, as well as production and the network itself are developing. For instance the feed-in of distributed renewable energy sources could affect grid impact as it creates a more local energy flow. This development is however not included in this study as more research is required on how these distributed electricity sources would or could be fed into the grid. More research is thus required on the expected energy developments. It is recommended to create energy scenarios including organic growth and distributed energy sources and to use them for calculating grid impact of different energy developments.

Charging concepts

Next to slow charging stations (used in the previous cases), also fast chargers can penetrate the market. As explained in section 2.1.3.4, the type of charging concept to be used in the future depends on many factors, including vehicle user preferences and behaviour, and governmental charging station deployment policy. This section will look into the effect of different charging concepts on the impact on the Utrecht grid. In addition, smart charging is included in this analysis as also smart chargers impact the individual effect of a charging station.

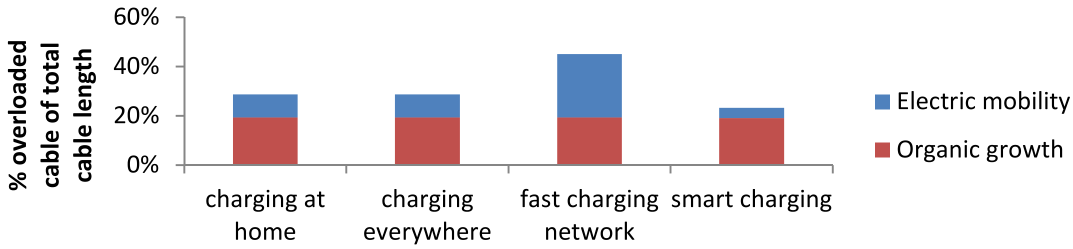


Figure 26 Case 6: Impact of different charging scenarios. Fast charging can have a large impact on the grid. Smart charging reduces the impact.

The figure above shows a significant increase of grid impact in case of a fast charging network. It can be concluded that the impact on the grid is strongly dependent on the market penetrations of different types of charging stations. Fast charger market penetration might have a significant impact on the grid. The graph also shows that the grid impact of electric mobility is significantly reduced by smart charging.

This analysis however only looked into four possible scenario options, of which two reflect extreme values for either slow, or fast charging and only one looks into smart charging. In addition, this analysis assumed a fast charging power demand of 50kW, while other power levels could be expected (possibly above 250kW). As the relative impact of fast charging stations is higher, especially in case of charging stations with power demands above 250kW, the impact is expected to be higher. In addition, this relatively larger impact per charging station also implies that the location of the charging station can be determining for the grid impact. More research is required on fast charging stations and the impact of these stations on the grid. Firstly research is required on the expected market potential of the charging stations, including both the expected rate of deployment of slow and fast chargers, and the expected power of which fast chargers will be developed. A second research recommendation is to look further into the potential of smart charging to reallocate load at peak demand. A final research recommendation is to use this research to create charging concept scenarios, like the concepts presented above. These concepts can be used to calculate grid impact for different types of charging station deployment (including both fast-slow and smart charging). The outcomes of such grid impact studies can also be used for policy makers to see the most preferable charging station deployment concept from a grid impact perspective[31].

[31] The umbrella organisation of Dutch network operators, NetbeheerNederland, already showed interest to researching charging concepts. During this thesis project Movares Energy received a quote request from NetbeheerNederland for, among other things, researching which information is required to come up with the most expected charging concept.

3.2.3 VERIFICATION AND VALIDATION OF GRID IMPACT CALCULATION

This section will evaluate the grid impact calculation in the Utrecht grid. Verification and validation are two different methods to evaluate a model. Verification applies to whether a model is made correctly. The purpose of validation of a model is to see whether the method applied is able to provide useful information and thus whether the model is correctly made.

3.2.3.1 VERIFICATION OF GRID IMPACT CALCULATION

Verification of the model looks into the internal validity of the model. The calculation used an existing grid model, which in normal cases is used by network operators for grid planning. Added to this model is an additional grid load model for electric vehicles. The addition to the model is done in accordance with the existing model. The additional vehicle load has similar characteristics as the existing household loads in the model. The model basis can thus be seen as verified, as it entails an existing model which is frequently used.

Another verification procedure is built into the Vision network analysis software. When a grid model is incorrect (for instance nodes are not connected to other loads, or cable branches are not connected to other branches), the outcome of the calculation will show no load flows in some cables or branches, or that branches operate in 'island'. The researcher continuously checked whether those situations occurred and was able to change the model when it occurred.

3.2.3.2 VALIDATION OF GRID IMPACT CALCULATION

Two types of validation exist, replicative and structural validation. Replicative validation compares the outcome of a model to the outcomes of other models to see whether the outcomes represent real life cases. Structural validation looks into the validity of the model structure. Structural validation can be checked by sensitivity analysis and by face validation. Face validation means that experts in the corresponding research field check whether the method is valid.

Replicative validation

In the previous chapter, cases from literature were presented which calculated grid impact for other grids. One of these cases [Verzijlbergh et.al., 2011a] also looked into the amount of grid components to be reinforced in case of large adoption rates of electric mobility or only organic growth. In section 3.2.1 the results of this case were already compared to this case. It was concluded that although the impact rates are higher than the Verzijlbergh case, explanations can be found in different electric vehicle shares and grid specific characteristics. It can however be concluded that the outcomes of the Utrecht case study are too limited in scale (only one municipality sub-grid is considered) to actually be able to say something about the extent of the impact of electric mobility on the grid. More grid calculations are required to do so. The case does however show how the impact can be calculated and which uncertainties are underlying the impact expectations.

Structural validation

During and after the grid calculation, experts in grid calculations from Movares Energy, network operator Stedin, and Delft University of Technology were asked for advice and checks on the grid impact calculation. These requests were introduced by explaining the model and providing insight in early results and outcomes. The criticism, discussions and questions of the experts were processed during the creation of the model and the formulation of the conclusions.

Another option for structural analysis of a model is sensitivity analysis. In a sensitivity analysis, extreme outliers in results can indicate faults in model input. In the sensitivity analysis, input values for -10% and 10% for the uncertain factors were therefore evaluated for extreme or unexplainable outcomes. When outliers were identified in the analysis input, variables were checked and reviewed. In one case a mistake in inserting input values showed. This mistake was corrected and new outcomes showed no further extreme or unexplainable values.

Structural validation for use of differentiation formula

One important assumption of the grid impact analysis, for which no earlier analyses was found in literature, was the use of the differentiation formula. As already indicated above, this formula does actually only indicate where a large share of electric mobility can be expected and was not meant to provide insight in the actual number of electric vehicles. As this formula entails an important assumption in this case study, but was not part of the uncertainties referred to in section 3.2.2, an additional sensitivity analysis is done.

The formula used in the impact calculations distinguishes different numbers of electric vehicles per city neighbourhood. In addition, the formula looks at differences in household income, property value and number of vehicles per household. Whether or not this formula makes a difference and whether a distinction between an average value of additional electric vehicle load per district, or a differing load per neighbourhood makes a difference, is tested in this sensitivity analysis. This analysis thus tests the validity of two assumptions which are included in the formula:

1. The use of correction factors for property value, household income and number of vehicles per household;
2. A differentiation between the number of vehicles per neighbourhood compared to one average value per district or city grid.

As said before, other studies did not yet make a differentiation between nodes in local grids. This differentiation provides more detailed information on local grid impact. However, including different loads per city neighbourhood is a time consuming business, compared to adding an average load to all grid nodes. In case more extensive research on grid impact is to be done, for several different grids, time consuming calculations can be very costly. The second aspect of the sensitivity analysis will look into the added value of including the differentiation. In case the sensitivity analysis shows almost no difference in outcome, it might be recommended to use the average load approach.

This additional sensitivity analysis is approached by looking at electric mobility market shares from 0%-100%. The percentage of cables to be overloaded will be compared to the same percentages in the case where the formula on vehicle adoption is used in the different neighbourhoods.

Correction factors in differentiation formula

The first analysis looks into the use of correction factors in the differentiation formula

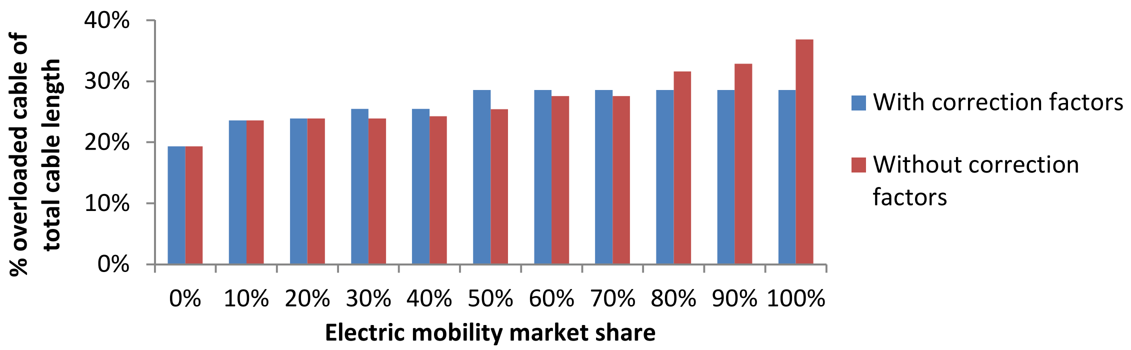


Figure 27 Sensitivity analysis input formula - with or without correction factors of property value, income and vehicles per household.

The figure shows no difference for an electric vehicle share up to 20%. For higher market shares, differences do show. In case of 30%-70%, the impact on the grid is higher for the calculations with correction factors. In case of 80%, 90% and 100% electric mobility, the impact of applying the correction factors is higher than without correction factors. These differences are relatively large when looking at the total impact by electric vehicles. A critical look at the usage of the correction factors is thus required. The factors correct for richer neighbourhoods, thus for households which are able to purchase expensive vehicles. Electric vehicles are currently far more expensive than normal vehicles, so such an assumption could apply in an early development phase. However, as referred to in appendix I.2, for large scale adoption of electric vehicles it is required that the barriers of for instance costs of the vehicles will be lowered. For later development stages, and thus for higher adoption shares, the assumptions of richer neighbourhoods having larger electric vehicle shares might no longer apply.

Since the correction factors show a large differentiation at high market shares, one can conclude that the use of correction factors for property value, higher income and number of vehicles per household can better not be included in case of high electric vehicle market share. The use of correction factors should be limited to the transition phase of electric mobility. The implications of the conclusion to exclude the correction factors for grid impact calculation on the calculations for higher market shares are that one should not take literally the outcomes of these calculations on high market shares of electric mobility. The case can only be used to compare different options, to provide insight in the effects of changing assumptions and to show an approach of calculating the impact of electric mobility on the grid.

Differentiation per neighbourhood

The second assumption looks at whether or not there is an added value in differentiating per neighbourhood.

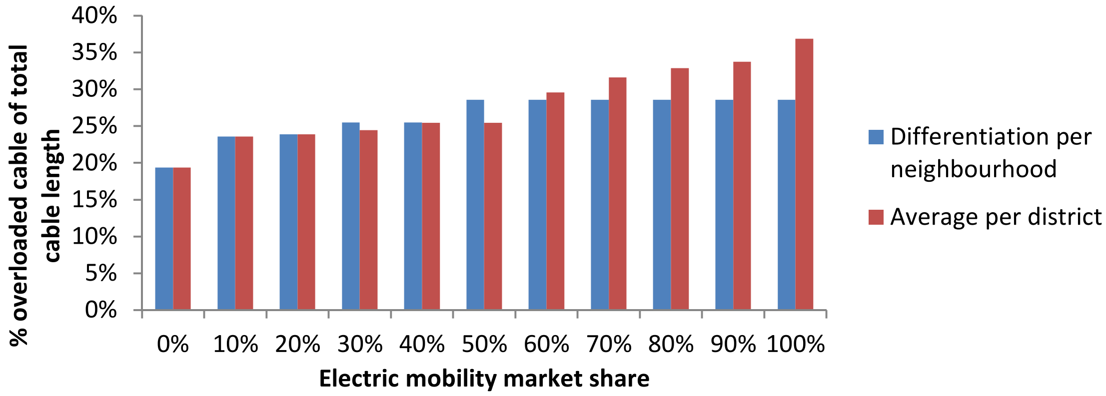


Figure 28 Sensitivity analysis input formula - differentiation of electric vehicles per neighbourhood or average number per district.

On shares up to 20%, again no difference between the impacts is visible. For higher percentages, differences do show, where the differentiation both results in higher and lower impact than the average value per district. The differentiation per neighbourhood provides a more detailed assumption on the number of vehicles and thus the amount of additional load on a node. As the outcome differs to taking average values for a larger district grid, it is concluded that it is better to differentiate per neighbourhood. As said, it is however a very time consuming business to apply these differences per neighbourhood for all different input parameters. It is thus recommended to study whether it is possible to include a scenario tool in Vision network analysis software (similar to scenario analysis in Microsoft Excel). In a scenario analysis the input values of different charging station loads could have several different values, depending on a scenario (for instance different power demands of charging stations).

To conclude the structural validation: the underlying assumptions of using the formula and a different value per neighbourhood have a significant impact on the outcome of the grid calculations. Based on this conclusion it is stated that the numbers resulting from the grid calculations should not be taken literally, especially on large electric vehicle market share. The grid impact calculations are merely meant to provide insight in the approach, uncertainties and underlying assumptions of grid impact.

3.3 IMPLICATIONS GRID IMPACT

The case above showed that there is a lot of uncertainty related to the impact of electric mobility on the electricity grid. Based on the cases in literature discussed in the previous chapter and the results on the Utrecht case it can however still be concluded that electric mobility will have an impact on the grid. This section will describe what this impact on the grid implies. First this section will describe the consequences of an exceeded capacity value. Secondly, a cost indication will be given on the grid impact in the Utrecht grid. Finally social implications of grid impact will be discussed.

3.3.1 IMPLICATIONS OF EXCEEDING THRESHOLD VALUE

A network operator does not simply have to reinforce every cable that exceeds the threshold value. First, as said, the grid components in the calculation are considered overloaded in case they exceed 60%. This threshold value is chosen as cables can exceed their maximum capacity for a limited time period and because cables have to take over load in case of component failure. These considerations mean that only in case of a failure, the grid components of about 60% load will exceed the maximum value, which is only a matter of minutes per year. In addition, as the grid is dimensioned to maximum peak demands, the threshold value is only exceeded during peak demand. The grid impact number thus assumes the worst case scenario of a peak demand during a component failure. Only then will the grid components actually be overloaded. Network operators can, however, not simply ignore the n-1 rule, as that would lead to a reduced reliability of the grid. Network operators are fined for long outage times and thus face financial consequences of such a reduced reliability. In addition, in the current society, which relies heavily on electricity, a reduced reliability is not expected to be socially acceptable. Smart grids might provide a possibility for network operators to deal with the n-1 rule while using the grid to a higher capacity. When network operators are allowed to switch off certain loads (with a lower need for reliability, which can be compensated via tariffs), overloading can be avoided. Network operators could for instance switch off charging stations in case of a grid failure and peak demand. In that case, during normal operation, the grid capacity can exceed the limit value which takes into account n-1. During grid failure operation and peak demand, the grid is able to use the capacity of the (switched off) charging stations for taking over load of a failing grid component. Smart grids could thereby loosen the n-1 rule and allow a larger grid capacity to be utilised, even during peak hours. Depending on the development of smart grids and the possibility of network operators to control load[32], not all grid components exceeding the limit value have to be reinforced.

Irrespective of the development of smart grids, also several grid components exceed a 100% load (in the 100% electric mobility case about 5% of total cable length exceeds 100%). Cables can be overloaded for a limited time period without malfunctioning, so these components might not fail immediately. Such an overload will, however, impact the life expectancy of the grid components, meaning that components will have to be reinforced in the near future (depending on the age of the component). Finally some grid components also exceed the 120% capacity utilisation load (in the base case no cables exceed 120%). These cables are loaded too much, get overheated and are automatically switched off. Such an overload of components reduces the grid reliability. These components are thus required to be reinforced. The impact of electric mobility on the grid would currently thus imply that several grid components will have to be reinforced, some due to insufficient capacity in case of grid failure, others will have to be replaced sooner than planned as higher thermal load impacts the components' life.

Network operators are required to measure grid capacity and load by hand per grid component as most components are currently not equipped with automatic communication devices. These measurements provide

[32] Such a role is not evident for network operators, as will be explained in chapter 4.

data for assessment of grid replacement. To assess whether or not replacement is required, network operators do risk assessments. These assessments are by Stedin[33] defined as being based on quality bottlenecks (disruption and maintenance), policy bottlenecks (changed policy) and bottlenecks due to capacity insufficiency (network calculations including the expected future network capacity) [Stedin, 2010a]. Developments like electric mobility affect the capacity sufficiency. In many cases, especially when many people will charge via an existing grid connection (for instance at home), network operators will have no insight in the increased load due to electric mobility[34]. Some required reinforcement might be expected beforehand due to a critical capacity of components during earlier measurements. In many cases, network operators are however expected to be confronted with the increased load in a later stage. As network reinforcements take time, they can occur after a load increase, which can lead to grid failure and thereby a lower reliability of the grid. It is thus valuable for network operators to obtain insight in the number of electric vehicles in a district. Such information can partially be based on the municipal objectives on electric mobility. It would be valuable information for network operators to translate this information to grid impact in order to locate critical grid components.

3.3.2 COST IMPLICATIONS GRID IMPACT

Adding or replacing grid components is very costly. One meter of medium voltage cable costs about €100. A medium voltage to low voltage transformer costs about €55.000, a high to medium voltage transformer about €5,5 million [van der Meer, 2011]. When looking at the outcome of the calculated impact of only organic growth or full adoption of electric mobility, where respectively 19% and 29% of the cables is overloaded, the following cost figure can be presented for replacing the overloaded cables. As mentioned before, the outcomes presented are dependent on the underlying assumptions and thus the numbers presented are merely an indication of the order of magnitude of the impact on the grid. In addition, these numbers only entail the replacement of the medium voltage cables of a small sub-grid of Utrecht, which contains about 55 kilometres of cable. For comparison, the Dutch medium voltage grid contains more than 100.000 kilometres of cable [Grontmij, 2005].

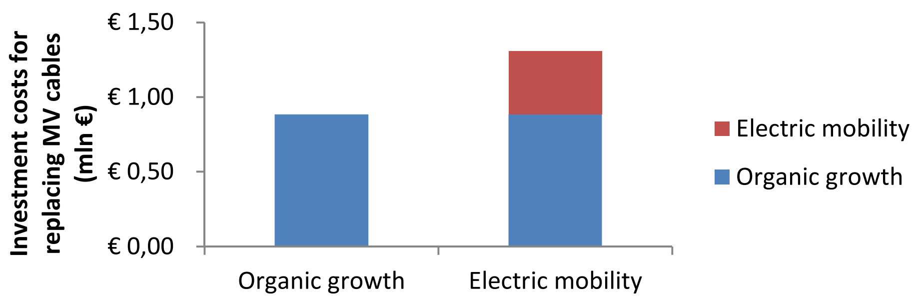


Figure 29 Investment costs for replacing medium voltage cables in the Utrecht sub-grid, investments costs for grid reinforcements rise up to €1,3 million.

Reinforcing this Utrecht sub-grid costs about a million euro. Network operators are responsible for replacement or reinforcement of the grids and thus the ones investing in it. The costs of investments by the network operators are recovered via socialised tariffs (explanation on the tariff structure will be provided in the next chapter). The costs of the impact electric mobility has on the electricity grid will thus lead to higher electricity prices for all consumers, also those people who do not own an electric vehicle.

[33] Other network operators have comparable assessments, but use different names.

[34] In case charging mostly occurs via charging stations which require a new connection, network operators will have more information as in those cases they will connect these charging stations and have insight in the number and location.

3.3.3 SOCIAL IMPLICATIONS GRID IMPACT

Grid impact is not only relevant to the network operators. Impact of electric mobility can lead to a reduced reliability of the electricity grid or to grid reinforcements. A reduced reliability is detrimental to companies (and provide nuisance to consumers) and thereby also to local governments as it might reduce the business climate of the municipality. Grid replacement or reinforcement will require the roads to be opened up to access the cables. Grid reinforcements thus causes a lot of nuisance to residents, especially in densely populated areas and thereby also to local governments. In addition, municipalities want a fast charging infrastructure deployment to stimulate electric mobility as fast as possible. Insufficient capacity of grids requires construction, and permits (with corresponding terms) to do so. Insufficient grid capacity will slow down the charging infrastructure deployment.

The socialisation of costs of impact of electric mobility has social implications. The first implication is already introduced in the section above. The costs for grid reinforcements will be recovered via socialised tariffs, thus all consumers pay for the consumers owning an electric vehicle. As said before, especially in early electric vehicle adoption phases, it is expected that richer, wealthier households will buy electric vehicles. Wealthy neighbourhoods are thus expected to be the first ones where a significant amount of electric vehicles is parked and charged[35]. Costs for network reinforcements are however not only paid by these wealthy households but by society as a whole.

Not all grids are alike. Newly built neighbourhoods have newer grids than old inner-city districts. As grids are planned for decades, network operators take into account years of demand increase. Newer grids have a larger spare capacity. Relatively new districts could possibly require a lower amount of grid reinforcements. Old inner-city districts, with old grids, are expected to require a larger amount of grid reinforcements. A difficulty arises here, as especially in the old densely build city districts, road construction is difficult and associated with a lot of nuisance. Newly built districts are in general built more spaciously and construction is less difficult. Such a difference also reflects another type of social inequality as newly built villa districts would have almost no hinder of increased grid impact, while less wealthy households in apartment buildings built in the '60s, or in inner city areas would be confronted with nuisance of construction and reduced grid reliability.

3.3.4 NEED FOR CALCULATING GRID IMPACT

The implications described above show that it is valuable for network operators to get insight in the expected amount of electric vehicles in order to anticipate to electric mobility. These expectations can for instance be based on the municipal objectives for electric mobility. By means of this network operators are able to anticipate to the impact and reinforce cables in time when necessary. In addition, options might be possible to limit impact. In order to identify critical grid components it is however important to differentiate these to local grid and load characteristics as much as possible.

This chapter presented a method to calculate grid impact based on certain penetration rates of electric mobility, using a differentiation formula. The textbox below will clearly present and summarise this method. The method can be used in practice to calculate the impact on a local grid based on electric mobility objectives and identify critical grid components. However, as presented above, several uncertainties currently affect the outcomes of the calculation. For the grid impact calculation to truly become valuable in practice, thus first these uncertainties are required to be reduced. To do so, the following research is recommended (these recommendations are also presented in the sensitivity analysis, for further argumentation, one is referred to section 3.2.2):

[35] In case electric vehicles will become a status symbol, wealthy households might even start outbidding and the number of electric vehicles might strongly increase in a short time frame.

- Research the expected development of the energy system, including expected organic demand growth and the development of distributed energy sources;
- Study the market potential and feasibility of different charging concepts and use data from pilots to monitor the simultaneity load of charging stations. Create charging concept scenarios with different simultaneity loads for different charging concepts based on this data;
- Look into component age for grid reinforcements to see whether certain city districts will be confronted with more reinforcements than others.

The textbox below shows the steps to calculate expected grid impact based on electric mobility objectives. Note that the steps are partially based on existing models. The differentiation formula for additional load by electric vehicles is added to the existing grid model. The formula merely applies for objectives in the electric mobility transition phase. For higher market shares of electric mobility, only differentiation on the amount of vehicles in districts should be used.

Steps for calculating grid impact based on electric mobility objectives

1. Differentiate municipal objectives to electric vehicles per neighbourhood, based on demographic characteristics:

$$EV_i = EV_{av} * Veh_i * \frac{HI_i}{HI_{av}} * \frac{VpH_i}{VpH_{av}} * \frac{PV_i}{PV_{av}}$$

EV_i	=	electric vehicle share in area i
EV_{av}	=	average electric vehicle market in the Netherlands
Veh_i	=	number of vehicles in i
HI_i	=	percentage higher income in i
HI_{av}	=	average percentage higher income in the municipality
VpH_i	=	number of vehicles per household in i
VpH_a	=	average number of vehicles per household in the municipality
PV_i	=	property value in i
PV_{av}	=	average property value in the municipality

The number of vehicles in municipalities or neighbourhoods can be derived from the Dutch statistic centre (CBS) [CBS Statline, 2011c]. Multiply the number of vehicles by the simultaneity load (P_s) of a charging station. For different charging scenarios, different loads apply.

2. Map municipal grid models to official city neighbourhoods and calculate the number of grid nodes in the neighbourhoods (N_i).

3. Insert the charging stations in the grid model as separate loads, where:

$$P_{chst} = P_s * \frac{EV_i}{N_i}$$

P_{chst}	=	additional power of charging station in grid node
P_s	=	simultaneity load of individual charging station
N_i	=	number of grid nodes in neighbourhood i

4. Analyse the load flow for the year in which the municipal objectives apply and the thermal load of grid components based on their location in the grid. Make sure the normal loads in the model are assigned with organic demand growth, possibly in different scenarios. First assume a threshold value of 60% thermal load. If components exceed this load, check per component the viability of this assumption (whether or not taking over of failing grid components is necessary for the n-1 rule).

5. Identify options to limit impact: see next section and the following chapters.

Note that for this method, software tool Vision network analysis is used. Vision network analysis is a regularly used tool for network operators to calculate the impact of changes to the grid (for instance addition of a new grid connection).

In case Vision network analysis is not available, also other impact calculation software can be used. The main added value of the Vision software lies in the fact that network operators use this software themselves. Existing grid models are therefore available in Vision network analysis. These existing models include grid component characteristics and topology and can be extended to include electric mobility load. In other network analysis software, the models would have to be created, which makes the calculation more time consuming. However, the same additional method to include electric vehicle load can still be used.

Downsides of the Vision network analysis software are the fact that the software is mostly based on individual changes to the grid and not designed for implementing grid based developments like electric mobility. The grid impact calculation is therefore time-consuming. However, in interviews and during the calculation, it was experienced that the designer of the Vision software, Phase to Phase, uses an iterative process to change the software based on customer needs. It is therefore expected that when demanded, the software will become more adjusted to grid-wide developments.

3.4 OPTIONS TO LIMIT GRID IMPACT

The method presented in the previous chapter provides a means to calculate expected grid impact of electric mobility. The next step is to look into technical possibilities to limit this impact. Two options are already indicated above. First it is possible to charge vehicles in a smart manner. By means of smart charging peak charging demands are reallocated to off peak hours and the grid capacity can be used in a more efficient way. A second option is to locate charging stations based on the ability of the grid to deal with additional load.

3.4.1 SMART CHARGING TO LIMIT GRID IMPACT

The grid calculations show that smart charging has a limited impact on the grid compared to ‘dumb’ charging. Smart charging (in the simplest form the delay of charging in case of insufficient grid capacity) will make more efficient use of grid capacity by displacing peak demand towards off peak demand. As explained in the system description in section 2.1.3.3, multiple smart charging options exist. This section will look into possible devices which can be used by network operators or other parties to limit the impact on the grid.

An example of a smart charging device is a device where the consumer is asked to enter the time of departure (similar to a parking meter), allowing the device to charge as cheap as possible. Network operator Enexis developed a similar device. This device allows consumers to communicate to the charging station via a smart phone. When plugging in the vehicle, consumers can indicate when they want to leave and for how many kilometres they want to charge. A tariff structure, compensating for charging delays, can be agreed on with the consumer. The network operator can then control how much and when the vehicle will be charged based on the data on other vehicles charging simultaneously and the capacity of the grid [Enexis, 2011b]. This concept is demand controlled as it stimulates consumers via financial incentives. Consumers can choose to pay more in case they do not want their charging to be delayed. The device has also load control characteristics as the network operator has control over when to charge. The consumers in the end however choose whether they allow that to happen.

The New Motion developed a load control device 'Moet je Watt' which automatically adjusts the charging speed to the capacity of the grid connection. Such a device might already be profitable for existing connections if a connection will require reinforcements due to electric vehicle charging. If households or companies are faced with insufficient connection capacity due to charging stations of electric vehicles, network operators could provide them with the option to either reinforce their connection, or install a smart charging device. The current The New Motion device costs €750 (but as the devices are still new, a cost decrease can be expected) [Thenewmotion, 2011], a new grid connection €570-€858 (depending on the required capacity) [Stedin, 2009a]. In some cases smart charging at home could thus be profitable.

A survey by Grid for Vehicles [Bunzeck et.al., 2011] shows that consumers with a private parking spot are more interested to join an automatic delaying scheme than consumers which are dependent on public charging facilities. In case of public charging stations, such a delaying application can thus be a little more complicated. Public charging stations are expected to be utilised for shorter periods (making the impact of a delay larger) and consumers might perceive the delay as a malfunction of the charging station. For public chargers more advanced (demand control) chargers, like the Enexis device would thus be more applicable.

Public charging stations have a frontrunners role in charging stations. For many early vehicle adopters, the current public charging stations will be an important charging possibility. Smart charging in public charging stations can therefore set an example for other charging stations and make vehicle owners accustomed to smart devices.

3.4.2 ASSESSING CHARGING STATION LOCATION TO LIMIT GRID IMPACT

The grid calculations showed critical cables in the Utrecht grid. In some cases it can be beneficial to connect charging stations to other grid cables in order to avoid reinforcement. Changing the location of a charging station is not possible for most single slow charging applications (home chargers cannot be located elsewhere), but it might be valuable for fast charging stations or stations with multiple charging spots. Not only can the location of fast charging stations be changed more easily, these charging stations also have a significantly larger individual impact on the grid[36]. The same accounts for large numbers of charging stations at the same location, for instance at large parking garages (although for these charging stations the location might be changed less easily). For assessing the location of charging stations, this thesis will refer to high power charging stations[37].

Basically two options to assess the preferable location of charging stations exist. Firstly, the grid calculations did not only show that certain cables were overloaded, but also that mainly the cables at the beginning of network branches are overloaded. As the most critical cable in a grid branch determines the capacity of the entire network branch, the additional load in the cable branch is limited by this first cable. These cables might

[36] Note however that when looking at low voltage grids, the location of slow charging stations could be decisive. As the calculations mainly focused on medium voltage grids due to data availability this section will also only look at medium voltage grids.

[37] Note that an alternative to changing the location is to change the type of charging station. In case grid capacity appears to be insufficient for a fast charger, a decision can be made to change the charging station to a lower voltage.

have to be replaced even for low electric mobility shares or in case of only organic growth. It can therefore be beneficial to first reinforce these cables and locate the charging stations at the beginning of network branches. If these cables are replaced by larger capacities, they will be able to cope with the increasing demand. Other cables further along the branch will then not have to deal with an increasing demand. A second option is to try to avoid all reinforcements and thus to locate charging stations at the cable branches with the highest ability to deal with charging station demand. Note that this option might not always be applicable as nearby branches with sufficient capacity will not always be available. The figures below display the two concepts of location assessment, where the first concept shows that cable reinforcement of three cables can be limited to reinforcement of one cable. In the second option the charging station is connected to a nearby grid branch with sufficient capacity.

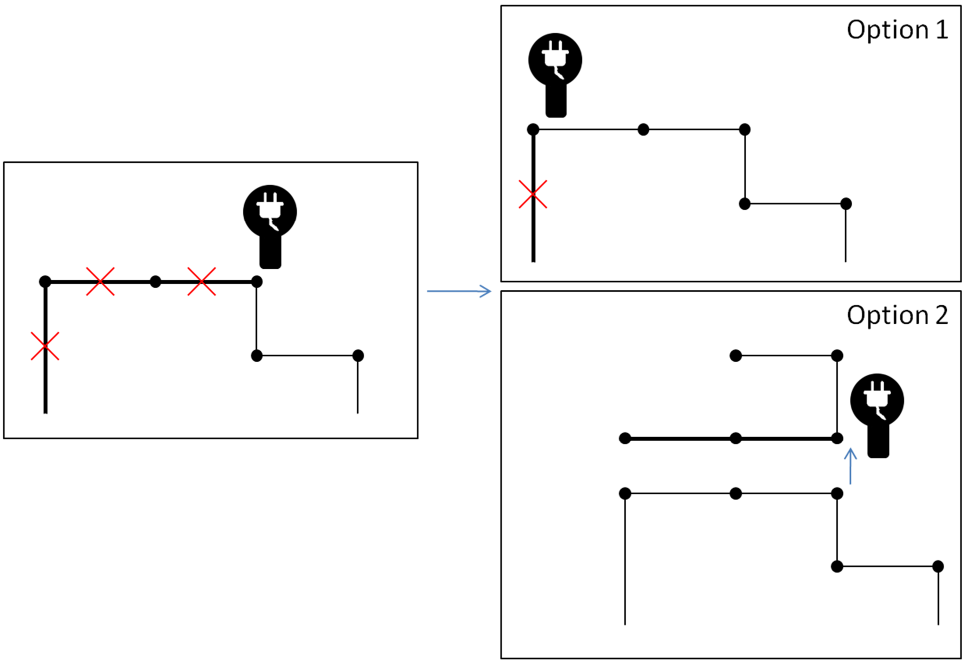


Figure 30 Two options to change the location of high power charging stations based on grid capacity. In the first option the charging station is located towards the beginning of the grid branch thereby limiting the amount of grid components to be reinforced. In the second option the charging station is connected to a nearby grid branch with sufficient capacity.

3.4.3 OTHER OPTIONS TO LIMIT GRID IMPACT

Other options to limit grid impact are also possible, for instance energy savings. The calculations above showed that a decrease in demand can compensate for the additional load of electric mobility (see section 3.2.2). A second option is to feed in distributed (renewable) energy sources. Distributed energy systems arrange energy flow on the lowest grid level. Electric vehicle home charging load could for instance be compensated by solar panels on the household roof.

These options are associated with their own complexities. Firstly, these options are dependent on willingness of households to save energy or invest in distributed energy systems. These options thus require stimulating policies, separate from the electric mobility policies. Secondly, there is a matter of time dependency for both options. In case of energy savings, these energy savings should especially apply during electricity peak demand, not to the average demand. The average electricity demand might decrease, but for network planning the peak demand determines the required grid capacity. In case of distributed energy production there is a question of time dependence of the production and electricity use. Many vehicles will charge after 6PM, when people arrive at home. During winter time when the sun sets around 5PM, solar panels will not be able to provide the solar energy for charging the electric vehicle. Either households will thus require energy storage facilities, or the network operators will not be able to depend on the production capacity. The grids would in that case still be required to be dimensioned without the distributed production capacity, and the network operators would thus still be required to reinforce the grid in case of grid impact.

These options are thus associated with their own complexity, which does not directly relate to electric mobility. Therefore only the two options presented above will be considered as technical options to limit grid impact.

3.5 CONCLUSIONS GRID IMPACT

Grid impact studies from literature have shown a variety of assumptions, approaches and outcomes. A grid impact analysis in this chapter shows how grid impact calculations are done and what the impact of electric mobility is in the municipality of Utrecht. The case study used a network planning software tool of electricity network operators to calculate the impact of large scale adoption of electric mobility in a small sub-grid in the municipality of Utrecht. For these calculations an existing grid model was used, which was supplemented by a new model determining additional load for electric vehicles based on local demographic characteristics.

The calculations showed that 19% of the grid needs to be reinforced by 2040 due to normal organic growth, and 29% of the grid components in case of full adoption of electric vehicles. In the considered grid, critical grid components were identified. The possibility to identify critical grid components can help to see which neighbourhood grid can, and which cannot deal with a load increase due to electric mobility. In addition, the identification of grid components can help to see where charging stations with a large power demand can be plugged in without overloading the grid.

The impact of electric mobility on the grid is affected by vehicle user behaviour and indirectly by municipal adoption incentives and charging station deployment strategies. These factors are translated into several uncertainties for grid operation. The effects of these uncertainties on grid impact of electric mobility were tested in a sensitivity analysis.

- *Effect of different electric vehicle adoption shares.* The impact of different shares of electric mobility shows more or less the same impact from 50% to 100%. In addition, a significant impact already occurs at 10%.
- *Effect of an increase in total vehicle fleet.* When increasing the total amount of vehicles in the district (with an electric vehicle share of 100%), one sees a significant increase of impact for 10% additional vehicles. This large increase is possibly explained by the fact that at 100% electric vehicle adoption, a large amount of cables is loaded up to a critical capacity. An additional load thus causes these cables to become overloaded.
- *Effect of a varying organic growth.* Lower organic growth rates have lower impacts. Electricity demand reduction can compensate a large share of the additional load of electric mobility. The calculations also show that with lower demand rates, the relative impact of electric mobility increases. This increase of impact implies that a number of grid components has a very limited overcapacity, which will be overloaded in case of a small demand increase, either caused by organic growth, or by electric mobility. Other grid components have sufficient capacity to deal with both.
- *Effect of other charging scenarios.* Four different charging scenarios were analysed: only slow charging, mixed slow and fast charging, mainly fast charging and smart charging. The scenario with mainly fast charging stations showed a large impact on the electricity grid. It is also concluded that, as high power charging stations have a relatively large individual impact, the locations of the charging can be determining for grid impact. The case also shows that smart charging, as expected, limits the impact of electric mobility on the electricity grid.

The analysis on the uncertainty factors show that the behaviour on consumers and municipalities can strongly influence grid impact. The behaviour of those actors, together with other factors, create a large uncertainty to the grid impact to be expected.

A validation of the model show that it is valuable to calculate the grid impact based on a differentiation formula on the number of vehicles in a city neighbourhood and (in the transition phase) on demographic characteristics. An average additional load for electric vehicle electricity demand does not reflect the additional demand of the number of vehicles located in a certain neighbourhood. Correction factors for higher income, property values and number of vehicles per household enable to identify neighbourhoods with a relatively large amount of vehicles and thus higher additional load. Additional load of electric vehicles should therefore be based on the number of vehicles within the grid area, corrected for demographic characteristics. Testing the use of the correction factors in the differentiation formula however shows that large shares of electric mobility strongly affect the calculated impact on the grid, while the formula is less validity for larger market shares. It is therefore proposed to merely use the formula in the transition phase of electric mobility.

The implications of grid impact of electric mobility are threefold:

- Grid impact can lead to reduced grid reliability if networks are not reinforced in time. Reduced grid reliability can cause a negative effect to the business and living climate of a municipality;
- Grid reinforcements in order to retain grid reliability is associated with high social costs, meaning that every electricity user will pay for the costs caused by electric vehicle users;
- It is difficult and costly to reinforce grids in inner city area, while these grids are expected to be more vulnerable to replacement as they are older than the grids in new city districts.

In order for network operators to anticipate to grid impact in time, there is a need for accurate estimation of grid impact and the location of grid impact. More research on possible energy scenarios and charging concepts is required in order to allow more accurately grid impact calculations. However, when these knowledge gaps are reduced, a general approach could be used to calculate the impact of electric mobility on power grids.

Additionally, there are several options to limit the impact to the grid. The first option is to apply smart charging. Smart charging can allocate charging load to off-peak hours, thereby limiting the required capacity for maximum load peaks. Smart charging devices exist, although they are not widely available on the market yet. A second option to limit grid impact of electric mobility is to base the decision on the location of high power charging stations according to the capability of the grid to deal with the additional demand.

4. INSTITUTIONAL ANALYSIS

In the system analysis in chapter 2, relations of the socio-technical system were identified. The previous chapter looked into the technical impact of electric mobility on the electricity grid and thereby into relation I, between the technical and actor system. This chapter will analyse how actors are affected by the impact, and whether the actors are capable and willing to limit the impact of electric mobility on the grid. This section will thus translate an impact in the technical system to actor behaviour in the actor system and look into interaction II.

In the first and second chapter of this thesis, a difficulty is identified in the incentive structure for limiting grid impact. This difficulty is caused by the roles and obligations of the municipalities and network operators. For analysing where exactly the problem lies and which options exist to deal with the incentive structure, it is important to look into the underlying reasons why actors act in a certain way. Underlying values for actor behaviour are often described by means of institutions.

In literature many definitions on institutions exist. A very broad definition is provided by Hunthington (1968, p.12) who describes institutions from an external point of view as a "stable, valued and recurring pattern of behavior". A more specified definition is described by Hodgson (2006), who defines "institutions as systems of established and prevalent social rules that structure social interactions". In the definition of Hunthington, institutions can apply to an individual, while Hodgson describes institutions as social rules applying to interaction between actors. Koppenjan and Groenewegen (2005) describe institutions as the set of rules (both formal and informal) by which actors act and are involved in a (technical) system. Institutions in their definition thus describe how and why actors act in a certain way, related to (technology) changes. Koppenjan and Groenewegen (2009) also adjusted a framework on different levels of institutions as is displayed and explained in chapter 1 in figure 1. In this framework also technology is assigned with an influential role towards actor behaviour.

The definitions above differ in broadness, but in general all describe that institutions are rules underlying actors' behaviour, whether applying to individuals or in social interactions. This chapter will look into two actors and will thus especially focus on institutions as a social interaction. In addition, this chapter will look into the influence of technology on actors and vice versa. The definition and framework of Koppenjan and Groenewegen refers specifically to the role of technology on institutions. Therefore, this framework will be adopted as a framework to structure the institutional analysis. Using the framework of Koppenjan and Groenewegen, the institutional analysis will provide insight in three aspects related to the interaction of the technical and social system of electric mobility:

1. The institutions will help to analyse why actors act in a certain way and how they are expected to act to technology changes. This insight can also help to create expectations how the actors will interact with each other;
2. The institutional analysis is meant to provide insight in the relation between the technical system and municipalities and network operators. The institutional analysis will look into how the technical system can be (or is) constrained by institutions;
3. Electric mobility is a relatively new development. Not all institutions are (yet) fixed. The analysis will therefore also go into possible changes in the institutions in order to change the technical system.

The four layer model of Koppenjan and Groenewegen (2009) describes four different types of institutions, namely informal institutions, formal institutions, institutional arrangements and interaction between actors. As figure 31 shows, all different blocks of the model will be described below for municipalities and network operators. In case of municipalities, this description is based on interviews, plans of actions and news items. The description of the network operators is based on meetings or interviews with the network operators and the network operators' websites. After discussing each institutional layer for both municipalities and network operators, the most important aspects of the institution, technology or process are discussed. These sections will combine the different perspectives of the actors on the corresponding block and look into possible options for dealing with grid impact. At the end of each section the main conclusions drawn from a certain institution will be summed up.

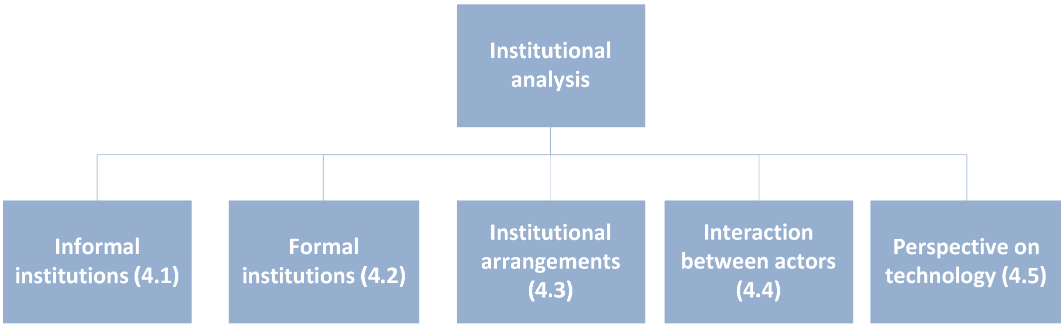


Figure 31 Institutional analysis - chapter structure

Below first the informal institutions related to electric mobility for municipalities and network operators will be described, followed by the formal institutions on electric mobility. After the formal institutions, institutional arrangements and informal interaction between the actors will be described. Finally the role of technology in the institutional framework will be discussed. At the end of this chapter the most important conclusions of the institutional analysis will be summarized.

4.1 INFORMAL INSTITUTIONS

Informal institutions describe the unwritten norms and values which underlie the actions of the actors. As municipalities and network operators are both public organisations, they deal with public values which underlie their actions. Bozeman (2007, p.13) describes public values as:

"A society's 'public values' are those providing normative consensus about (a) the rights, benefits and prerogatives to which citizens should (and should not) be entitled; (b) the obligations of citizens to society, the state and one another; and (c) the principles on which governments and policies should be based."

This definition provides a broad perspective of the public values municipalities and network operators face. Municipalities and network operators however have different tasks and thus deal with different values.

4.1.1 INFORMAL INSTITUTIONS MUNICIPALITIES

The quote above shows that public values describe the principles on how governments should do their tasks. Municipalities have a numerous number of tasks, varying from helping citizens at the public office, to creating an energy or spatial planning policy.

When looking at electric mobility, public values are related to the associated tasks (mostly divided into organisational departments) of the municipality. In this case, energy, environment, mobility and spatial planning are considered. Relating to these tasks, the following public values are identified:

- **Liveability** of the municipality environment;
- **Sustainability** of energy and mobility;
- **Low cost** of measures to stimulate electric mobility;
- **Facilitate** the sustainable citizen.

Sustainability of transport, in the sense of limiting CO_2 emissions and increasing air quality, appears to be the main driver of municipalities to actively stimulate electric mobility. Sustainable energy systems are often described using the Trias Energetica: reduce energy demand, use sustainable energy sources and if necessary use conventional fuels as efficient as possible [Lysen; Duijvestein, 1996]. As part of their sustainable energy and environment strategy, the municipalities have also committed to sustainable mobility. When looking at mobility from a Trias Energetica perspective, three types of sustainable mobility systems can be identified:

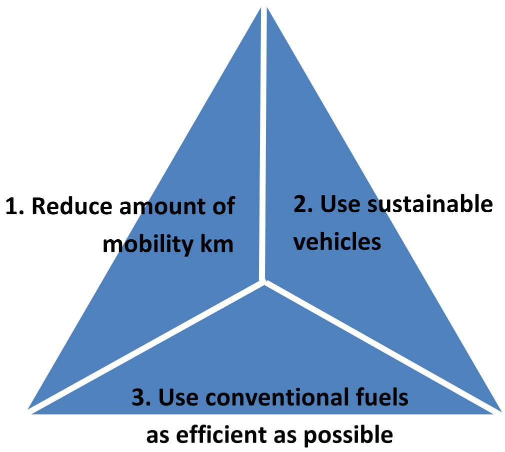


Figure 32 Trias Energetica adjusted to mobility, showing three ways to make mobility sustainable, one of which is sustainable, for example electric, vehicles [adjusted from Lysen; Duijvestein, 1996]

Electric mobility is a sustainable vehicle technology. Other sustainable vehicle technologies are biofuel and hydrogen vehicles. Both have several disadvantages. Biofuels for instance still emit local emission. Hydrogen requires a completely new infrastructure and requires an additional production process and is therefore only seen as a long term vehicle transition technology [Hanscke et.al., 2009].

Sustainability of both the energy and mobility sector is possible, but it comes with costs of measures to stimulate more sustainable energy and mobility technologies. Electric vehicles are more expensive than conventional vehicles. In addition, investment is required to deploy charging infrastructure.

The final value mentioned above, is to facilitate the sustainable citizen. Due to the increasing attention to electric mobility, some consumers are already interested in electric vehicles (the early adopters). Municipalities have a decisive role in deciding whether or not a charging station can be installed on a certain location due to public property ownership. Municipalities thus not only *stimulate* electric mobility for air quality and CO_2 objectives, but are asked to *facilitate* the consumer interested in electric vehicles.

4.1.2 INFORMAL INSTITUTIONS NETWORK OPERATORS

A network operator serves public interests by transporting and distributing energy. Public values are thus underlying the network operators' activities. In the energy sector, basically three public values are emphasised, namely reliability, affordability and sustainability [Ministry of Economic Affairs, 2008].

Reliability of the electricity network refers to security of supply and security of delivery. Security of supply means that in the long term the network operator will have sufficient capacity to deal with demand and supply. Security of delivery refers to short term reliability, meaning that the electricity network is able to deal with short term fluctuations in demand and supply. Both reliability values relate to the availability of sufficient grid capacity. Reliability of the electricity network is embedded in the legal framework of network operators, as will be discussed below.

The public value of affordability of the network refers to the fact that the costs of a network operator are socialised. Technically, network operators face no financial risk, as the companies are fully regulated. In case costs of the networks appear to be extremely high, the network operator would be repaid via public tariffs. Legislation (see section 4.2.2) is therefore created by the Dutch state which enforces network operators to operate cost efficient.

Reliability and affordability are strongly embedded in the legal framework of the network operators,. Sustainability is mostly associated with the production of sustainable energy sources, which is not a network operators' task. For network operators sustainability lies in the capability to feed in decentralised fluctuating renewable energy sources and to deal with a changing energy environment.

Electric mobility and the corresponding additional load can reduce the reliability of the grid in case of insufficient capacity leads to component overload. If reinforcement to the grid is applied to deal with this insufficient capacity, affordability of network operation is affected.

4.1.3 DISCUSSION INFORMAL INSTITUTIONS

When looking at the effect of electric mobility on public values for the two actors, one can conclude that municipalities gain value benefits to sustainability and liveability, and a (limited) effect on affordability. Network operators are mainly confronted with a negative effect on cost and reliability of the electricity network. Both organisations are public organisations. The costs and benefits are thus both public. The costs associated with grid reinforcements due to electric mobility will be socialised. For society, it would be beneficial if these costs are kept as low as possible and benefits as high as possible. To take societal costs and benefits of electric mobility into account, both municipalities' and network operators' costs and benefits would have to be considered. However, municipalities and network operators are accounted for their own operation in cost efficiency, sustainability and other public values (mostly on cost efficiency). They are therefore focused on their own operation and have no incentive to look at the societal optimum. One could speak of a value allocation conflict in these incentives, as the values of costs are not in the same hands as the benefits. Due to the incentives for the actors to focus on their own operation, social costs due to network impact are not considered in electric mobility policy making.

Another difficulty in solving the different effects on the public values of municipalities and network operators is inherent to informal institutions. Informal institutions are underlying values and norms of society. They are thus not easily changed. If informal institutions change, this is often related to incremental trends of society, to sudden developments which change the world view, or to a change in one of the other blocks in the four layer model of institutions (another form of institutions, a process or technology development) [Koppenjan, Groenewegen, 2005]. A formal link between the municipalities and the network operator exist, which could help to deal with the public value allocation conflict. Network operators are owned by the local governments. During the privatisation of the electricity market, the decision was made to retain a public ownership of the electricity networks (in contrast to the production and retail companies) to safeguard public values [Stuurgroep visie netbeheerder, 2011]. Municipalities are thus (at least passively) involved in the network operators' public values. As shareholding is a form of institutional arrangements, it will further be discussed below.

4.1.4 MAIN CONCLUSIONS INFORMAL INSTITUTIONS

- Municipalities benefit from electric mobility by increasing liveability (air quality) and sustainability. Network operators are faced with costs of electric mobility due to the impact on the grid.
- A conflict occurs in public value allocation;
- Other institutional layers can possibly deal with a public value allocation conflict

4.2 FORMAL INSTITUTIONS

Formal institutions refer to legislation and regulation. Legislation and regulation can be an important driver of actor behaviour. Formal institutions can also constrain the acts of actors. Below the formal institutions of municipalities and network operators related to electric mobility will be discussed. Firstly the section will discuss the institutions which relate them to electric mobility. Secondly, this section will describe the role of the actors in electric mobility. After the description on the formal institutions of both actors, the differences will be discussed.

4.2.1 FORMAL INSTITUTIONS MUNICIPALITIES

Formal institutions are an important push factor for municipalities to stimulate electric mobility. Municipalities have to comply to European environmental targets, both for climate change and air quality. This section will therefore shortly look into this legislation and regulation pushing municipalities towards electric mobility. This section will end with a description of the formal role of municipalities in electric mobility.

4.2.1.1 FORMAL INSTITUTIONS PUSHING MUNICIPALITIES TO ELECTRIC MOBILITY

Transport is a large contributor to both CO_2 and local emissions. As electric mobility emits less CO_2 and no local emissions, it can help achieving targets for both air quality and CO_2. The legislation and regulation to which municipalities have to comply will be discussed below.

Local air quality

The European air quality directive [European Parliament and the Council, 2008] states targets for different types of emissions[38]. These emissions affect the local air quality (in contrast to CO_2 emissions, which has a global effect) and are therefore also referred to as local emissions.

To comply with these European rules, the Netherlands transposed the European regulation air quality in the *Wet Milieubeheer* (Environmental Management Act). European air quality policy already started in the 1970's and most national measures have already been taken. For instance electricity plants are obliged to clean their exhaust gas. However, on a local level (especially in urban areas), air quality problems remained. Part of the national air quality policy is thus delegated to local governments [NSL, 2009].

The European air quality standards had to be met and were reinforced in 2010 [CBS et.al., 2010]. Many successful measures have been taken to improve air quality. Municipalities for instance enforced environmental zones for trucks and vans in the inner-city areas and most emission standards were met. Lowering the emissions of NOx and PM_{10} remained problematic and the Netherlands got postponement of the deadline,

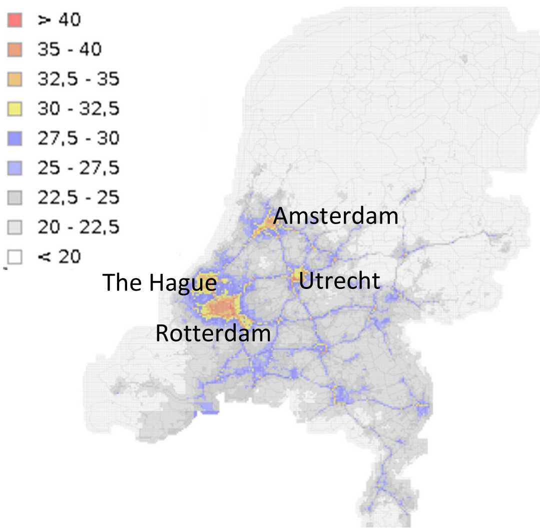


Figure 33 Background concentration NO_2 (norm value NO_2 for yearly average: 40 µg/m^3). Based on remediation tool of the national air quality cooperation (NSL) [Goudappel Coffeng, 2009]

[38] Sulphur oxide (SO_2), nitrogen oxides (NO and NO_2, also referred to as NOx), ozone (O_3), dust particles ($PM_{2,5}$ and PM_{10}), Lead (Pb), Benzene (C_6H_6), Coal monoxide (CO), Arsine (As), Cadmium (Cd), Nickel (Ni), Benzopyrene (B[a]P). For an overview of the norms see: www.compendiumvoordeleefomgeving.nl (in Dutch) [CBS et.al., 2010].

2011 for PM_{10} and 2015 for NO_2 particles. The picture below shows the background concentration of NO_2 in 2011. In this case only NO_2 is considered as the contribution of road transportation on NO_2 emissions is largest and because problems with PM_{10} particles are no longer expected after 2011 [Passier et.al., 2009, p.35].

In the introduction, the large municipalities are assumed to have the largest motivation to stimulate electric mobility. When looking at the figure of NO_2 background concentration above, four large municipalities can be identified as exceeding the NO_2 targets (of 40µg/m^3). The four large municipalities with air quality problems are Amsterdam, Rotterdam, The Hague and Utrecht. The Hague does currently not yet have an active electric mobility policy [Gemeente Den Haag, 2011] and was therefore not selected to be considered in this thesis. The other three municipalities are.

Despite past improvements, busy roads still cause critical areas with exceeding emissions [PBL, 2010]. According to recent research of the audits of the large municipalities in the Netherlands the air quality will not meet the standards. Large contributors to these problems are internal combustion engine vehicles [Rekenkamer Rotterdam, 2011].

CO_2 reduction

To reduce the effect on the climate, the EU has set targets to reduce CO_2 emissions by 20% in 2020 and by 80-95% in 2050. The Netherlands has to achieve a CO_2 reduction of 16% in 2020 [Directorate-General for Energy, 2011]. Although climate change and CO_2 reduction is mostly a national and international problem, there is also a role for municipalities to limit CO_2. About 80% of CO_2 emissions are expected to be produced in cities [Gemeente Utrecht, 2011b]. Many municipalities have therefore set individual CO_2 objectives.

Table 8 Municipality CO_2 objectives

Municipality	Objective	Source
Amsterdam:	CO_2 reduction of 40% in 2025 compared to 1990; Internal municipality organisation climate neutral in 2015	NieuwAmsterdamsklimaat.nl, 2009
Rotterdam	CO_2 reduction of 50% in 2025 compared to 1990;	RCI, 2011b
Utrecht	CO_2 reduction of 30% in 2020 compared to 1990; Climate neutral in 2030.	Gemeente Utrecht, 2011b

In the Netherlands, about 17% of total CO_2 emission is caused by road transport [CBS Statline, 2011a]. Electric mobility could thus significantly contribute to the achievement of these CO_2 objectives.

4.1.2.2 FORMAL ROLE OF MUNICIPALITY IN ELECTRIC MOBILITY

During the interviews with the municipalities of Amsterdam, Rotterdam and Utrecht, the question was asked which role in electric mobility the municipalities have and are expected to have in the future. All municipalities replied with more or less the same answer. Currently municipalities are actively stimulating electric mobility in order to support an accelerated development of electric vehicles. These policies are based on the fact that when barriers for adoption are low enough for market players to come into play, electric mobility will be left to the market. Municipalities will in that case withdraw from their stimulating role. However, there is still a formal role left for municipalities to play. As many consumers in the city will at least partially be dependent on public charging stations, there is a role for municipalities in spatial planning. Public charging stations are located on public ground, which is municipality's property and thus a legal task to the municipality. If parties want to make use of public ground to install a charging station, they will have to request the municipality for *Opstalrecht* (Lease Rights) [E-laad.nl, 2011a]. The municipalities will thus have a facilitating role in assigning locations for charging stations, even when electric mobility is left to the market. Leasing rights provide an opportunity for municipalities to set requirements for the charging stations, even when the deployment of the infrastructure is left to the market.

Currently the municipalities are however still in an active stimulating role, where they install charging stations themselves (via a public tender). In this role, municipalities decide on the type and locations of the stations. When the stimulating policy will shift towards a facilitating role will depend on the development of the electric mobility market (will market parties take over the municipalities' role) and the political willingness to keep investing in sustainable solutions like electric mobility.

4.2.2 FORMAL INSTITUTIONS NETWORK OPERATORS

Network operators are state-owned, regulated companies. Their tasks and obligations are laid down in the Electricity act. This section will look into the legal framework of network operators and provide insight in the formal role of the network operator.

4.2.2.1 LEGAL FRAMEWORK NETWORK OPERATOR

The Electricity act describes the tasks and obligations of network operators[39]:

- Guarantee safety and reliability of electricity transport in the most effective way, taking into account developments of renewable electricity, energy savings and demand management;
- Retain sufficient reserve capacity to deal with demand and supply fluctuation (network planning);
- Construct, restore and renew networks;
- Provide those who request with a connection to the grid.

The responsibilities and obligations of network operators are further laid down in secondary legislation by means of codes. Two technical codes, namely the Grid and Metering Code describe the conditions of maintenance and operation of the grids and system services to be done. In addition, the technical codes describe the responsibilities of network operators in case of grid failure. Network operators are for instance obliged to a compensation arrangement in case of long outage times. A third technical code, the System code, only applies to the national high voltage grid operator. This code describes actions the transmission system operator can take in order to balance demand and supply on the high voltage grid.

A Tariff code determines how network operators can recover investment costs. The tariff structures should provide sufficient income to cover investment costs, but at the same time incentivise efficiency of investments. The tariffs are determined by yardstick regulation. The yardstick is determined by the aggregated average costs per unit outcome of all network operators. The advantage of yardstick regulation is the stimulation of cost efficiency. A disadvantage of this regulation is that not all network operators receive reimbursement for their costs and are therefore stimulated to invest in a conservative manner. To avoid that cost efficiency is improved at the expense of quality, a quality factor is included in the tariff structure. The quality factor includes the number of failure minutes and thus stimulates grid reliability [NMa, 2010].

Network operators believe that the current national regulation does not provide the right incentive to network operators to invest in smart technology and anticipate to new developments [Enexis, 2011c]. The income (tariffs) of network operators is based on their past expenses and benchmarked between the network operators. Planning ahead to deal with electric mobility is therefore inefficient, because that makes the costs of that network operator higher than those of other network operators and thus results in uncovered costs exept when the network operators all invest at more or less the same time.

[39] Electricity Act *§ 2. Art 16 and § 4. Art 23*

4.2.2.2 FORMAL ROLE OF NETWORK OPERATOR IN ELECTRIC MOBILITY

Currently network operators only have a formal role in connecting charging stations to the electricity grid. Network operators are by law not allowed to be involved in commercial activities[40]. The difficulty here lies in the definition of 'commercial'. Stichting E-laad has been installing charging stations, which could be defined as a commercial activity. Governments could also restrain the charging stations from the commercial sector and make it the responsibility of network operators to install and maintain charging stations as part of their network.

In 2010, a discussion was initiated on market roles in electric mobility. These roles relate to the operation of charging stations and the corresponding tasks. Two reports were written, one commissioned by parties in the electricity sector (the umbrella organisation of network operators (Netbeheer Nederland) and of the energy companies (EnergieNed)) [Accenture, 2010] and one commissioned by the national government (the ministry of Economic Affairs, the ministry of Traffic and the Formula E-team) [Boekema et.al., 2010]. Both organisations identify new roles for electric mobility, but do not fill in who should fulfill these roles. Several new roles for electric mobility are identified (differences between the reports exist, mainly in naming): charging station operator, charging station provider (a service provider to the electricity distributor), charging station owner[41] and a service provider for consumers. The market models presented in the reports show different combinations of roles. The formal role of the network operators in all market models is that of connector of the charging station to the grid. However, as the other roles are not yet filled in, possibilities exist to get involved in other tasks as well. The network operator could become the charging station owner. Market parties can in that case compete on the services on the charging stations[42]. Other parties might disagree on this role as there can also be a possibility for competition between charging stations.

The market model options associated with charging station ownership basically describe two different economic models for infrastructure. In the first option, competitors compete *on* the network of charging stations, which is also the case in the electricity sector itself, where the network is a state-owned monopoly and competition occurs on production and delivery of electricity. The second option describes competition *between* networks, which is the case in for instance the internet infrastructure (cable and adsl cables compete). The second option is only viable in case different network types can actually compete and when the infrastructure does not create a large barrier to enter the market. Both requirements seem to apply to electric mobility charging stations. It is possible for different types of charging stations (for instance fast and slow) to compete. In addition, the costs of charging stations are relatively low, as the underlying infrastructure (the electricity grid) is already available and the investments would thus entail the physical charging stations. Competition is thus already possible with low investment costs. Moreover, one could compare charging stations to the current fuel station concept, where also multiple parties compete. It is thus concluded that, based on these competition principles, one could expect a competitive role between charging stations. As the current Dutch liberal government might also prefer market options above regulated options, such an outcome might therefore be viable. However, networks are often associated with network externalities [Frischmann, 2005]. Allowing market parties to deploy charging station infrastructure, without allowing network operators to have a say in the type and location of charging stations depending on grid limitations, could lead to higher social costs of grid impact. Due to this effect of the charging station on the electricity network, one could consider that it is better to include charging stations in the definition of the electricity grid, thereby allowing network operators to maintain and operate the charging stations. The market model discussion is thus a

[40] Electricity Act *§ 2. Art 17*

[41] Not included in as a separate role in the Ministries and Formula E-team report

[42] Network operators recently obtained a similar role in the deployment of smart meters. The metering market used to be open, but in the deployment of smart meters, network operators by law obtained a monopoly position [Akkerboom et.al., 2011, p.48].

consideration between network externalities and competition possibilities. The difficulty here is that the market model does not only involve the network operators' interest, but several parties are involved from different industries (the automotive industry, energy sector, governments, ICT industry and vehicle and service providers). There is not only a consideration between the network operators' interests and the competitors for charging stations. Several different actors play a role in the discussion, making the outcome very uncertain.

The market model discussion is continuing and the discussion of the role of competition in the market is not yet decided. Innopay wrote a roadmap which describes a process plan to come to a market model [Jansen, Lycklama, 2011]. The roadmap entails three phases, namely preparation (come to a program of requirements), development market model and deployment market model. The Innopay report expects the three phases to take 15 months in total (of which three months of preparation). The report was written in May 2011 and during the writing of this thesis, the parties were still in the starting phase of phase 1. It can thus be expected that the discussion on the market model will take at least another year.

While the discussion on formal charging station roles is continuing, the cooperating foundation of network operators, E-laad, is installing charging stations throughout the Netherlands. On those stations, E-laad is fulfilling the task of ownership, maintenance, operation and service provider. When looking at the legal framework, one could question the legitimacy of this role. The network operators not only install the charging stations (of which the competitiveness could be questionable) but also do possible commercial services on the charging stations. Stichting E-laad however continues to deploy infrastructure and they currently do not face a real opposition, as they are lowering barriers for electric mobility adoption and are, next to municipalities, the only party which is willing to invest in charging station deployment throughout the Netherlands. In addition, as stated by the interviewee of Enexis, Stichting E-laad filfills that role as long as there is no market for it. When a market emerges, E-laad will withdraw from at least the service providing role. Depending on the outcome of the market model discussion, individual network operators will take over some of the non-service functions, for instance charging station ownership.

Active network operator role

In chapter 2 the concepst of smart grids and smart charging are discussed. Smart grids and smart charging entail a different role of a network operator. The smart grid requires some sort of steering of demand by the network operator.

It is, however, currently uncertain whether an active role of the network operator in steering load is allowed. When looking at demand control (financial incentives), distribution grid operators are bounded to maximum tariffs for their electricity delivery, they can thus not apply higher tariffs for peak load hours. They are, however, allowed to provide discounts to the tariffs [Akkerboom et.al., 2011]. Furthermore, the system code allows the national grid operator TenneT to do system services, including switching off loads to prevent or limit blackouts. The national grid operator is thus allowed to steer demand to safeguard the balance on the network. This system code is however not applicable to the distribution grid operators.

Another perspective on active control can be found in the Electricity Act[43]. The act states that during the installation of a grid, network operators are required to consider local (sustainable) production or demand control to avoid grid replacement or reinforcement [Akkerboom et.al., 2011]. This definition does link network operators to active control, although it does not state whether network operators are allowed to apply it.

The role of network operators in active load or demand control is thus ambiguous and based on different interpretations of legislation and codes. Changes to the codes are often based on suggestions by the cooperating network operators and assessed by the competition authority [NMa, 2011]. The cooperating

[43] Electricity Act *§ 2. Art 16.1c*

network operators could thus suggest a code change due to the emergence of smart grids and electric mobility. A code change would be valuable for ensuring a less ambiguous interpretation of the network operators' role.

4.2.3 DISCUSSION FORMAL INSTITUTIONS

The first conclusion to be drawn from the formal institutions of municipalities and network operators is similar to the conclusions drawn from informal institutions. Municipalities can implement electric mobility to achieve sustainability objectives and obligations. Electric mobility is for network operators an external development to which they are required to anticipate. Network operators are in many ways constrained by regulation. One of these constraints is that they will possibly not be allowed to do active control on demand or load, which is required for smart charging or smart grids. Network operators do however have the possibility to suggest code changes and thereby to suggest changes to their legal obligations and responsibilities. It is then up to the Dutch competition authority to decide on these code changes. In addition, the Electricity Act states that network operators are allowed to issue demand control to balance the grid. Although the legal ability of the network operator is thus not completely certain, it is in this thesis assumed that network operators are or will be allowed to use control of demand and load.

Not only network operators are required to anticipate to electric mobility. In many cases, municipalities will be the owner of the property on which a public charging station will be located. This ownership thus requires municipalities to react to other parties who want to install charging stations on public property. However, in contrast to the network operators' anticipative role, municipalities have a choice. Municipalities can choose whether or not to respond to public charging station requests, while network operators are actually obliged to ensure a reliable grid. One could thus say that for network operators the formal institutions cause constraints in operation. Network operators have a very limited influence in charging station deployment. For municipalities formal institutions are enablers of electric mobility and provide them some freedom in deployment. A freedom in charging station deployment allows municipalities to adjust the charging station deployment to limit impact of electric mobility on the electricity grid. Network operators have limited freedom to do so. However, in contrast to network operators, municipalities have limited incentives to adjust the deployment based on the impact on the grid. One could thus speak of a skewed incentive structure for grid impact and the freedom to limit this impact.

When looking at the network operators' perspective of safeguarding grid reliability, one could wonder why network operators cooperate in Stichting E-laad in order to facilitate the deployment of electric mobility. To safeguard grid reliability, a slow deployment might be more beneficial for grid reliability (more time to anticipate). An opposition of network operators towards electric mobility can however not be expected. It lies in the legal framework of network operators to deal with developments of the energy sector, like electric mobility. Electric mobility is for network operators thus a given fact with which they will be confronted and to which they need to anticipate. By getting involved in electric mobility in an early development phase, network operators hope to collect data on the possible impact of the charging stations to the electricity network. Furthermore, network operators might hope to gain a permanent role in charging station deployment. Legally, network operators have a very limited role in this deployment. By an early involvement, they could increase their value in the deployment process.

In addition, electric mobility is for network operators not only a threat to normal operation. Electric mobility also provides opportunities for the network operator to apply a smart grid concept and thus have a more active role in network operation.

The role of network operators and other parties surrounding charging stations are not yet fixed. Currently a discussion is in progress on a possible market model. The outcome of the discussion on the market model for electric mobility (see previous section) will determine the formal responsibilities and powers of the network operator and other parties involved in charging station services. The negotiation process can determine whether or not the ownership and maintenance will become a legal responsibility to the network operators or if it will become a market activity. For market parties (like energy companies or service providers like The New Motion), it might be more beneficial if charging station ownership and maintenance is a market activity, as these parties will have a business opportunity for charging station deployment. From an economic point of view, one could expect that competition between charging stations is possible, as the investment costs for charging stations are relatively low (the underlying electricity infrastructure is already there). However, due to the impact of the charging stations on the underlying grid, it might be socially more beneficial to allow network operators to operate the charging stations and thereby limit social costs related to the impact of electric mobility to the electricity grid. However, in the current (liberal) Dutch political climate, one could expect that leaving a possible market activity in public hands is not the governments' preference. In addition, many different parties are involved, thus several different interests play a role in the outcome of the discussion. All these social, economic and political factors make it very difficult to predict the outcome of the market model discussion.

For limiting the impact on the grid it is beneficial if, in the market model, network operators are granted with the responsibility to install and maintain public charging stations. Network operators will then decide whether or not the grid will be able to cope with the increase in load caused by the charging station. In relation to the municipalities it also would change the interaction between the two actors. Municipalities will remain the owner of the public ground and can thus decide whether or not a charging station can be located at a certain point. The network operators are however the ones submitting an application. They can in that case assess the ability of the grid to deal with the additional load. For municipalities the network operators' role can provide both advantages and disadvantages. On the one hand in case of network operator ownership, the municipalities would have merely one partner to cooperate and make agreements with on charging station deployment. Once agreements on certain municipal requirements are made, network operators could be granted with some autonomy, saving municipalities time and effort. An ownership role for network operators' role also comes with disadvantages to municipalities. If the network operator is not willing to install charging stations on certain locations, the municipalities cannot ask another party to do so. Network operators could then frustrate municipal charging station deployment strategies.

4.2.4 MAIN CONCLUSIONS FORMAL INSTITUTIONS

- For municipalities formal institutions, like European air quality obligations, are drivers for enabling electric mobility. For the network operators formal institutions are mainly constraining their actions;
- Municipalities currently have an active stimulating role. It is expected that this role will shift towards a more facilitating role when the electric mobility (and charging station) market is fully developed. The facilitating role is based on ownership of public property on which many charging stations will be located.
- The formal role of network operators is currently uncertain. Firstly multiple interpretations exist on whether or not network operators should be allowed to do active load or demand control in order to limit grid impact. Secondly, based on a market model discussion, network operators will, or will not be allowed to deploy and operate charging stations. This discussion provides opportunities for network operators to obtain a more active role in charging station deployment and operation.

4.3 INSTITUTIONAL ARRANGEMENTS

Institutional arrangements refer to formalised relations between actors. As this thesis focuses only on municipalities and network operators, only institutional arrangements between these two actors will be described. As they apply to both actors, this section will not be divided into sub-sections on institutional arrangements of municipalities and network operators individually and does not include a discussion section to combine the institutions.

4.3.1 SHAREHOLDING RELATION

The first institutional arrangement where municipalities are formally related to the network operators is shareholding. While some of the energy retail and production companies were sold to foreign energy companies, the network operators remain state-owned. Appendix VI provides a list of the largest shareholders of the distribution network operators, which are mainly large municipalities and provinces. As can be expected, the regions in which the network operators operate, determine in which operator the local governments are involved. The municipality of Utrecht is the only large municipality that does not have shares of a network operator. Utrecht used to be the owner of energy company REMU. REMU was sold to Eneco in 2003[44] [Jansen, 2003]. The other two large municipalities are either involved in Stedin (Rotterdam) or Liander (Amsterdam).

Due to privatisation, municipalities were confronted with a decreasing influence on energy companies. Their role was decreased to a passive shareholder role. In addition, energy companies merged with and acquired others, causing scaling. Due to this scaling, the geographical coupling between the local governments and the energy companies loosened.

The interpretation of the role of network operator stakeholders is under debate. Derks et.al. (2009) state that public shareholding provides opportunities to steer network companies to commit to public values like sustainability and reliability. After all, one of the reasons network companies remained in public hands was to safeguard public values. Deloitte states the opposite, by recommending municipalities to limit the shareholders' role to influence on outlines and control afterwards. Deloitte states that steering on public values requires detailed knowledge on the operation of the company [Ten Have, 2006].

A steering group commissioned by the ministry of economic affairs [Stuurgroep visie netbeheer, 2011; Roland Berger, 2010] did a survey on shareholders of network operators to create an overview of the perspective of the shareholders on their tasks and obligations. Shareholders indicate that they have been showing greater involvement in recent years, often via informal contact. In addition, shareholders of smaller network operators indicate that they are actively involved in local sustainable initiatives of network operators. In contrast, about half of the survey respondents indicate that it is not a municipality's, but a province's or national government's task to influence network operators via shareholding. They consider the national government the most logical shareholder of network operators as it also decides on regulation and legislation for network operators.

Furthermore, the survey shows that municipalities are mainly interested in the dividend from the network operators. Only 14% of the respondents would be willing to invest or financially support the network operator, while more than 50% of the respondents indicate that network operators' dividend is a structural budget item. When looking at the types of interest identified by the shareholders, dividend is identified as being in their own interests, while values like reliability, sustainability and affordability is indicated to be of national energy policy interest [Roland Berger, 2010].

[44] Eneco Holding is currently shareholder of network operator Stedin. The shares of Eneco are in the hands of Rotterdam, The Hague and smaller municipalities.

The steering group also wrote recommendations in favour of active shareholding. The group for instance proposed cooperation between shareholders by arranging formal and informal platforms [Stuurgroep visie netbeheer, 2011]. For safeguarding public values, it is recommended for shareholders to specify the public values they want to safeguard via shareholding. This recommendation can help to couple the public values of municipalities and network operators on electric mobility. By specifying public values shareholders want to safeguard, local governments get actively involved in the underlying values of long term operation of network operators. It is therefore recommended that if municipalities were to become active shareholders, they should specify the public values and specifically include long term objectives of energy developments like electric mobility in this specification.

During the interviews with the municipalities, a question was asked whether an active shareholding role was deemed possible and preferable for the municipalities. The reaction of the municipal officials was reticent. Shareholding is the responsibility of another municipal department (Economic Affairs) than the department having operational contact with the network operator. In an interview with one of the network operators it was also identified that knowledge of municipalities might be lacking in order to get involved in the business of network operation.

From a network operators' perspective, active shareholding might not always be in their advantage. An active role of a shareholder might lead to more control and thus less freedom to act for the network operator. In addition, as indicated during an interview with one of the network operators, network operation is a very complex technical business, which requires technical knowledge and a very long term perspectives (grid planning is issued for thirty to forty years). Municipalities often have short term policies, with projects which fit within a term of four years. These different time scopes and the need for difficult technical knowledge might make it difficult to arrange an active shareholding role. As said before, this conclusion is shared by the Deloitte report.

Recent developments however show that an active shareholding role in the energy system is possible. Although energy companies were sold to market parties, a trend within municipalities can be found in the foundation of sustainable energy companies[45]. These companies are founded to help achieving municipalities' sustainability objectives. Although the foundation of small local companies is different from shareholding large embedded network operators, the trend shows that municipalities seem to be willing to get involved in companies in the electricity sector to achieve sustainable energy policies

4.3.2 COMBINED TENDERING PROCEDURE

As mentioned before, municipalities and Stichting E-laad installed, or plan to install, a number of charging stations. This charging station deployment involves a tendering procedure. The municipality of Amsterdam for instance tendered the realisation, exploitation and maintenance of their charging stations in 2009 and 2011[46]. The tender procedure of both the municipalities and Stichting E-laad also entails requirements for technology specifications. As mentioned before the municipalities of Rotterdam and Utrecht indicated to initiate public tender procedures together with Stichting E-laad. Possibilities for an institutional arrangement of a combined public tender thus exist. Cooperation between network operators (or their cooperative foundation) and municipalities would allow for both parties to set requirements for charging station deployment.

For network operators and Stichting E-laad, deployment of the charging stations has advantages as it allows them to have control over the location and the requirements of the charging station, thereby possibly providing options to limit impact on the grid (for instance on smart charging devices). For municipalities it can also be beneficial to keep the electric mobility policy in their own hands. Firstly, deployment of charging

[45] Currently only actually done by Apeldoorn, Veenendaal and Tilburg [Donicie, 2009]
[46] See section 2.2.3.1

infrastructure provides a sustainable image of the municipality. Secondly by keeping deployment in their own hands, municipalities are able to change their policy if it turns out to have unexpected, undesirable effects (for instance nuisance of public space occupation to citizens). These requirements do not per definition conflict. Municipalities and network operators can thus cooperate in a tendering procedure. Municipalities can set requirements for for instance shape and design of the charging station. Stichting E-laad and the network operators can set requirements on for example smart charging technology. By co-financing the tender, the actors can finance the potential additional costs of their requirements. In addition, the cooperation is associated with frequent contact and discussion between network operators and municipalities. This type of contact, where both parties have an equivalent role, provides opportunities for mutual understanding of each other's problems, potentially enabling a more informal way of dealing with grid impact (see the next section on 'Interaction between actors').

One should, however, note that the role of the network operators (and Stichting E-laad) in charging station deployment might only be temporary. When looking at the legal responsibilities of network operators, it might not be allowed for Stichting E-laad and the network operators to invest in the competitive charging station business. However, as discussed above it is not yet sure who is allowed to take which role in charging station operation. Depending on the outcome of the market model discussion, the role of the network operators and thus also the possibilities for municipalities and network operators to cooperate might change.

4.3.3 ARRANGEMENTS ON OPERATIONAL LEVEL

When an actor wants to connect something (whether it is a new office building, a new city district or a charging station) to the grid, a request for connection needs to be submitted to the network operator. In case a charging station cannot be connected to an existing connection (for instance a household, company or parking garage connection) a request needs to be submitted for a new grid connection. Such a request is standardised and centralised via *Centraal Meldpunt Aansluitingen* (Central Contact Point for Connections). A requestor submits a request via a centralised website [aansluitingen.nl, 2011], after which the network operator is obliged to install the connection [Stedin, 2011a]. Due to the standardisation of the procedure, there is formaly no need for real interaction between the two actors on this matter.

In case grid impact occurs and grids need to be reinforced, other arrangements between municipalities and network operators apply. These arrangements consist of permits for constructing and installing lines and cables. In Rotterdam the *Leidingenverordening* (Line Regulation) states that a permit is required for cables and lines in public property. Exceptions to this permit requirement are made for cables shorter than twentyfive metres, in that case a shorter procedure applies [Gemeentewerken Rotterdam, 2010]. As the municipality prefers shorter permit periods, charging stations are, when possible, installed at a distance of less than twentyfive metres from a grid connection. Utrecht and Amsterdam have similar regulations [van Gool, 2008; Beishuizen, 2011].

In these arrangements no possibilities to deal with grid impact are identified, as the arrangements are centralised and formalised. In one of the interviews with the municipalities, an interest of municipalities in the Leidingenverordening was however identified. Permits cause a delay of the charging infrastructure deployment which is said to be undesirable. During one of the interviews this interest was said to be a reason for municipalities to consult network operators on grid limitations in assessment of feasible charging station locations.

4.3.4 MAIN CONCLUSIONS ISTITUTIONAL ARRANGEMENTS

- Municipalities are shareholders of network operators. Shareholding provides options to safeguard public values and thereby create a mild coupling between municipalities' and network operators' public values. Municipalities might get more involved in the social costs the network operator faces due to electric mobility. The public value allocation conflict might therefore possibly be reduced.
- A cooperation between network operators (or Stichting E-laad) and municipalities on tendering procedures for charging station deployment allows both parties to enforce requirements for charging station deployment. Network operators could thus demand for options to limit the impact on the grid, for instance by applying smart chargers and assessing the location of charging stations based on available grid capacity.

4.4 INTERACTION BETWEEN ACTORS

The section on institutional arrangements above described the current formalised arrangements between network operators and municipalities. This section will look into the non-formalised interactions.

4.4.1 CURRENT INTERACTION BETWEEN ACTORS

On an operational level, contact between network operators and municipalities is mainly about the connection of a charging station to the grid. Technically a municipality does not have to consult a network operator about the possibilities of a grid connection. However, as mentioned above, municipalities already take grid possibilities into account, based on the distance to the grid. From the interviews and meetings with network operators and municipalities it also appeared that municipalities did consult (or were willing to consult) with network operators on a broader operational level. This can be explained by the fact that electric mobility is in an early development phase, where parties are searching for expertise and partnerships. As network operators are strongly involved in the electric mobility deployment and have built up knowledge through pilots, they can be an interesting partner.

In Amsterdam, the consultation between municipalities and network operators also applies on a strategic level. As appeared from the interviews, the municipality of Amsterdam and Liander already communicate about grid possibilities by comparing maps of the electricity network with maps of expected electric vehicle demand. The municipality of Rotterdam plans to create a demand map where locations for charging stations are specified based on requirements on for instance permits and mobility. During the interview with the municipality of Rotterdam, it was stated that also a role for network operators could be assigned in the creation of this map. Utrecht plans to create an assessment framework for charging station locations. It is however unknown whether grid impact will be included in this framework [Gemeente Utrecht, 2011a].

In pilot projects, municipalities are also cooperating with network operators. Stedin is for instance involved in a pilot with Eneco and the municipality of Rotterdam for the purchase a pool of seventy-five electric vehicles. Network operators are involved in these pilots by connecting charging stations and collecting data from the charging stations to learn on electric mobility.

It can be concluded that currently municipalities have the intention to consult network operators about grid possibilities. It should, however, be noted that electric mobility is in an early phase of deployment where no grid impact problems are expected to occur and actors are still searching for their role to play. In a later phase, during wide scale deployment when the grids are actually constrained and market models are fixed, the situation might change.

4.4.2 POSSIBILITIES FOR PROCESS DESIGN

Municipalities have a role in assigning and assessing locations for charging stations in which network impact could be taken into account. As explained in the previous chapter, the location of high power charging stations can be determining for grid impact. From a network operator's perspective, it would be beneficial to be consulted on the location of high power charging stations. Formally, municipalities are not obliged to do so. From the current interaction between the actors and the interviews it is however concluded that the municipalities do not appear to be unwilling to consult with network operators. Possibilities for a process thus exist in enabling the technical option to limit impact by assessing locations of high power charging stations based on grid capacity.

This section will first identify problems which could be associated with the process, by looking into the four elements of a process in a complex decision making process by De Bruijn and Ten Heuvelhof (2003):

- openness: the process should be open for all stakeholders to get involved inside the process and in a common outcome;
- protection of core values: parties will not commit to an outcome in case it harms their key interests;
- speed: processes often end up in a lengthy negotiation with no or limited outcome;
- substance: the process should have substance and a sufficiently detailed content.

The theory of De Bruijn and Ten Heuvelhof refers to 'multi-actor' complex decision making. As this interaction looks only into the interaction between two actors, this process between municipalities and network operators might show differences with the processes described by De Bruijn and Ten Heuvelhof. The four key elements in the process management theory describe difficulties in interaction between actors. These difficulties do not only apply to multi-actor interactions, but can also apply to processes with only two actors. The theory will therefore be used to identify problems in the interaction between the municipalities and network operators. These problems will help to see whether a process will be difficult or whether options exist for informal interaction between municipalities and network operators.

Below the four elements will be discussed for the municipality and network operator interaction:

- **Openness** is important in a process as actors who are excluded from a process might block or delay the outcome of a process in case they do not agree with it. In case of assigning the location of charging stations, also other interests can be identified. Charging station locations should be assessed based on permit requirements, mobility, consumer and resident demands, and the grid limitations. Currently most of these tasks are fulfilled by municipalities, who are responsible for building permits and intend to study the feasibility of a charging station location. In addition, from the interviews it showed that the considered municipalities currently only assign charging stations based on consumer requests. It is therefore expected that by including only municipalities and network operators in assigning a location for a charging stations would include all interests. It would however be valuable to design a process which also allows for different interests and constraints to be included.

- **Protection of core values** is especially important in case parties do not seem to be willing to get involved in the process. Core values refer to the essence of an organisation; they underlie the actors' behaviour. Actors who do not want to get involved in a process can be convinced by ensuring them that their core values are protected. Although the values of network operators and municipalities on the location of charging stations differ, they are not expected to per definition contrast. Not only network operators benefit from limiting the impact of electric mobility on the grid. Section 3.3 already showed interests of local governments in grid impact implications. First municipalities want a smooth and fast charging station deployment. Grid impact and possible required grid reinforcement will slow down such a deployment process. Second, grid impact can causes reduced grid reliability and corresponding nuisance to local consumers and businesses if network operators will not be able to anticipate to an increased demand in time. Third, road construction for grid reinforcements cause nuisance to residents and is especially extremely difficult in old crowded city districts. There thus appears to be a willingness and interest for municipalities and network operators to cooperate and no need for specific protection of core values.

- **Speed** of a process refers to the risk of processes to become sluggish. In order to have an effective process, it is important to guarantee speed and progress. It is not expected that the process will become sluggish and slow. The municipalities (the actors with the lowest interest in the cooperation) benefit from a fast process as an objective is to achieve a fast deployment of charging infrastructure. Network operators will not want to delay or block the process as they might lose their role in the process. The problems of the process thus also not lie in the speed and progress of the process.

- **Substance** can in some processes diminish due to conflicts between actors. In the case of impact of electric mobility, the danger of lack of substance can be found in the different perspectives on, and the knowledge required to understand the problem. To provide substance to the process, it is important to speak a common language to avoid misunderstanding and incomprehension. Here a problem of the process can be identified. Municipalities and network operators have a different perspective on electric mobility and thereby also a different knowledge base. The grid impact calculation in chapter 3 illustrated a large complexity of the electricity grid and the impact of electric mobility. It is difficult for municipalities to understand the problem of impact on the grid and options to limit this impact.

Problems identified based on four key elements of process management

In first instance, the interest of consulting network operators in the decision of locations of charging stations seem to account only for the network operators. However, also municipalities face disadvantages of grid impact. Electric mobility can lead to reduced grid reliability, causing nuisance to residents and companies. In addition, grid reinforcements cause a delay to charging infrastructure deployment and nuisance to residents. It is thus in both their interest to initiate a process to limit impact of electric mobility on the grid although the interests of the network operators are significantly larger than those of the municipalities. A process could entail the assessment of the location of charging stations based on grid capacity. A discussion of the four key elements of process management identified two problems to be solved by the process:

1. Municipalities and network operators have different knowledge bases on charging station deployment. The impact of electric mobility on the grid is expected to be difficult to understand for municipalities and therefore also to include in decision making.
2. Although it is expected that the assessment of locations for charging stations can be managed by municipalities and network operators, it would be a valuable contribution to allow for different interests to be included in the process. One reason to do so is that municipalities already have to take into account several interests, including permit requirements, consumer requirements and mobility.

Although the problem of different knowledge bases exists there is a willingness of both actors to cooperate on the assessment of location of charging stations. It is therefore expected that the design of a process for consultation of the location of charging stations provides an institutional option to limit the impact of electric mobility on the grid. Such a process will have to focus on creating a shared understanding of the problem and on providing a low threshold way to look at possible impact limiting options. The process would not only allow network operators to assess locations on the consequences to the grid, it would also allow them to inform municipalities on the consequences of grid impact.

4.4.3 MAIN CONCLUSIONS INTERACTION BETWEEN ACTORS

- Municipalities and network operators seem to be willing to cooperate in deploying charging infrastructure and are currently already doing so on pilot projects.
- Possibilities for a process design exist. Such a process should deal with different knowledge bases and be able to take into consideration multiple objectives.

4.5 ROLE OF TECHNOLOGY

Technology developments influence acts of actors and institutions. Electric mobility can be used to achieve formal objectives or can harm the performance of formal tasks. Below the perception of municipalities and network operators on electric mobility and their perception of the role of electric mobility will be discussed.

4.5.1 ROLE OF TECHNOLOGY MUNICIPALITIES

Municipalities stimulate electric mobility in order to achieve air quality standards and limit CO_2 emissions. Municipalities are interested in electric mobility to satisfy formal and informal (public values of sustainability and liveability) institutions. For municipalities, the ability of the vehicles to reduce emissions is thus the most important characteristic of electric mobility. Charging stations are required as a complementary technology in order to achieve a large adoption of electric mobility.

While the system definition in chapter 2 defined electric mobility as a part of the electricity system, municipalities thus focus more on the vehicles themselves. The electricity system, in which the system diagram in section 2.3.1 places electric mobility, is not the system considered to municipalities. For municipalities, electric mobility is part of a changing mobility system. One can consider the vehicle technology and mobility system as quite variable in time. Firstly vehicle technology is, compared to an electricity infrastructure, a quite variable technology which changes much faster than an infrastructure. Secondly, one can consider the mobility system as quite variable in time from a policy perspective. Electric mobility is part of a sustainable mobility policy and not the only technology considered in this policy. A few years ago, electric mobility was not yet expected to become a successful technology. Instead, technology development and policy makers focussed on bio fuels, natural gas vehicles and hydrogen vehicles. These technologies have been alternating in expectations and stimulating policies. Another reason to consider electric mobility as a variable technology from a municipality's perspective is the fact that the role of municipalities to stimulate electric mobility is only temporary. The municipalities provide a kick-start for electric mobility to develop. However, when the market has matured, municipalities will withdraw from an active role in electric mobility. As explained, the technology will then only be considered in a spatial planning matter.

The four layer model places technology at the first layer of institutions, parallel to stable, informal institutions. One can question whether that reflects the perspective of municipalities on the development, as municipalities focus mostly on the vehicles themselves, rather than on the infrastructure. Vehicle technology and the role of municipalities in electric mobility are rather variable. Technology in the four layer model of institutions from the municipality's perspective is thus better reflected on a lower institutional level. To identify which level, one should also consider the time scale of electric mobility technology. Large scale adoption of electric vehicles is expected to occur only after 2020. Electric mobility therefore has a relatively long technology transition path for a municipality (most municipal objectives are based on four year coalition periods). In addition, the formal institutions to achieve air quality obligations and CO_2 objectives are the most important driving factors for electric mobility. Technology is therefore deemed to fit best on the formal layer level. Note that for municipalities without air quality obligations and without actual policy on electric mobility, a lower level might be more viable.

4.5.2 ROLE OF TECHNOLOGY NETWORK OPERATORS

The Dutch electricity network is a very reliable network. Network operators are required to operate and maintain the network and its reliability. Electric mobility entails a change to normal grid operation. It is however not the only development occurring in the electricity network. As discussed before, in production as well as demand, changes are occurring to the electricity system, affecting network operation. For network operators electric mobility is part of this changing environment.

During the meetings with network operators, the researcher perceived differences in the perspectives of the three network operators on the role of electric mobility in the changing network environment. Comparing the three network operators, one can see that while Enexis perceives electric mobility, besides an external development to which anticipation is required, as an opportunity to enable smart grids, Stedin perceives electric mobility as a threat. Liander appears to be more or less in between those two perspectives. Irrespective of these differences, the network operators are faced with a lot of uncertainties. The three network operators have different approaches of reducing this uncertainty. Liander and Enexis participate in Stichting E-laad in order to collect data on charging stations and charging behaviour. In addition, Enexis participated in several theoretical studies on the impact of electric mobility on the grid and developed a smart charging device [Enexis, 2011b]. Stedin mainly invested in several small scale pilots on electric mobility to investigate the impact of these charging stations on the local grid. For learning purposes the different perception and approaches of these network operators are very valuable, at least in case this knowledge is also mutually shared. Knowledge sharing appears to occur both within Stichting E-laad and in the cooperating organisation NetbeheerNederland, where a working group is initiated specifically on electric mobility.

The role of technology in the perspectives of the network operator is that of a change to the electricity infrastructure. The main technology considered in electric mobility is not the vehicle, or the charging station, but the electricity network to which they will be connected. As an infrastructure, the network is a stable, long term technology. When thus considering the role of electric mobility in the four layer model of institutions from a network operator’s perspective, the total system can thus be considered viable at the highest institutional level.

4.5.3 DISCUSSION ROLE OF TECHNOLOGY

The perception of municipalities and network operators on technology in electric mobility differs. In case of network operators, electric mobility is seen from an electricity grid perspective. Municipalities perceive electric mobility as a changing mobility system and part of their sustainable mobility policy. These differences in interest can lead to misunderstanding in communication between the actors. Process management, as described above, can deal with such a misunderstanding.

When comparing the role of technology for the actors with the role of technology in the four layer model of institutions, it is concluded that for municipalities, technology is more variable than presented in the institutional model and is thus not viable at the highest institutional level. For network operators the role of technology as indicated in the model does seem to be viable at the highest institutional level.

4.5.4 MAIN CONCLUSIONS ROLE OF TECHNOLOGY

- The perspectives of the municipalities and network operators on the role of electric mobility differ. For municipalities electric mobility is considered from a sustainable mobility policy. The most important technologies considered are the vehicle and the charging station technology necessary for electric mobility;
- For network operators, electric mobility is an external development which influences the operation of the distribution network. Their technology focus thus lies on the existing energy infrastructure.

4.6 CONCLUSION INSTITUTIONAL ANALYSIS

This chapter described the institutional framework related to electric mobility for the municipalities and network operators. From the institutional analysis three main conclusions can be drawn. These conclusions will form the basis of the strategy in the next chapter.

1. *The actors are faced with different roles of institutions*:
   For municipalities, the institutions are drivers for electric mobility. For network operators the institutions require them to anticipate to electric mobility[47]. In addition, a public value allocation conflict is identified in the allocation of cost and benefits of electric mobility.

2. *The actors have a different perspective on the role of technology*:
   For network operators, electric mobility is a long term development on the existing electricity grid, which on the one hand impacts their normal operation and on the other hand provides opportunities for a more active steering role in the electricity system. For municipalities electric mobility is a tool to achieve sustainability and air quality objectives.

3. *Possibilities in institutions to limit grid impact exist in*:
   - The market model discussion possibly allows for operators to gain a role in **charging station ownership**, thereby possibly providing them with more autonomy in charging station deployment;
   - A **combined tender** can allow to include grid limitation requirements;
   - **Active shareholding** can allow for a mild coupling of public values, thereby dealing with the public value allocation conflict;
   - A process can be initiated to enable a **consultation of network operators on grid impact**.

The institutional analysis allowed identifying the rules by which the actors act. The different levels of institutions have different influences on the interaction between the technical and actor system and actors in between. By applying the broad institutional analysis it was possible to identify different rules and reasons which determine how the actors are required to respond to electric mobility and the impact on the grid. These rules and reasons not only determine how actors will react to electric mobility, but also towards each other. The analysis thus provided insight in the interests of the actors and in the possibilities of the actors to take each other's' interests into account. In addition, the institutional model allowed identifying several options to change the institutional system. Although in the next chapter only one of these options will be selected and detailed, the different options allow seeing degrees of freedom for institutions and can be used as a basis for further research on these options.

[47] Note that also possibilities for network operators within the institutional framework exist to benefit from electric mobility (mainly in flexibility in electricity demand)

Proposition for revised four layer model

This chapter described the involvement and interests of municipalities and network operators on electric mobility by means of the four layer model of institutions. During the analysis it was experienced that the four layer model was applicable to describe the reason why actors act in a certain way. The institutions described the drivers and constraints of the actors and could thereby explain the involvement of the actors in electric mobility. During the analysis, a difficulty was experienced in the fact that many aspects of electric mobility are still undecided and uncertain. These uncertainties well reflect the different layers in the four layer model. The public values in the informal institutional layer are not (yet) subject to changes. On the formal institutional level already questions of uncertainty arises on the responsibilities of the network operator. On the institutional arrangement level, new arrangements are possibly arising (combined tendering procedures). On the interaction between actors level, almost no past experience is available. This level is associated with a large amount of uncertainty and possibilities to change the acts of actors. These uncertainty aspects are reflected by the institutional theory, as in the theory the lower institutional levels describe more change and volatility than higher levels of institutions. The model was thus very applicable to describe the acts of actors and the related uncertainty.

For describing two different actors the model was also deemed feasible as the model enabled to compare underlying reasons for actors to act in a certain way. In addition, the two lowest institutional levels described the existing interactions between the actors.

The existing interactions between the institutions and between the institutions and technology in the four layer model also apply to the electric mobility case. Informal institutions correspond to formal institutions (both focused on sustainability) and these institutions determine the roles of the actors in institutional arrangements and their interaction. In addition, technology development requires for new interactions and institutional arrangements to be designed.

However, technology is in the model presented as a relatively stable system component, only influenced by formal and informal institutions. As already identified above, for municipalities this stable role of technology does not apply. In addition, when looking at the options to limit impact, especially on institutional arrangements and interaction between actors level, options are identified to limit the technical impact on the electricity grid. These lower level institutions are thus able to change technology. Furthermore, one of the options presented above is to change the public value allocation conflict (informal institutions) by active shareholding (institutional arrangement). All these interactions are not reflected by the four layer model of institutions.

A possible explanation to the differences in role of technology is the fact that the one of the actors is focused on technology development instead of on the system itself. This technology development is again a technology itself. In other words, the municipalities do not look at the (electricity) system, but at electric mobility, which is in itself also a technology with corresponding developments. This technology is much more volatile than the system, causing the role of technology to be more volatile than reflected in the framework. This argument can also explain the fact that lower institutional levels influence technology. These institutions mainly adjust the technology development, and to a limited extent the technical system.

To summarize the feasibility of the four layer model of institutions; the model applies to describe and compare the actors' involvement in electric mobility. In case of electric mobility and the corresponding impact to the grid, the role of technology in the model does however not suffice. The role of technology in electric mobility is less stable than suggested in the four layer model of institutions. In addition, the interactions between technology and institutions in the model do not describe all possible interactions of technology. The figure above therefore proposes a revised version of the four layer model of institutions.

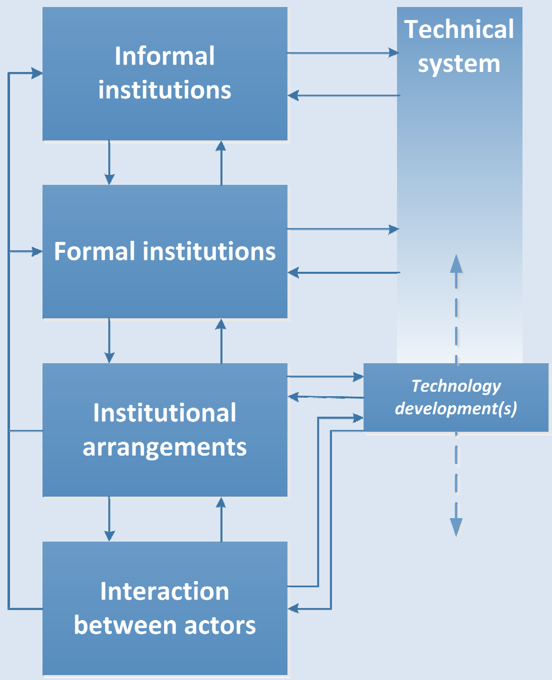


Figure 34 Revised four layer model of institutions, including a role for technology development.

In this proposed model, technology is not seen as one separate technology, but as a technical system, which is rather stable. Within the system, multiple sub-systems exist, of which some are emerging or developing. In this case one could say that the electricity system (technical system) itself is rather stable. A new sub-system is emerging in the electricity system; electric mobility. Electric mobility is a separate technology, which develops and causes changes to the technical system. In the electric mobility case considered, one can see that municipalities are mainly interested in the developing technology. Network operators focus on the technical system. The stability of their perspective on technology thus differs.

Note that this revised model involves a more system thinking approach; the technology is part of a technical system which faces developments and interacts with other technical aspects in the system and a social system (the institutions).

5. STRATEGY TO DEAL WITH GRID IMPACT

The previous chapters presented options to limit the social costs of electric mobility. First technical options to limit the impact of electric mobility on the grid were presented through a technical analysis on grid impact in a municipality. Second, an institutional analysis identified the effect of grid impact on municipalities and network operators and the possibilities these two actors have to apply the technical options. The institutional analysis looked into the possibilities and constraints for municipalities and network operators to limit the impact of electric mobility on the distribution grid.

This chapter will shortly summarise the technical and institutional options and describe their relations. The most promising option will be selected from the list and elaborated further into a strategy to limit social costs of grid impact of electric mobility.

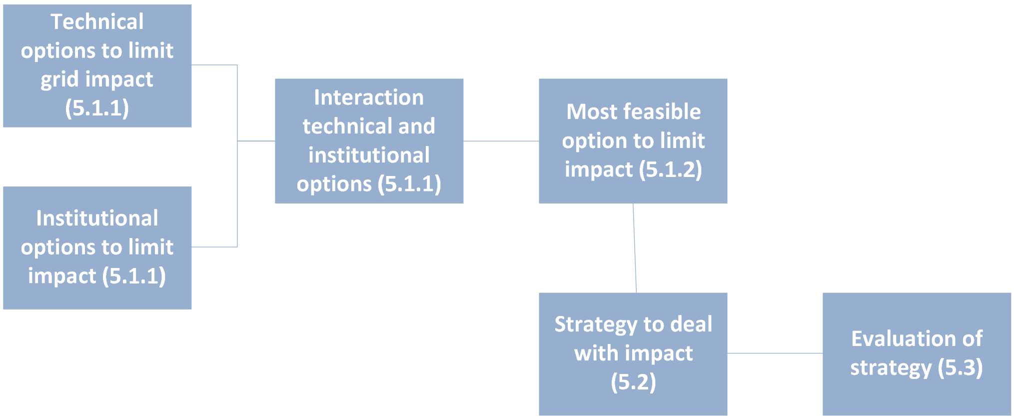


Figure 35 Strategy - chapter structure

5.1 TECHNICAL AND INSTITUTIONAL OPTIONS TO LIMIT GRID IMPACT

This section will first shortly summarise the technical and institutional options to limit grid impact of electric mobility and present the interaction between these options. This section will end with a selection on the most feasible option.

5.1.1 RELATION INSTITUTIONAL AND TECHNICAL OPTIONS TO LIMIT GRID IMPACT

Two technical options to limit grid impact of electric vehicles were presented in chapter 3, namely smart charging and to base the location of high power chargers on available grid capacity. However, the skewed incentive structure between network operators and municipalities make it difficult to apply these options. Changes in the current institutional system are thus required to deal with this skewed incentive structure and allow for one of the parties to apply one of those measures.

The institutional analysis identified the possibilities to deal with the incentive structure. These possibilities are located at different institutional levels. The first option is provided by a market model discussion which currently takes place between several parties involved in electric mobility. In this discussion, network operators could be assigned with the role of charging station owner, which allows them to assign certain options to limit grid impact. A second option is for municipalities to adopt a more active shareholding role of the network operators and especially in safeguarding public values. Such a role could help to couple the public values of municipalities and network operators and thereby create an interest for municipalities to limit grid impact. A third option is a combined tender procedure between the cooperating foundation of network operators, Stichting E-laad, and municipalities, thereby allowing for smart charging requirements in public charging stations. The cooperation based on the combined tender can also help to create a better understanding of the other parties' interests. The final option is to create a process of interaction where municipalities consult network operators on the location of high power charging stations based on grid limitations.

The following figure displays how the institutional options, resulting from the institutional analysis, can enable the technical options presented in the technical grid analysis. Note that the block 'Shared public values' on the informal institution layer is a result of 'Active shareholding'. As mentioned in section 4.1.3, informal institutions are not easily changed by itself. Informal institutions can however be changed via other institutions, in this case an institutional arrangement.

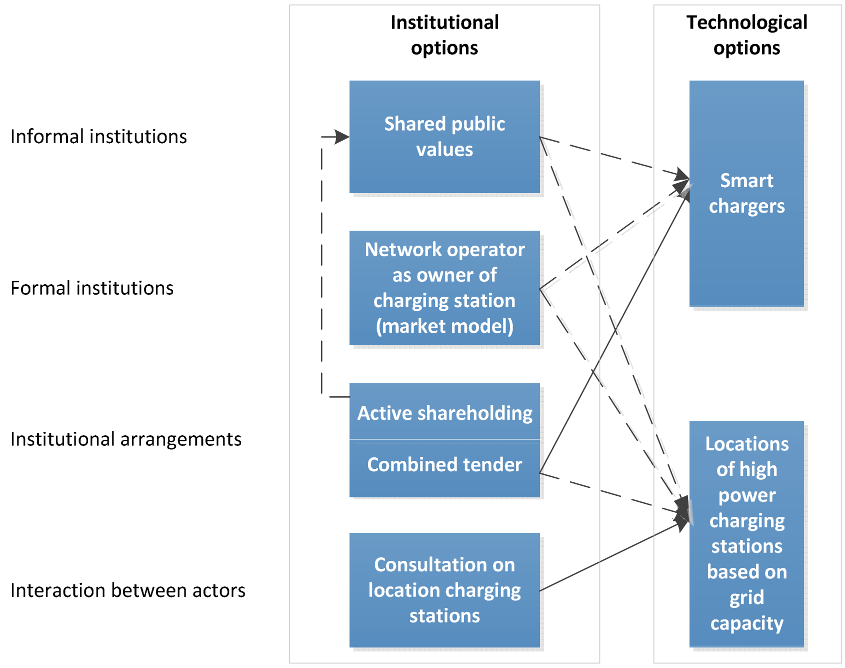


Figure 36 Influence of the institutional options to the technical options to limit the impact of electric mobility on the grid. Full lines indicate direct influences, dashed lines indicate indirect influences.

The figure displays different influences of the institutional options to the technical options. The dashed arrows display an indirect influence, meaning that the institutional change *could* influence the technical options. For instance, a coupling of public values could have some influence in the interest of municipalities in grid impact, thus incentivising them to apply one of the technical options. Active shareholding does however not directly apply one of the options. The full lines display a direct influence of institutions to the technical options. A combined tender procedure between municipalities and Stichting E-laad can for instance directly arrange smart charging requirements for the public charging stations. In addition, a consultation of municipalities and network operators on the location of charging stations directly arranges the technical option to arrange high power charging stations according to grid capacity.

5.1.2 SELECTION OF OPTIONS TO LIMIT GRID IMPACT

All options presented above provide the municipalities, network operators, or both possibilities to limit the impact on the grid. Due to time constraints of this thesis project, not all options can be elaborated upon. Therefore a selection of the most feasible option will be made. For the other options, recommendations for further research or references to other studies will be presented.

1. **Network operator as owner of charging station (market model)**
The market model discussion provides options for the network operator to be granted with more formal responsibilities and thus more possibilities in the charging station deployment. This market model discussion however entails many more interests than those of network operators and municipalities. In addition, as discussed in the previous chapter, the discussion is associated with economic, political and social factors, making a prediction of the outcome very difficult. It is thus difficult to design a strategy in which all different interests are included. In addition, recent research does go into options to help the market model discussion. Helmer (2011) looks into the possibility of serious gaming in order to reach an agreement between the actors involved in the market model discussion and how their different interests can be included in a simulation game. Due to this earlier research and the fact that the other actors' interest lie outside this thesis scope, the market model discussion will not be further taken into account.

2. **Active shareholding**
In this thesis, active shareholding is identified as a valuable interaction between municipalities and network operators in order to limit grid impact of energy developments as it creates awareness to the municipalities what the impact of electric mobility is on the grid. In addition, if municipalities actively steer on the safeguarding of public values of the network operators, active shareholding allows for a coupling of the public values of network operators and municipalities. Such a coupling would provide incentives for municipalities to take the costs of electric mobility to some extent into account in their stimulating and facilitating policy for electric mobility. In section 4.3.1 several options in favour and against an active shareholding role are presented. The question whether or not active shareholding is preferable, is very complex. The most important aspect of active shareholding is the willingness of the actors to become an active shareholder. As appeared from the discussion in section 4.3.1 this willingness of shareholders is not always evident.

   Therefore, it is in this theses merely recommended to further research this possibility related to the full spectrum of the network operators' businesses and not only to electric mobility. In addition, this research should examine whether or not there is willingness and ability (especially in knowledge on the operation of the grid) from the shareholders perspective to get more actively involved.

3. **Combined tendering procedure**
Stichting E-laad is cooperating with municipalities on new tenders for public charging stations in Utrecht and Rotterdam. This cooperation allows for both parties to set requirements for the charging stations to be deployed. The network operators in Stichting E-laad could thus demand for smart charging devices in charging stations and will have a say in the location of charging stations. Although the cooperation is a valuable option to limit the impact on the grid, more research is required on the current status of the cooperation between Stichting E-laad and the municipalities of Rotterdam and Utrecht to know whether smart charger requirements can still be included in the tendering procedure. In addition, as the current charging stations are not yet applied with smart devices, it is not certain whether or not Stichting E-laad wants to install smart devices in this phase of charging station deployment. More study is thus required on the willingness of the foundation to do so. Moreover, the role of Stichting E-laad and the network operators in installing charging stations is very uncertain due to the market model discussion. It is therefore uncertain whether a potential combined tendering procedure will be possible in the long term.

4. **Consultation process on charging station locations**
A process of interaction can be arranged between municipalities and network operators where the network operators are consulted on the location of high power charging stations. The previous chapter looked into common difficulties in complex processes to identify whether or not such a

process would be possible. It was identified that the willingness of the actors to inform or be informed is present. The problem with the interaction would be that there are different knowledge bases between the actors. A common language is thus lacking. A process design can provide an outcome for these different knowledge bases. A process of the creation of a common language can be designed in order to arrange an interaction between the two actors which allows for them to take each other's interest into account.

The process design on a consultation process for charging station locations is deemed to be the most feasible institutional option for allowing incentives to apply one of the technical options (in this case adjustment of location of charging stations according to grid capacity). The actors already seem to be interested in an interaction and the difficulty arising from these interactions are not impossible to solve. In addition, most of the other institutional options require further research in order to come to a valuable solution. The consultation process will therefore be elaborated into a strategy. The fact that the institutional possibility at the lowest level is the most feasible one is not illogical when one looks at the characteristics of the different layers. The lower levels are more dynamic and thus have more possibilities for changes. Note however that also the other options can be valuable for reducing social costs, possibly on a longer term. In addition, the analysis of the options on all institutional levels can be used as a basis for further research in dealing with social costs of electric mobility.

The broad institutional analysis allowed to see interactions between existing and potential institutions. The existing institutions thus shape the process. Moreover, the developments on the options can influence each other. A change in one of the other three options could influence the role of one of the actors in the process. Firstly, the outcome of the market model discussion is important for the role of the network operators and thus also for the interaction between the network operators and municipalities considered in the strategy. If network operators would obtain an ownership role in the market model, they would have more autonomy in charging station deployment and thereby in assigning locations to charging stations. The process will in that case still be valuable, as municipalities and network operators will then be required to together decide on the locations. A network operators' ownership role would even increase the feasibility of the process, as the network operator will obtain a formal cooperative role with the municipalities. The second institutional option also strengthens the process as the formal cooperation between the actors would lead to more understanding of each other's interests. Also active shareholding would increase the actors' understanding on their interests. At the same time, an informal interaction between the actors can influence the other options. A positive experience in the process can convince the municipalities to cooperate on a tendering procedure. In limiting social costs, a combination of all options would thus be most successful.

5.2 CONSULTATION PROCESS DESIGN

The municipalities deploy a part of the infrastructure themselves due to their stimulating electric mobility policy. In addition, municipalities have a role in spatial planning. This role in spatial planning provides municipalities with an assessment possibility of the suitability of a certain location to position a charging station. For network operators it would be very valuable if the municipalities take grid capacity into account in this assessment. A process strategy will therefore be proposed is this section.

Based on the analysis of the four key elements of a process design by De Bruijn and Ten Heuvelhof in the previous chapter, the main obstacle identified for such a cooperation between network operators and municipalities is the differences in knowledge base on the impact of electric mobility to the electricity grid. In addition the process would have more added value if it allows for the inclusion of other interests and objectives. The process design should thus focus on creating a low threshold approach which allows municipalities to easily consider grid impact without requiring detailed knowledge on grid operation. The guideline can be used on an operational level to assess grid feasibility for the installation of a single charging station. The guideline can also be used on a strategic level in order to create a strategic infrastructure deployment plan. As indicated before, the municipalities of Rotterdam and Amsterdam both indicated to create a strategic plan for locations of charging stations. These plans allow for assessing the long term suitability of locations for charging stations. The guideline of the network operators can be taken into account in such an assessment.

Geographical representation for infrastructural constraints – The *Watertoets* (Water test)
Problems, where the complexities of infrastructures are difficult to comprehend for policy makers are not unique to the electric mobility case. In water management, similar problems occur. In new construction plans, water management considerations were often overruled by other spatial planning requirements. To deal with this issue, in 2001 the *Watertoets* was introduced. This test allows municipalities or project developers to easily see whether or not a new construction project will be harmful for water management (see www.dewatertoets.nl). This *Watertoets* is a low threshold geographical tool in which municipalities can indicate the location and implementation of a project. The tool tests whether a project will be harmful to the water management of the district and is used as a consultation tool between municipalities and project developers and the Waterboards.

5.2.1 GRID REQUIREMENT GUIDELINE

Municipalities might be willing to take grid impact into account, but a consultation with the grid operator should not become a threshold or a delaying factor in infrastructure deployment. The process therefore focuses making grid requirements a low threshold requirement for municipalities to assess the capability of the grid to deal with planned charging stations. This section will therefore describe how a guideline can be created. The next section will go into the way this guideline can be used in the interaction between the actors.

A low threshold set of requirements can be created by mapping the infrastructural constraints. Network operators can indicate for a neighbourhood grid the capacity to deal with additional load. Software tool Vision (also used for the grid impact calculation) is equipped with a Google maps application which allows grids to be mapped. This tool can thus directly couple the capacity of the branch to the corresponding neighbourhood. Network operators can create three categories of grid components:

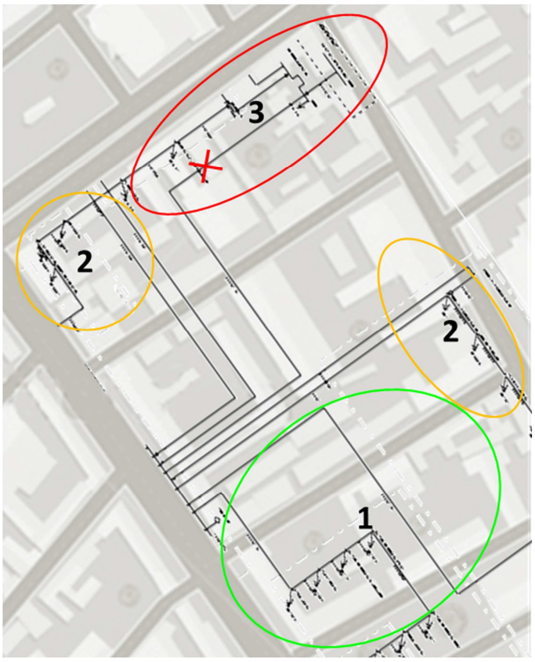


Figure 37 Hypothetical guideline to be created by network operators. Guideline shows capacity of grid branches to deal with additional load of charging stations.

1. Grid capacity is sufficient to deal with an increase in capacity for several charging stations;
2. A limited number of charging stations is possible in the neighbourhood[48];
3. Charging stations will require reinforcements to the grid.

Figure 37 provides an image for such a guideline in a hypothetical grid.

[48] Here network operators indicate that each individual charging station requires additional simulation to see whether the grid will be able to deal with the additional load

In order to assign the categories, the network operator will assess grid components by their ability to deal with additional load. There are basically two options to do so:

1. Start with the grid impact analysis as presented in section 3.3.4. This analysis will provide insight in which grid component will be critical in case of increased demand for electric vehicles. The spare capacity of this critical component determines the capacity of an entire network branch. This spare capacity equals the nominal current of the critical cable (the maximum allowable current) minus the current flowing through the cable (based on peak demand).
2. It is also possible to identify critical grid components by merely looking into the additional capacities, as the cables with the lowest additional capacity in a branch are the most critical ones. This method directly allows to see how much additional load the current grid is able to deal with.

Which option to choose depends on whether the network operator and municipality want to use the guideline for future or current grid impact calculations. For current grid impact, the current loads and grid design and thus the second option can be used. Future impact calculation requires to include organic demand growth and the inclusion of (non-public) other charging stations. For that option it is better to use the first option. This option is however more time consuming as it requires to include the loads for charging stations.

Note that in case smart charging by load control is applied, the possible number of charging stations differs. In case of load control, network operators can switch off charging stations in case of grid failure, thereby allowing charging stations to use capacity up to the maximum capacity during normal operation. Charging stations can in that case thus be connected up to 120% of component load, instead of 60% load (see section 3.1 for explanation of these capacity factors).

Note also that a guideline for an entire city grid would be easier and less time consuming than creating a mapped guideline per neighbourhood. The grid calculation in chapter 3, however, showed differences between grids based on local characteristics. The approach of visualisation therefore does not provide a guideline for the entire grid, but looks at separate branches and the most constraining grid components in these branches.

The following section will describe how the guideline can be used in the communication between a network operator and a municipality.

5.2.2 CONSULTATION PROCESS

As said before, the guideline can be used for both operational and strategic purposes. Preferably, the process takes place in an early charging station deployment stage, as the use of the guideline creates an understanding of municipalities on grid limitations and the consequences. In addition, by creating a guideline in an early phase on a strategic level, the guideline can also continue to be used on an operation level for the installation of an individual charging station[49]. This section will describe the process of using the guideline to create a strategic infrastructure deployment plan including different interests and location requirements.

Need for combination of interests

The guideline presented above is meant to provide an easy, low threshold option for municipalities to check whether or not the electricity grid can deal with the additional load of a high power charging station. Grid limitations are however not the only factors a municipality has to consider when deploying charging infrastructure. To assign locations for public charging stations, also permit requirements, spatial planning issues, expected demand for electric vehicles and charging stations, and requirements of residents and vehicle users are taken into account. A network operator's requirements would have to be put side by side with the other requirements. The guideline can be used to see whether charging stations have an impact on the

[49] A continued use would require a constant consultation with the network operator, as conditions influencing the impact might have changed (for instance an increased load due to organic growth).

electricity grid and compared to other local requirements guidelines. As the guideline is rather simple, visualisation of all local requirements (including capacity of the grid) can be used to create a common requirement map.

As mentioned before, the municipality of Amsterdam has already worked on a strategic plan for charging station deployment by comparing maps of expected electric vehicle demand with the grid maps, thus comparing two requirement sets. Rotterdam is planning to define search areas by combining demand, mobility, permit, spatial planning and possibly grid requirements. Combining both approaches would lead to a detailed structure where requirements are visualised on maps which can be compared.

Figure 38 Example of strategic charging station deployment map (map is based on Google maps), showing on which location charging stations can be located. In green neighbourhoods the

In the end, the process should thus lead to a map where city neighbourhoods are assigned with feasibility for charging stations, like for instance the (hypothetical) map for the Utrecht inner-city below.

Tools to visualise and compare data already exist. A software tool called "Geographic Information System" (GIS) allows to combine maps of data and can be used for planning and data communication purposes [Raju, 2003].

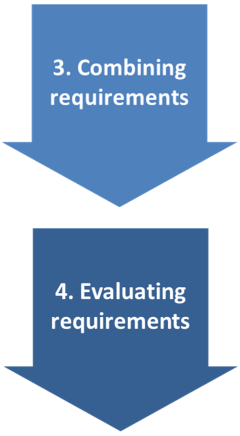
As this thesis only looked into the impact of electric mobility on the grid and thus merely on the location of charging stations on the electricity grid, the creation of the other guidelines will not be discussed in detail. The process will however look into how the trade-off between the requirements can be made.

Process steps

The consultation process of using the guidelines is divided into the following steps:

1. *Initiation:* Municipalities initiate the process (as indicated, two of the municipalities have shown steps or interest in creating a strategic charging station deployment map). Network operators can also urge for the municipalities to do so, by informing them of the consequences of grid impact (reduced grid reliability, deployment delay, construction).

2. *Preparation*:
   I. Municipalities on beforehand create a map with possible locations for charging stations can be located. These locations are parking spots near:
      - Shopping malls;
      - The city centre;
      - Main roads (highway or inner-city roads);
      - City districts where most households do not have private parking spots (for instance near large apartment buildings).
   II. Network operators create the guideline for grid feasibility;
   III. Municipalities use their own possible locations to look into other requirement sets of for instance availability of parking spots and permit requirements. Possibly input of boroughs can help to create these requirement maps;



3. *Comparing requirements:* All guideline maps can be combined in GIS in order to locate problematic locations. When critical grid locations show, network operators will explain the consequences of grid impact for the particular location, thus the required construction for grid reinforcement and an expected term for these reinforcements.

4. *Evaluating requirements:* Based on these expected consequences, municipalities can evaluate the chosen location by their benefits (for instance the fact that it is located near a very crowded shopping mall) and their downsides (associated with construction and delay).

Figure 39 Process steps for municipalities and network operators

From the evaluation municipalities can still consider installing charging stations in a category 3 area or expect to exceed a category 2 area's capacity. In that case municipalities consult with the network operators on the consequences. Also options to limit the impact can be discussed, for instance to connect the charging station to a nearby cable, to use a charging station with a lower power demand or to use a smart charging station[50].

Evaluation of different interests

The evaluation of the municipality thus entails a trade-off between different interests. Examples of these interests are summed up below. Note that these interests are not elaborated in detail. As said before, this thesis merely looked into grid requirements. More research is required for specifying the other location requirements.

- Mobility figures
  Will the charging station be located near busy roads so that vehicles will have easy access to charging stations
- Permit requirements and procedures
  Does the location have other purposes and what permits (including permit terms) are required in order to use the property for charging stations.
- Consumer (electric vehicle users) requirements
  An amount of charging stations needs to be available for a certain number of vehicle users[51]
- Availability of parking spots
  The charging station should not exclude parking spots when insufficient parking spots are available.

As can be seen in the list above, there is a large difference between the types of requirements. For evaluating the feasibility of a location different requirements need to be compared and assessed. As said above, the end result of the consultation process is to create a map in which neighbourhoods are indicated with their feasibility for high power charging stations. This feasibility would thus have to be assessed on a comparable factor, on some sort of common denominator. Keeney (1994) describes three types of factors (attributes) to which situations can be assessed, namely natural attributes, proxy attributes and constructed attributes. Natural attributes in general have a common interpretation. The costs of grid reinforcements are an example of a natural attribute to the network operator. Proxy attributes can also be measured based on an objective, however, this measurement is not a direct effect of the objective. The delay of charging station deployment to municipalities caused by grid reinforcements would for instance be a proxy attribute to grid reinforcements as

[50] If the network operator is allowed to use load control, where vehicle charging is delayed during peak hours, the charging station will have limited impact on peak demand.

[51] Here a 'demand map' could be created, using the formula as used in the grid impact calculation (see section 3.1.1). Such a map can identify high-demand areas and thereby assign a certain number of charging stations based on the expected charging demand.

it is an indirect effect of reinforcements on charging station deployment. Natural or proxy attributes are the most favourable common denominator to use. The values of the attribute could directly follow from the assessments of the requirements, or be translated via correction factors (to for instance translate delay of permits into costs). In many problems, where requirements, costs or effects have to be compared, money is used as an attribute. Different requirements are then translated to costs or benefits[52].

In the consultation process between municipalities and network operators it would however be difficult to use money as a common denominator as the costs and benefits apply to different actors. The costs for the network operator are very high especially when one compares those costs to possible costs of for instance permit requirements. For municipalities these costs are however irrelevant as they are not required to pay them.

It is thus difficult to translate the requirements into a natural or proxy attribute where the network operators' interests are included in the municipalities' interests. However, one can also look at constructed attributes. Constructed attributes can be used if the effects of a certain action cannot be measured. As mentioned in section 3.3, the municipality also faces implications of grid impact, namely those related to nuisance to residents and companies. It is therefore recommended to evaluate the different requirements based on a constructed nuisance factor, for instance a grade between 1 and 5. This nuisance factor can either be based on nuisance to residents (for instance road construction, reduced grid reliability, reduction of available parking spots), or on nuisance to vehicle users (for instance the distance vehicle users have to drive in order to have access to a charging station). The sum of the nuisance factors would correspond to the nuisance of locating a charging station in a certain neighbourhood. The higher the nuisance, the lower the feasibility for that location.

Effect of consultation process on grid impact

The process presented above is a rational process to deal with grid impact. One should however note that the process is merely based on an informal interaction, meaning that there is no guarantee that the process will be a success.

Evaluation of The *Watertoets*

In 2008 the *Watertoets* was evaluated [Van Stokkum, Van den Broek, 2006]. The conclusions were twofold. On the one hand the evaluation concluded that the *Watertoets* was a useful way to reduce the 'cultural and language differences' between the water authority and the municipality. When the municipality was willing to deal with water management, the tool was also successful in including water considerations in construction projects. However, the success of the consideration depended on this willingness of the municipalities to include water considerations in projects and even when this willingness existed, other factors (like internal communication within the municipalities) can decrease the effectivity of the tool. Furthermore, in many cases water management was not included as other spatial planning requirements overruled water management requirements.

The section above describes how a guideline can be designed for electricity grid constraints and used in a process. The process described is more or less similar to the *Watertoets* in providing a low threshold test to see whether a new project (construction project or charging station) will be harmful to a certain infrastructure (water management or electricity grid). However, also an important difference exists between the *Watertoets* and a guideline for grid limitations. The *Watertoets* has a legal basis. It is required for municipalities to consider water management in new construction projects. The success of the guideline might thus be even more dependent on the goodwill and willingness of municipalities to cooperate with network operators.

[52] One can for instance do a social cost benefit analysis where social, as well as monetary effects of an activity can be analysed and compared [Harberger, 1984].

From the *Watertoets* case presented above, it can be concluded that even with a legal basis, the success of a process of cooperation will always depend on the willingness of the actors to cooperate. Both in the case of electric mobility and in the *Watertoets* case, the network operator and water authority are dependent on the willingness of the municipalities to cooperate. In addition, other factors, like internal communication in a municipality or other requirements overruling grid impact can in the end make the process unsuccessful. As already described, the willingness of the municipalities appears to be present although it can still then not be guaranteed that the municipalities will act according to that willingness.

However, even in case no changes to the location are made based on the guideline, or when the municipalities decide that other requirements override the grid limitations (so municipalities still decide to install charging stations on category 2 or 3 locations), the network operators are still provided with valuable information as network operators are informed on charging station locations. The plan would allow them to know in an early phase of charging station deployment, if charging stations are considered to cause an excess of grid capacity. Network operators can anticipate beforehand to the additional load. This anticipation will not always directly involve grid reinforcements, as it is at that moment in time uncertain if the additional load of charging stations will definitely occur, but network operators do risk assessments to grid components to decide whether or not they require replacement. Based on the strategic charging station deployment plan, network operators can further specify this risk assessment. The process allows them to better estimate an expected demand growth.

The guideline is not only useful for the process with the municipality. The guideline also allows for simulation of the impact of high power charging stations which are not located on public property. High power charging stations are in one of the charging concept scenarios (see section 2.1.3.4) considered to be located at current fuelling stations. As these locations are not public property, the municipalities will not have a say on the location. Private companies like fuelling station owners might not be as willing as the municipalities to cooperate with the network operator in order to limit the grid impact. These parties have no public interest and it is probably not possible, or more difficult, to change the location of the charging station as these parties only own a limited amount of property. The network operator guideline would in that case not allow for a process, but it can help the network operator to identify critical grid components requiring reinforcement. Network operators can in that case again better estimate when impact can occur.

5.3 EVALUATION OF STRATEGY

The section above provides a possible process design to deal with grid impact in charging station deployment. This section will evaluate the process by looking into the objective of the strategy to limit social costs and by discussing the general value of the strategy to other actors than considered in this thesis.

5.3.1 EVALUATION OF STRATEGY TO MEET OBJECTIVE

The thesis objective is to determine a strategy in order to limit social costs of charging station deployment. In chapter 2 the system was described based on a system diagram. The project steps were described by the interactions in the system diagram. The first step of the project was to study the impact of electric vehicle use on the distribution grid, thereby looking into the interaction between vehicle users, via electric vehicles and charging stations to the distribution grid. This step was done in chapter 3. The second step was to see how actors influenced this impact and how actors were influenced by the impact. These interactions were analysed by means of related institutions in chapter 4. The institutional analysis looked into degrees of freedom and influences of existing institutions on the technical options. This step identified several potential strategies of which one was chosen. In the third step, discussed in this chapter, an option to limit the impact of electric mobility on the distribution grid and corresponding social costs is presented, taking into account the institutions of network operators and municipalities. The process above describes a possible interaction between municipalities and network operators in order to apply the technical option of assessing the location of charging stations based on the grid capacity. The institutional analysis identified a way to apply this option, taking into account the existing institutions.

As mentioned before, it can not be guaranteed that no grid impact will be caused by charging station locations. The consultation process however still has value if municipalities do not comply, as network operators will have information on expected charging station locations. The process can thereby lead to lower chances of grid failure due to unexpected load increases and faster charging station deployment. In addition, the process allows the network operator to inform municipalities on grid impact and the corresponding consequences.

Reflecting to the thesis objective, thus to the ability of the consultation process to limit the social costs of charging station deployment, the following can be concluded. In the case where the process does lead to different locations of charging stations, social costs are avoided by reducing the need for grid reinforcements. In case the process allows network operators to anticipate to an increased load on critical grid components, social costs are reduced by avoiding a reduced grid reliability. In both cases also the municipalities' interests are safeguarded as charging station deployment can occur fast (no delays due to reinforcement construction) and the process is rather simple and does therefore not take much additional time.

The institutional analysis in the previous chapter not only looked into the possibility of a process to deal with grid impact, but looked into all institutional layers. The options which were identified in the other institutional layers provide the potential to limit social costs of electric mobility and thus to meet the thesis objective, but have not been elaborated in detail. The options can nonetheless form the basis for further research on limiting social costs of grid impact.

5.3.2 EVALUATION OF GENERAL VALUE OF STRATEGY

To assess the general value of the combined strategy presented in this thesis, two different aspects will be looked at. The first aspect relates to the fact that only municipalities with an active electric mobility policy are considered in this thesis. It is however valuable to look into the feasibility for municipalities which have still to decide which policy to apply. A second aspect of general value of the strategy is the applicability of the strategy for other systems than electric mobility.

5.3.2.1 GENERAL VALUE OF STRATEGY TO OTHER MUNICIPALITIES

In order to assess the general value of the strategy to other municipalities, interviews were conducted at two municipalities which are in an earlier phase of electric mobility deployment. These municipalities are The Hague and Delft. The main difference between these municipalities and the three municipalities considered in this thesis is the value they assign to electric mobility. Amsterdam, Rotterdam and Utrecht see an added value of electric mobility in increasing the air quality and achieving the CO_2 objectives. Both The Hague and Delft invested in other sorts of sustainable mobility, mainly in natural gas and biogas vehicles. Electric mobility is therefore for them less valuable to invest in and seen as an external development to which anticipation is required. The municipality of The Hague is however looking into a change of policy to possibly actively stimulate electric mobility.

The difference in perspectives on electric mobility could create a difference in the willingness of municipalities to cooperate with the network operator. A smooth and fast deployment (which can be delayed by grid reinforcements) might be of lower interest. However, during the interviews, the municipalities indicated a willingness to cooperate on charging station deployment with network operators via Stichting E-laad. In the interview with The Hague it was stated that cooperation and sharing knowledge with Stichting E-laad was seen as a valuable possibility to come to a public tender. Stichting E-laad already has experience with tendering for charging infrastructure, which the foundation is willing to share. One of the other institutional options, namely a combined tender to include smart charging devices, could thereby be applicable to these municipalities.

The mapped guideline by the network operator will also be valuable in cities that have not yet deployed infrastructure, as an easy set of requirements can be taken into account when assessing charging station locations. A question which rises here is however whether network operators will be willing to undertake the time-consuming business of creating such a map if it is not certain whether municipalities will act according to it. However, all municipalities will at some point have to form a certain policy for charging station deployment due to their role in spatial planning. The municipalities thus have to come up with a set of requirements by which to decide how charging station locations will be assessed[53]. Grid specific requirements can be included in such a requirement set. The consultation process can help to do so.

To conclude this section, interviews with two other municipalities showed no reason to believe that the recommendations are not applicable to other municipalities than the three considered, although they might only be applicable when the municipalities reach a later stage of electric mobility deployment. A question can however a rise whether network operators will be willing to create the time consuming guideline for all municipalities.

5.3.2.2 GENERAL VALUE OF STRATEGY IN OTHER SYSTEMS

Electric mobility as a development of the electricity system is not unique as a socio-technical system. In general, in all infrastructure systems, complexities related to technology and actor involvement can be identified [Ottens et.al., 2006]. An additional matter of complexity in infrastructure systems is the existence of network externalities. Infrastructure systems are often involved with social costs or external effects which cannot be assigned to individual users. These externalities require governments to be involved in the system. However, due to the technical complexities of the networks, governments often have limited insight in the operation of the network.

Although the strategy above specifically applies to the impact of electric mobility on the electricity grid, the application of a more or less similar process in the Watertoets case showed that the strategy can also be applicable in other cases. The strategy entails mapping of infrastructural constraints and allows for identification of critical infrastructure components in order to include those in policy making considerations. Four general steps should be taken into consideration for mapping infrastructural constraints, where each step will shortly be referred to the application in the electric mobility (a) and Watertoets case (b).

1. Identification of the infrastructure and the scope considered
    a. *Electricity grid in municipality*;
    b. *Groud and surface water in municipality*.
2. Identification and mapping of constraining factor(s) of the infrastructure
    a. *Loading of critical grid components*;
    b. *Water safety, health, drought, water quality etc.*
3. Mapping the (policy) objectives
    a. *Look at possible charging station locations*;
    b. *New construction project.*
4. Combine the mapped infrastructural constraints and objectives to identify critical components of the infrastructure

[53] Municipalities might also consider refusing the use of public property for charging stations. In that case the proposed process would not apply. It is however expected that in case of wide-scale electric vehicle adoption most municipalities will not refuse as it is one of their public values to facilitate the (sustainable) citizen.

a. *Look at critical charging station locations*;
b. *The Watertoets.*

Mapped infrastructural constraints allow for better communication between infrastructure operators (or owners or providers) and policy makers, enabling policy makers to adapt policy according to infrastructure capabilities thereby possibly reducing externalities on the infrastructure.

5.4 CONCLUSIONS STRATEGY

Options to limit grid impact of electric mobility can be found in combinations of technical and institutional possibilities and degrees of freedom. Several options were identified in this thesis. Based on the current information availability and institutional feasibility of the options, a process of consultation on high power charging station location is identified as the most feasible option.

The largest problem of coming to such a consultation is to make grid impact requirements an understandable and low threshold requirement for the assessment of the location of charging stations. The process proposed in the combined strategy is for network operators to create a mapped guideline which provides quick insight for municipalities in the capacity of the grid component to deal with additional load of a charging station. Municipalities can use the guideline to assess locations of charging stations for their feasibility and, together with the network operator, to create a strategic infrastructure deployment plan. This plan can assign feasible locations for charging stations in an early phase of charging station deployment. In this assessment also other factors need to be taken into account, such as spatial planning, permit requirements, and consumer and residents requirements. Due to the relative simplicity of the guideline, it is possible to include these other interests as well. These requirements would however have to be translated into a common denominator. The common denominator is difficult to identify as costs and benefits apply to different actors. It is therefore recommended to use nuisance to residents and electric vehicle users as a variable for the feasibility of charging station locations. The higher the nuisance, the lower the feasibility.

The process allows for municipalities to be informed on grid impact implications and for network operators to anticipate to grid impact in an early deployment phase. The process also allows municipalities and network operators to assess the feasibility of certain locations based on grid impact, thereby limiting social costs of grid reinforcements. One should, however, note that the proposed process is a rational process. The success of the process always depends on the acts of actors and there can thus not guarantee that municipalities will actually adjust their charging deployment strategy based on grid limitations. Other local requirements can overrule the grid requirements. In that case, the process would merely have value in knowledge sharing of municipalities and network operators.

The process is designed for network operators and municipalities with an active electric mobility policy. The process is also expected to be feasible to municipalities who do not yet have an active electric vehicle policy. In general, all municipalities have a role in electric mobility due to their public property ownership and thereby have a role in assessing the location of charging stations. Grid impact requirements can be included in this assessment.

6. CONCLUSIONS AND RECOMMENDATIONS

Climate change, high energy prices, dependency on fossil fuels and air pollution are driving mobility towards sustainable solutions. A promising option for sustainable mobility is electric mobility. Electric mobility helps to reduce CO_2 emissions and emissions causing air pollution. Due to these promising environmental advantages of electric mobility, national and local governments alike are stimulating consumers and companies to switch to electric mobility solutions.

Electric mobility does however increase electricity demand, causing a risk for lower reliability of the network. In case of wide scale electric vehicle adoption, the network operators have to deal with a significant increase in demand, possibly during existing peak demand hours. Grid components might no longer have sufficient capacity to deal with this demand and will require reinforcement. Currently, the impact of electric mobility on the electricity grid is uncertain and network operators do not know to which impact they should anticipate. Some large municipalities in the Netherlands have however already initiated a stimulating policy for electric mobility. Part of this policy is to deploy a charging infrastructure throughout the municipality. Municipalities face the benefits of electric mobility on air quality and CO_2 emission reduction. Network operators mostly deal with impact on reliability of the grid and with potential high costs for grid reinforcements. Both organisations are public organisations, meaning that both the benefits and costs of electric mobility are socialised. The problem with the allocation of the costs lies in the fact that municipalities in general do not have an incentive to take the costs of grid reinforcements into account.

The problem of the impact of electric mobility on the grid is identified as a socio-technical system. The impact of electric mobility on the grid is not only complex due to the (technical) complexity inherent to the electricity grid. The complexity is increased by the actors involved in the system and their formal and informal relations. Therefore the impact of electric mobility is not only described from a technical perspective, but also described by means of two actors involved in this impact, namely municipalities and network operators.

The objective of this project is to come up with a strategy for municipalities and network operators to limit the impact of charging station deployment for electric mobility on the grid. The main question to be answered in this thesis is therefore:

How can municipalities and network operators come to a strategy to limit social costs of electric mobility charging infrastructure?

The strategy will look into the most feasible combination of institutional and technical options to limit social costs. In the thesis social costs refer to grid impact, municipalities to three municipalities actively involved in electric mobility (Amsterdam, Rotterdam and Utrecht) and network operators to the three largest network operators of the Netherlands (Liander, Stedin and Enexis).

6.1 ANSWERS TO SUB-QUESTIONS

The main question is divided into five parts, each considering different aspects of the research. The five sub-questions related to these aspects are answered below.

1. What does the electric mobility system look like?

Electric vehicles will charge via the existing electricity network. The electricity network is subject to several developments on load, supply and the network itself. Electric mobility is one of these developments and influences the electricity system by increasing load, possibly on peak demand hours. Electric vehicles can be

charged via a normal plug, connecting the vehicle to an existing grid connection, but in many cases public charging stations are also required. These public charging stations require new grid connections.
The Dutch electricity grid is a very reliable network. Developments like electric mobility alter normal grid operation. When left to consumers' convenience it is expected that the peak of charging demand will occur at the same time as the normal electricity demand peaks. Electric mobility can therefore harm the reliability of the grid. Basically there exist two ways to deal with this impact. The first is to reinforce grid components, which comes with high social costs. The second option to deal with the impact is to apply smart grids, whereby the grid capacity is used more efficiently. The legal as well as technical concept of smart grids is however still in development.

When looking at the relevant actors, three main actors can be identified. First municipalities, of which three are currently really deploying infrastructure. These municipalities actively stimulate electric mobility by deploying charging infrastructure, non-monetary incentives like free parking spots or access to environmental zones and by electrifying their municipal vehicle fleet. In addition, municipalities have a role in public property ownership on who many public charging stations will be located. The second actor is the network operator which is responsible for operating and maintaining a reliable grid. The network operator will be faced with an increased electricity load. Network operators are initiating pilots in order to gain insights in charging behaviour of vehicle users. These vehicle users form the third actor group. Users determine the deployment of electric vehicles and influence the grid via their charging behaviour. However, users are merely considered as passive actors, included in models by their charging behaviour and vehicle demand.

2. How will electric mobility impact the electricity system?

By means of their charging behaviour, users impact the electricity grid. The impact of full adoption of electric vehicles is calculated in 2040 for a sub-grid in Utrecht. In the calculation, also normal electricity demand growth (organic growth) is included. The model applied used a *differentiation formula* for additional load of electric vehicles per neighbourhood, based on demographic characteristics. These demographic characteristics entail income, property value and number of vehicles per household in a neighbourhood. The calculations indicate that organic growth overloads 19% of the grid components. In case of full adoption of electric vehicles, 29% of the grid components is overloaded. An uncertainty analysis showed how different electric mobility deployment strategies influence the impact of electric mobility on the grid. This analysis implies that certain grid components are already at critical loads and will be overloaded. The sensitivity analysis also shows that fast charging has a significantly larger individual impact to the grid than slow charging and that smart charging can significantly limit grid impact. Furthermore, the calculations show value to the differentiation formula, which bases the additional load on local demographic characteristics, as these calculations provide more detailed information on the grid impact to be expected. Note however that the differentiation formula merely apply to lower shares of electric mobility.

Implications of grid impact entail either a possible reduced grid reliability and corresponding negative consequences to consumers and the business climate in the region, or high socialised costs for grid reinforcements. These socialised costs could be associated with social inequality and a nuisance for construction for reinforcements.

In order for network operators to plan reinforcements accurately and on time (before reduced reliability of the grid is an issue), it is important to know where the impact can be expected. It is therefore valuable for network operators to calculate the expected impact of municipal objectives for electric mobility on beforehand. These objectives can provide insights as to which grid components will need to be reinforced, thus helping the network operator to anticipate to electric mobility. In order to have insight in local impact of electric mobility, the objectives need to be translated to a load per grid node taking into account local grid and demographic characteristics. It is therefore recommended to use the *differentiation formula* for calculating local grid impact based on electric mobility transition objectives.

Two options are identified to limit the impact of electric mobility to the grid. The first is to install smart chargers in public charging stations, which are able to allocate charging load to off peak hours. A second option to limit the impact of electric mobility to the grid is to base the location of high power charging stations on the ability of the grid to cope with the additional demand. Charging stations can be located on other grid branches with sufficient capacity to deal with the charging station load, or located at the beginning of grid branches in order to limit the amount of reinforcements required.

3. What is the institutional environment of the municipality and network operator related to electric mobility?

The institutional environment is analysed by means of the four layer model of institutions by Williamson (1998) (adapted by Koppenjan and Groenewegen). This four layer model describes four types of institutions: informal, formal, institutional arrangements and interaction between actors. These institutions shape actor behaviour and define the role of technology in this actors behaviour. The analysis describes which institutions play a role for municipalities and network operators in electric mobility and which institutional options exist in order to limit impact of electric mobility to the grid and the associated social costs.

From this institutional analysis, three main conclusions can be drawn:

1. *The actors are faced with different roles of institutions*:
   Municipalities are bounded to sustainability and air quality objectives and obligations. Electric mobility can help to achieve these objectives. Network operators are responsible for operating a reliable grid. Their legal responsibilities and powers oblige them to anticipate to electric mobility but provides limited possibilities for them to actively influence the electric mobility system.

   A public value allocation conflict is identified, which refers to the fact that municipalities are mainly faced with the benefits of electric mobility to the public values of sustainability and liveability. Network operators are mainly faced with the costs of electric mobility. This conflict leads to a skewed incentive structure where municipalities are able to limit social costs of electric mobility, but have very limited incentive to do so as they are not faced with most of the social costs. Network operators deal with the social costs of grid impact, but have limited possibility to reduce them.

2. *The actors have a different perspective on the role of technology*:
   For the municipalities, electric mobility is a tool to achieve sustainability and air quality objectives. Municipalities are thus mainly focused on the vehicle and charging stations technology, which is required for electric vehicle adoption. For network operators electric mobility is a long term development on the existing electricity grid. Their perspective on technology thus differs, possibly leading to miscommunication.

3. *Possibilities in institutions to limit grid impact exist in*:
   - A market model discussion which is meant to arrange actors' roles in charging station services. This discussion allows for a possible **ownership role for the network operator**. A more active role would allow for the network operators to apply impact limiting options;
   - A **combined tender** on public charging station deployment between cooperating network operators and municipalities, which can allow for inclusion of grid limitation requirements;

- **Active shareholding** of municipalities on network operators can allow for a mild coupling of the public values, thereby dealing with a public value allocation conflict and increasing the municipalities' interests in the social costs of grid impact;
- A process can be initiated to enable a **consultation of network operators on grid impact**.

The application of the four layer model of institutions to describe the interests and involvement of the two actors is deemed largely feasible. The model is able to describe and compare the underlying reasons why the municipalities and network operators act in a certain way.

The role of technology and the interactions with technology in electric mobility is however not completely reflected by the four layer model of institutions. For municipalities, the technical system considered is the relatively unstable vehicle and charging station technology. The difference can possibly be explained by the fact that the emergence of a new technology (electric mobility) can cause developments on the existing technical system (the electricity system). Where municipalities look at the technology causing developments on the existing system, the network operators consider the entire system. The figure below proposes a revised four layer model, showing the differentiation between a technical system and developments occurring in one of the sub-systems. The technical system can be composed of multiple developments. Note that by considering technology as a technical system, composed out of sub-systems and developments, the revised model includes a more systems thinking in the four layer model.

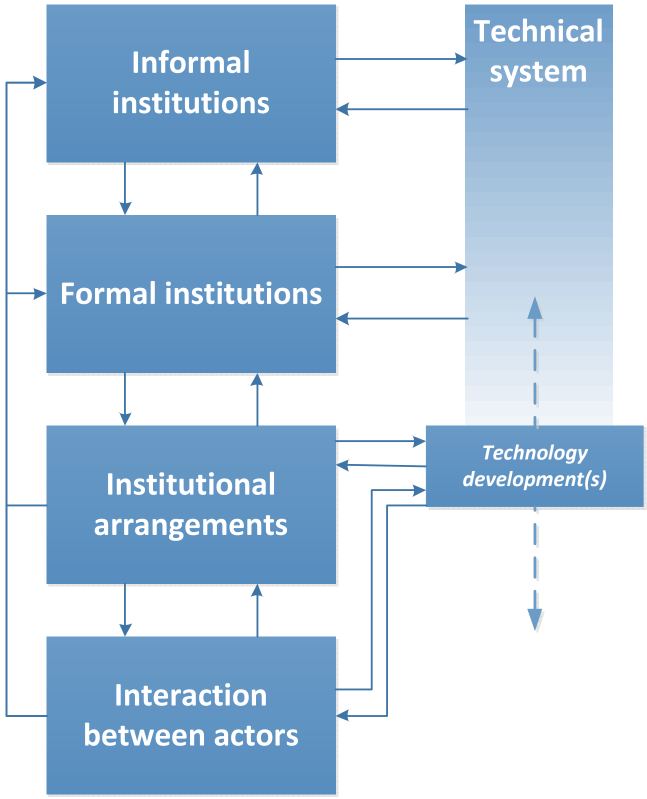


Figure 40 Proposition for revised four layer model of institutions, based on [Koppenjan, Groenewegen, 2005]. The revised model differentiates between a technical system and subsystems developing within the system.

4. How can institutions be arranged in order to limit social costs of electric mobility?

From the institutional analysis, several options were derived which had potential to limit grid impact. The strategy only looks into the option of interaction between actors in consultation on the location of high power charging stations, as the other options either require further study or have a lower feasibility. The other options are however valuable to serve as a basis for further research and provide insight in the developments of the electric mobility institutional system.

The consultation process enables the technical option to arrange charging station location based on grid capacity. The institutional analysis identified two problems to be solved by the process design, namely that the process had to be able to combine multiple objectives and that the actors had different knowledge bases. The grid impact study showed a great complexity of grid operation and grid impact. It is thus difficult for municipalities to know what kind of impact they have to take into account. Therefore the process focuses on creating a low threshold set of requirements for municipalities to take grid impact into account. Such a guideline would also have to be able to be combined to other objectives of municipalities or, in the future, of other actors. It is therefore proposed to visualise grid based requirements for high power charging station locations. Network operators are advised to create a map for the municipalities where grid branches and the neighbourhoods in which they are located are assessed into three categories, illustrated by figure 41.

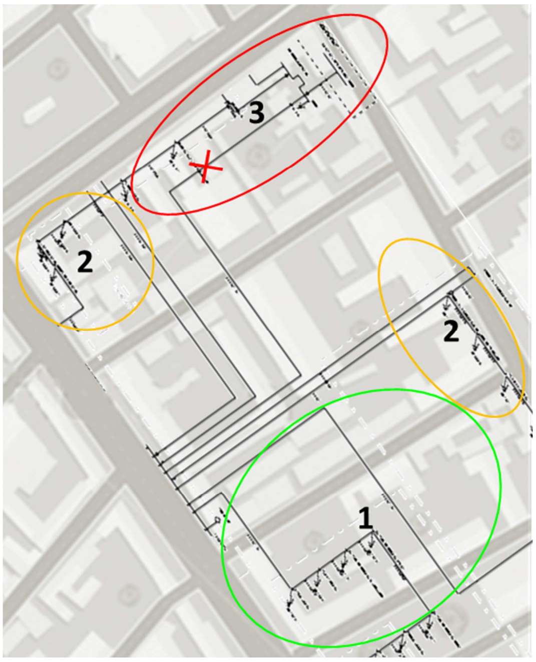


Figure 41 Hypothetical guideline to be created by network operators. Guideline shows capacity of grid branches to deal with additional load of charging stations, where 1. indicates no problems, 2. indicates that a limited capacity increase is possible and 3. indicates that reinforcements are required when installing charging stations.

This requirement map can be used in a process where the municipality creates a feasibility map for charging stations together with the local network operator. Based on the grid feasibility of a certain location, municipalities evaluate whether or not the location is still feasible. This evaluation includes also other location specific requirements. To do so, it is recommended to translate all requirements to nuisance for residents or electric vehicle users. The nuisance caused by grid reinforcements can in that case be compared to other location specific requirements. As the process is merely informal, it cannot be guaranteed that municipalities will conform to the process and no impact of the public charging stations will occur. However, when municipalities decide to locate charging stations at category 2 or 3 locations, network operators are still, in an early phase of deployment, informed on expected increases in load demand by electric vehicles. Network operators will thus have more information on which impact they should anticipate.

6.2 ANSWER TO MAIN QUESTION

Technical options to limit the social costs of electric mobility exist, namely smart charging and base the location of high power charging station on grid capacity. These options limit the impact of electric vehicle charging on the electricity grid and thereby social costs. Network operators, however, have limited legal freedom to apply these options. Municipalities do have the possibility, but have a limited incentive to do so. Several institutional options have been presented to overcome the skewed incentive structure. Of these options a consultation process between municipalities and network operators is deemed most feasible. Municipalities appear to be willing to take network operators' interest into account. It is however expected that they will only do so if it does not cause a large barrier for charging station deployment. A process design which is focused on the creation of a low threshold guideline and a strategic feasibility map will allow municipalities to assess locations on the occurrence of grid impact. In case they still decide to locate a charging station on a critical grid location, network operators will be informed in time to anticipate on the increased demand load. Such an anticipation avoids unexpected demand increases, thereby reduces the possibility of grid failure, of reduced grid reliability and corresponding social costs. In the case that the process leads to different locations of charging stations, social costs are avoided by reducing the need for grid reinforcements.

To conclude this section, one should note that in many complex infrastructure sectors, similar relations between technical and actor systems, and between actors exist. Although the strategy specifically applies to the impact of electric mobility on the electricity grid, the concept of mapping strategies can also be valuable in other sectors. In general terms, the strategy entails mapping of infrastructural constraints. The map allows for indication of critical infrastructure components. Mapped infrastructural constraints allow for better communication between infrastructure operators (or owners or providers) and policy makers, enabling policy makers to adapt policy according to infrastructure capabilities thereby possibly reducing externalities on the infrastructure.

6.3 RECOMMENDATIONS FOR MUNICIPALITIES AND NETWORK OPERATORS

One of the research objectives presented in the beginning of this thesis was to recommend how municipalities and network operators can limit social costs of grid impact of electric mobility. This section will translate the conclusions presented above into three main recommendations for municipalities and network operators.

Consider electric mobility from a broad perspective
Electric mobility is not a standalone development. When looking at the social costs of electric mobility, several other developments play a role, for instance smart grids and energy savings. For network operators it is therefore recommended to come up with energy scenarios to use for grid impact studies. These energy scenarios describe different scenarios of expected growth, renewable distributed energy input and smart grids which influence electric mobility and the electricity grid. Municipalities currently often consider electric mobility mainly as a temporary objective for sustainable mobility. This perspective does not take into account the effect electric mobility has on the existing energy system. In order to limit social costs, municipalities are recommended to consider electric mobility also as an energy development. To do so, it is important for the municipalities to gain knowledge on potential grid impact. The next recommendation describes how this knowledge can be gained.

Estimate expected grid impact of electric mobility objectives and participate in a process to limit this impact
The implications of grid impact (potentially reduced grid reliability, socialised costs of grid reinforcements, nuisance of construction for grid reinforcements etc.) imply that it can be very useful to anticipate to and avoid grid impact of electric mobility. In order to anticipate or avoid the impact, it is firstly required to make thorough estimations on the expected impact. These estimations can be based on municipal electric mobility objectives on the number of electric vehicles in the coming decades and on the expected location of high power charging stations. It is recommended for the network operator to calculate the expected grid impact based on these objectives. For the municipalities it is recommended to communicate their objectives and expectations to the network operators in an early stage. Communication in an early stage allows network operators to anticipate to required grid reinforcements (thereby avoiding reduced grid reliability) and come up with possibilities to limit the grid impact. The calculation in an early stage also allows the network operators to translate potential grid impact and possibilities to limit the impact into the guideline presented above. Furthermore it is recommended

to both municipalities and network operators to participate in the above presented process of the creation of a strategic charging station location map.

The most important aspect underlying the process presented above is the communication between network operators and municipalities. For network operators, the impact which electric mobility causes on the grid is not per definition a large problem, it is merely the uncertainty related to electric mobility which makes it difficult to anticipate to the problem. Communication between the two actors is thus essential for network operators to anticipate to the coming developments. The communication can also provide an opportunity to the municipalities to limit nuisance of network constructions in dense populated areas.

Look into the institutional possibilities to limit grid impact

This thesis elaborates upon only one institutional option to limit grid impact. However, also other institutional options to limit the impact are presented which have the potential to reduce social costs of electric mobility. Firstly the market model discussion provides opportunities for network operators to have a say in charging station deployment. From a social cost point of view, it would be valuable for the network operators and municipalities to commit to this market model option. The second option presented was for municipalities to become an active shareholder in safeguarding the network operators' public values. If this option is deemed possible by the actors, it is recommended for the municipalities to specify the public values which they want to safeguard and specifically include long term objectives of energy developments like electric mobility in this specification. The third institutional option presented in this thesis is to opt for a combined tender procedure between Stichting E-laad (or an individual network operator) and municipalities, thereby including requirements for smart charging. As said, cooperation in tenders exists between Stichting E-laad and the municipalities of Rotterdam and Utrecht. It is recommended to include requirements for smart charging in this tendering procedure. For those options, however, first additional research is required, as will be discussed in the next section.

6.4 RECOMMENDATIONS FOR FURTHER RESEARCH

In the thesis project many uncertainties were identified. A number of these uncertainties were reduced by research in this thesis project, but others remain. This section will describe recommendations for further research in order to reduce these uncertainties as well. Some of the recommendations have been mentioned throughout the thesis report. Other recommendations result from the conclusions.

Including multiple actors

This thesis looked only into cooperation between two actors. The market model discussion, however, shows that in charging station deployment more than two actors are involved. It is therefore recommended to further look into the interests of other actors involved in charging station deployment. Several actor analysis tools can be used to do so. An example of such an actor analysis tool is DANA. DANA is a software tool which uses several actor analysis methods to create actors' perception graphs and to combine them. The combined actor perspectives can illustrate the added value of actors and whether or not conflicts can be expected. Such an actor analysis tool can be used to see whether conflicts on infrastructure deployment can arise. Based on the outcome of DANA, a new process can be designed including multiple actors.

Not only should the interests of multiple actors be analysed, it would also be valuable to test the applicability of the process to the actors. Serious gaming allows for 'simulation' of actors behaviour. In a serious game, actors are confronted with a realistic but simulated case, where they are assigned with a role. The game provides the actors with feedback on their actions. Gaming can be used either to simulate the behaviour of actors by using people who are assigned to a certain role, or to provide feedback on the behaviour of the actual actors. It is recommended to use gaming for network operators and municipalities (and possibly for other actors like residents or boroughs) to test the applicability of the guideline and other requirements proposed in the strategy. In an ideal situation network operators and municipalities would test the creation and the applicability of the guideline and use it to create a long term strategy for a small or hypothetical grid. Such a gaming pilot will show the feasibility of the guideline and the willingness of the actors to use it. If the willingness is high, the guideline can be used to real, larger scale cases.

As said in the beginning of this thesis, vehicle users are key actors, but their expected behaviour is currently unknown. In an Agent-based model, actors are simulated as agents which act according to certain sets of rules that arrange how actors react on environmental changes. Agent-based models can help to analyse the users' behaviour. The user will be modelled as an agent with attributes like willingness to adopt a vehicle[54], its driving distance and its charging behaviour[55]. Other actors can be modelled in a similar way. The system diagram presented in chapter 2 provides a starting point for modelling agents as it provides insight in the attributes (defining actor behaviour) of actors. An Agent-based model with users as central actors can provide insight in the expected behaviour of consumers, although research is still required on the expected sets of rules to apply to the agents. It is recommended to look into these sets of rules to see whether they can be made applicable to Agent-based modelling.

Local scale

In contrast to including more actors in an actor analysis study on charging infrastructure deployment, also more research is required on individual municipalities and their local network operator. This thesis focused on three municipalities and three network operators. Differences were however identified between municipalities and between network operators.

During the interviews it was for instance noticed that municipalities have a different organisation of electric mobility. Rotterdam has more or less outsources electric mobility to an internal engineering company. Utrecht has electric mobility arranged via an internal project bureau. In Amsterdam, electric mobility falls under the department of sustainability. Electric mobility in The Hague, which was still initiating electric mobility during the writing of this thesis, was scattered between several departments. Plans existed to initiate a working group in which all departments could participate. When looking at specific local options to deal with the impact one could for instance think of a formalisation of the process, based on the local organisation. A working group like in The Hague could give a seat to an advisory role of an external party like the network operator, thereby involving them into the decision making on electric mobility.

Institutional options to limit grid impact

In chapter 4 and 5 several institutional options were presented which could help to limit grid impact. Only one of those options was studied in detail. More research could however help to also implement the other options.

Municipalities and network operators have a formal connection via shareholding. Active shareholding on safeguarding public values can allow for more interest of municipalities in the impact of their energy policy (including electric mobility) on the grid. More research is required on identify the willingness of municipalities to get more actively involved in safeguarding the public values of network operators and to identify the effect such an active shareholding role would have on other aspects of network operation.

A combined tendering procedure between municipalities and network operators (or Stichting E-laad) can help to combined the interests and requirements of municipalities and network operators on charging station deployment. Currently already cooperation is initiated between Utrecht and Rotterdam and Stichting E-laad. More study is required on the status of this cooperation. In addition, it is unknown what the willingness of both

[54] The rule can for instance be that a user buys an electric vehicle in case the costs per year are below its current vehicle costs per year.

[55] The rule would for instance be that the user plugs in its electric vehicle when arriving at home.

parties is to come to such a cooperative procedure and include smart charging. More study on the willingness of Stichting E-laad and the municipalities to cooperate is thus required.

In the end of the institutional analysis, a new framework was presented. This framework attempts to include systems engineering aspects in the four layer model. It is recommended to, in future research, look into the feasibility of the model to other socio-technical systems than electric mobility.

Grid impact calculations

It is recommended to do more detailed grid impact studies. Firstly these studies should look into other (medium, as well as low voltage) grids to see whether the conclusions apply there as well. Secondly these studies should entail research on the expected market penetration of fast and slow chargers. The charging concepts have different effects on the grid. It is thus recommended to look into more detailed scenarios for fast, slow and smart charging. A third aspect of more detailed grid studies relates to organic growth. In the case study, organic growth caused the largest share of grid impact. As already stated in the report, it is not sure whether there will be an organic demand growth in the future. As the growth is determining for the outcome of long term grid calculations, it is recommended to research long term demand developments.

During the grid calculations, a difficulty with network software Vision (designed by software company Phase to Phase) was experienced. The software appeared to be designed to change single grid components and calculate the impact. This was however not really applicable to the electric mobility case, as that case involved changes to an entire set of loads. Calculating different scenarios was thus very time consuming. It was however also identified from interviews that people working with the software indicated that Phase to Phase is a company which adjusts to their customers' (network operators) requirements. It could thus be valuable to create a new set of requirements for Vision network analysis to enable network wide adjustments to grid components. One of these requirements would be to include scenario possibilities (like the scenario application included in Microsoft Excel software) in Vision Network Analysis software.

The grid impact calculation paid attention to the n-1 concept. Grids require redundant capacity to cope with additional demand in case of component failure. However, the smart grid concept might allow for different ways to deal with grid failure. In smart grids, loads could for instance be switched off to balance demand and supply. More research is required to see if the n-1 concept can be loosened for some parts of the grid (especially for medium voltage, as for these grids n-1 is not obliged by law). This research should entail both a study of the technical ability of a smart grid to deal with outages and social studies on the social feasibility of loosening reliability criteria of the electricity grid. This subject also touches upon another n-1 related recommendation. In the calculations in chapter 3, grid components were assumed to be overloaded when exceeding 60% load. This value is however merely an average value and does not reflect the true overload capacity for single grid components. For more thorough calculations of each grid component, the true threshold value needs to be determined. For studying individual grid component overloads, more detailed study of the individual threshold value is required.

7. REFLECTION

This reflection will look into the process which led to this report. This section will look into difficulties faced during the project, will reflect on the research framework and on the thesis scope.

The problem described in this thesis project is a real life problem, bound to happen when electric vehicles become widely adopted by the market. Electric mobility will come with social costs, but due to the incentive structure it will be difficult to deal with those costs. Such a problem will not only occur for electric mobility, but can also be translated to other socio-technical systems. The difficulty to deal with the problem was also reflected in the process of this graduation project. One can expect that if a simple solution to a problem of social costs existed, it would have been implemented already (if not for electric mobility, than for other infrastructure systems). It was therefore very difficult to find a real contribution to solving the problem.

The main difficulty was found in the split incentive structure. From a general point of view, it is clear that the impact of electric mobility on the electricity grid is not a social optimum. However, the actors causing the problem (vehicle users and municipalities) have a very limited interest in dealing with the impact. This issue is reflected througout the entire project. The success of the proposed strategy depends on the willingness and ability of the municipalities to deal with the problem. Although it was perceived that the actors are willing to cooperate, a success cannot be guaranteed.

The dependency on actor behaviour made it difficult to come to an actual strategy. Another difficulty is the fact that most actors are still searching for their role to play in electric mobility. It is not yet known which actors will have which role and interest in electric mobility in the future. The process described in chapter 5 tries to take this uncertainty into account and looks into a possible process which can be followed more or less irrespective of changing roles. Still, one should note that the process is merely one of several options by which the actors can deal with the problem. The researcher hopes that by analysing the skewed incentive structure and by identifying where the problem lies, hopefully a contribution is made to solving the problem. By informing the actors on the issue (for instance in the interviews) and by proposing a possible way to deal with it, the actors will have more incentive to take the problem and possible solutions into consideration.

Research frameworks

Due to the difficulty to come to an actual contribution on solving the social cost problem, initially the research was set up very broadly. This broad research definition can still be found in the system and institutional analysis. Both research tools look at a system from a very broad perspective, which has certain consequences on the research. Some aspects researched have only a small contribution to the final strategy. For instance the system analysis looked into the entire electric mobility system, while the remainder of the research focused on the grid impact. The same can be said for the institutional analysis where merely the interaction between actors, and process management is used for the final strategy.

Both the institutional and system analysis have nonetheless shown great value for researching the electric mobility case. The problem considered appeared to be very complex and ill defined. Although the technical system was studied before and knowledge was available on social aspects of electric mobility, the coupling between the technical and social system was lacking. The system analysis allowed defining which interactions in the socio-technical system were uncertain or unknown. In addition, the broad system definition allowed identifying perspectives on electric mobility (where vehicle and charging station technology is more essential to municipalities, the electricity grid and impact on the grid matter to network operators).

Systems are normally defined from a certain perspective. In this research problem not merely one actor was defined as a problem owner. It was thus difficult to define the system. Therefore the choice was based on problem focus, which mostly lay in the electricity system. In addition, the definition was kept rather broad in order to also include multiple actor perspectives. The researcher is aware that this definition might better reflect the network operators' than the municipalities' perspective. This choice can be justified by the fact that network operators simply have a much larger interest in the problem considered. Municipalities have almost no natural interest in the problem defined in this research(note that this is also the main cause of the social cost problem).

Once the system analysis was defined, it allowed a better definition of the problem. The next step was to analyse the three different unknown interactions. The approach to study the first interaction (the impact of user behaviour on the electricity grid) was the easiest one to find, as this interaction mainly entailed a technical analysis of certain actions for which the basis (load flow analysis) is regularly used by network operators. It was more difficult to find a suitable approach for the bilateral interaction between the technical system and municipalities and network operators. The institutional framework of Koppenjan and Groenewegen provided a tool to structure interaction between actor behaviour and technology. This tool was therefore used to further look into actor behaviour and into possible institutional changes to deal with grid impact. From the four layer model of institutions analysis, several options were selected, of which only the lower layer process was elaborated into a strategy.

The broad institutional analysis helped to define the perspectives of the two actors on the problem considered. Knowing the institutions and institutional options on higher levels allowed to see constraints and drivers for the actors to act in a certain way. These institutions also strongly influenced how the actors act or would act towards each other (thus in the lower institutional layer). The institutional analysis thus allowed to find out where the main problem lies and to analyse a possible solution space. Furthermore, even though only one aspect of this solution space was detailed into a strategy, the other options can be used as a basis for future research on limiting social costs of electric mobility.

Project scope

In the project, several aspects related to the problem were left out of the project scope. The scope definition has, per definition, an effect on the final outcome of this thesis. One of these scope definitions (actor definition) was already reflected on in section 6.4 on recommendations for further research. Another aspect outside the thesis scope is the concept of Vehicle to Grid where electric vehicles can be used as an electricity backup facility. Vehicle to Grid was left out of the thesis scope as the feasibility is debatable. The concept does however change the perspective of the network operator on electric mobility defined in this thesis. The perspective of network operators on electric mobility is mainly defined by the negative impact and to a limited extent benefits to flexibility of steering demand. Vehicle to Grid could increase this benefit. It is nonetheless expected that the strategy does not have to become invaluable, as impact of electric mobility can time still occur. The interaction between network operators and municipalities will thereby still be valuable to limit this impact.

A third scope definition is associated with social costs. In this project, merely grid impact is considered as social cost. One could think of more social cost aspects (battery afterlife), or include also social benefits (air quality, CO_2 reduction). These social costs are however only slightly related to grid impact and the strategy proposed here does not per definition impact the other social cost aspects. Broadening the social cost scope would thus mainly lead to a broader research scope and require the inclusion of more technical aspects as well as actors in the proposed strategy. By the current scope definition it was possible to come to an actual contribution to the problem within the time frame available for the thesis project.

REFERENCES

Aanbestedingskalender.nl (2011). *Aanbestedende dienst: Gemeente Amsterdam, Dienst Milieu en Bouwtoezicht. Voorwerp van de opdracht: Opschaling oplaadpunten elektrisch vervoer.* http://www.aanbestedingskalender.nl/noticedetails.aspx?id=c6a22446-2e80-4ed5-bf87-3867dc4d9ec0 Last revisited July 22, 2011

Aansluitingen.nl (2011). *Één Centrale Landelijke Ingang om alle aansluitingen aan te vragen.* http://www.aansluitingen.nl Last revisited July 19, 2011

Accenture (2010). *Studie Marktmodel Laadinfrastructuur ten behoeve van Elektrisch Vervoer.* Comissioned by Netbeheer Nederland and EnergieNed: April 13, 2010

AgentschapNL (2011). *Formule E-team.* http://www.nlmilieuenleefomgeving.nl/formuleeteam/ Last revisited April 12, 2011

Akker, van den G. (2010). *Feedback TNO op 'Recommendation reader and card technology EV Charging systems'.* Nederlands Normalisatie Instituut: December 8, 2010

Akkerboom, S., Buist, G., Huygen, A., Ottow, A., Pront-van Bommel, S. *Smart Grid Pilots. Handvatten voor toepassing van wet- en regelgeving. CONCEPTVERSIE.* Amsterdam, Delft, Utrecht: Juli, 2011

Anegawa (2008). *Development of the most suitable infrastructure for commuter electric vehicles*. TEPCO: Tokyo.

Axsen, J., Burke, A., Kurani, K. (2008). *Batteries for Plug-in Hybrid Electric Vehicles (PHEVs): Goals and the State of Technology circa 2008*. Institute of Transportation Studies University of California Davis: May, 2008

Beek, R.B. van (2010). *Smart Integration of Electric Vehicles in the Dutch Power System.* Master Thesis Systems Engineering, Policy Analysis and Management TU Delft: August 5, 2010

Beishuizen, R. (2011). *WIOR – Aanleiding en achtergrond.* http://www.amsterdam.nl/gemeente/organisatie-diensten/sites/coordinatiestelsel/kennisbank-0/dossier-wior/aanleiding/ Last revisited June 28, 2011

Berg, van den J., Harms, I., Schroeders, J., Sonderleijker, S. (2009). *Actieplan Elektrisch Rijden – Op weg naar één miljoen elektrische auto's in 2020.* C,MM,N, DHV: March 2009

Betterplace.com (2011). *Battery Switch Stations.* http://www.betterplace.com/the-solution-switch-stations. Last revisited April 14, 2011

Blijie, B., Hulle, R. Poulus, C., Hooimeijer, P. (2009). *Het Wonen Overwogen. De resultaten van het woononderzoek Nederland 2009.* ABF Research, Universiteit Utrecht commissioned by: Ministry of VROM and CBS. 2009

Blind, K. (2009). *Standardisation: A catalyst for innovation.* Inaugural Adress Series Research in Management. Erasmus University Rotterdam

Boekema, J., Rumph, F.J., Lycklama, D., Bottelberghs, L. (2010). *Notitie Visie en Roadmap Marktmodel Laaddienstverlening Elektrisch Vervoer.* TNO, Innopay: Oktober 7, 2010

Boer, J. den, Houtepen, R., Hesen, P.L.J. (2011). *Spanningskwaliteit in Nederland, Resultaten 2010 (laag-, midden- en hoogspanning t/m 150 kV).* KEMA Consulting Arnhem: April 28, 2011

Botsford, C., Szczepanek, A. (2009). *Fast Charging vs. Slow Charging: Pros and cons for the New Age of Electric Vehicles* EVS24 Stavanger, Norway: May 13-16, 2009

Bozeman, B. (2007). *Public Values and Public Interest.* Georgetown University Press: 2007

Brooks, A. N. (2002). *Vehicle-to-Grid Demonstration Project: Grid Regulation Ancillary Service with a Battery Electric Vehicle.* California Air Resources Board and California Environmental Protection Agency. San Dimas: p.43

Brooks, A. N. G., T. (2001). *Integration of Electric Drive Vehicles with the Electric Power Grid - a New Value Stream.* 18th International Electric Vehicle Symposium and Exhibition Berlin, Germany

Bruijn, de H.; Heuvelhof, ten E. (2003). Proces Management – Why Project Management Fails in Complex Decision Making. Dordrecht: Springer.

Bunzeck, I., Feenstra, C.F.J., Paukovic, M. (2011). *Preferences of potential users of electric cars related to charging – a survey in eight EU countries.* Grid for Vehicles: March 31, 2011

CBS, PBL, Wageningen UR (2010). *Nationale luchtkwaliteit: overzicht normen* (indicator 0237, versie 08, 14 september 2010). www.compendiumvoordeleefomgeving.nl. CBS, Den Haag; Planbureau voor de Leefomgeving, Den Haag/Bilthoven en Wageningen UR, Wageningen

CBS Statline (2010a). *Motorvoertuigen; totaaloverzicht per periode en naar technische kenmerken.* CBS Statline Den Haag/Heerlen: July 2010

CBS Statline (2010b). *Motorvoertuigen; per postcode naar regio-indelingen.* CBS Statline Den Haag/Heerlen: October 2010

CBS Statline (2011a). *Luchtverontreiniging, emissies berekend volgens het NEC-protocol.* CBS Statline Den Haag/Heerlen: Februari, 2011

CBS Statline (2011b). *Elektriciteit; productie en productiemiddelen.* CBS Statline Den Haag/Heerlen: July 15, 2011

CBS Statline (2011c). *Kerncijfers wijken en buurten 2004-2010.* CBS Statline Den Haag/Heerlen: April 7, 2011

CBS Statline (2011d). *Motorvoertuigen; verkopen naar voertuigtype, per maand.* CBS Statline Den Haag/Heerlen: May 11, 2011

Chan, C.C. (2002). *The state of the art of electric and hybrid vehicles.* IEEE, vol. 90, nr. 2, February 2002.

Clement, K., Haesen, E., Driesen, J. (2008) *Stochastical analysis of the impact of plug-in hybrid electric vehicles on the distribution grid.* In: Electricity distribution, 2009. CIRED 2009. 20th international conference on electricity distribution, 2009. (p.1-4)

Cowan, R., Hutlén, S. *Escaping Lock-in: the Case of the Electric Vehicle (Technology Forecasting and Social Change)*. University of Western Ontario and Stockholm School of Economics: 1996

Cready, E., Lippert, J., Pihl, J., Weinstock, I., Symons, P., Jungst, R.G. (2003). *Technical and Economic Feasibility of Applying Used EV Batteries in Stationary Applications.* Albuquerque: Sandia National Laboratories

Datawonen.nl (2009). *Discoonline. Bron: WoOn09.* 2009. http://www.datawonen.nl/disco/ Last revisited June 20, 2011

Derks, G., Everts, F., Evenhuis, E., Heitkamp, V., Schimmel, R., Terpstra, S. (2009). *Marktwerking – over publieke waarden en marktwerking.* Commissioned by NSOB-MPA: June 5, 2009

Directorate-General (2011). *Energy 2020 – A Strategy for Competitive, Sustainable and Secure Energy.* Luxembourg: Publications Office of the European Union: 2011

Donicie, C. (2009). *Comeback of Gemeentelijk Energiebedrijf.* Binnenlands Bestuur: Februari 20, 2009

e-laad.nl (2010). *E-laad.nl*. FOD Mobiliteit en Vervoer Brussel: 20 april 2010

e-laad.nl (2011). *Waarom verlangt e-laad.nl opstalrecht voor haar oplaadpunten?.* http://www.e-laad.nl/gemeente/119-waarom-verlangt-e-laadnl-opstalrecht-voor-haar-oplaadpunten Last revisited July 22, 2011

EnergieNed (1996). *Elektriciteitsdistributienetten.* Deventer: Kluwer Techniek. First edition: 1996.

EnergieNed (2003). *10 jaar verzuringsconvenant – Resultaten van het bestreiden van SO_2 en NOx door de Nederlandse energieproductiebedrijven.* Arnhem: Februari 3, 2003

Enexis (2011a). *Enexis en Elektrisch Rijden.* http://www.enexis.nl/site/slimnet/elektrischvervoer/elektrischrijden/ Last revisited May 23, 2011

Enexis (2011b). *Mobile Smart Grid* http://www.enexis.nl/site/slimnet/elektrischvervoer/mobilesmartgrid/ Last revisited July 6, 2011

Enexis (2011c). *Mobile Smart Grid – Regulatory Issues.* http://www.mobilesmartgrid.eu/index.php?id=30&zoek=regulatory Last revisited June 28, 2011

Enserink, B., Hermans, L., Kwakel, J. et al. (2008). *Policy Analysis in Multi Actor Systems. Delft: TUDelft*

Essent (2011). *Pilot gemeente Den Bosch: van deur-to-deur elektrisch rijden.* http://www.essent.nl/content/overessent/activiteiten/elektrisch_rijden/ontwikkelingen/gemeente_den_bosch.html Last revisited 29-6-2011.

Essent Netwerk B.V. (2007). *Kwaliteit en Capaciteitsdocument Elektriciteit 2008-2014.* Essent Netwerk B.V. October, 2007

Eurlings, C. M. P. S., Hoeven, van der M.J.A. *Brief van de Ministers van Verkeer en Waterstaat en van Economische Zaken: Mobiliteitsbeleid.* Den Haag: July 15, 2010.

European Parliament and the Council (2008). *Directive 2008/50/EC on ambient air quality and cleaner air for Europe.* May 21, 2008

Frischmann, B.M. (2005). *An Economic Theory of Infrastructure and Common Management.* Minnesota Law Review. Loyola University Chicago, School of Law

Gemeente Amsterdam (2010). *Amsterdam Elektrisch – Het plan.* Gemeente Amsterdam Programmabureau Luchtkwaliteit: Januari 2010

Gemeente Den Haag (2011). *Klimaatplan Den Haag – Bijlage 2: Analyse Klimaatproblematiek Den Haag.* April 2011.

Gemeente Utrecht (2010). *Oplaadpunten.* http://www.utrecht.nl/smartsite.dws?id=346169 Last revisited February 23, 2011

Gemeente Utrecht (2011a). *Actieplan schoon vervoer 2010-2014.* Gemeente Utrecht

Gemeente Utrecht (2011b). *Programma Utrechtse Energie 2011-2012*

Gemeentewerken Rotterdam (2010). *Handboek leidingen.* Rotterdam: 2010

Gool, R.J. van (2008). *Raadsvoorstel: Aanpassing Kabels- & Leidingenverordening, invoering Verlegregeling voor kabels en leidingen en invoering Telecommunicatieverordening.* Gouda: July 31, 2008

Goud, M.O.W. (2011). *Master Thesis Project – Impact of Future Residential Loads on Medium Voltage Networks.* TU Delft, Enexis B.V. Delft: May, 2011

Goudappel Coffeng (2009). *Saneringstool 3.1.* Commissioned by NSL

Green, R.C., Wang, L, Alam, M. (2010). *The impact of plug-in hybrid electric vehicles on distribution networks: A review and outlook.* Renewable and Sustainable Energy Reviews 15 (2011) 544-553

Grond, M.O.W. (2011). *Impact of Future Residential Loads on Medium Voltage Networks.* Thesis Project TU Delft: faculty of Electrical Engineering, Mathematics and Computer Science

Grontmij (2005). *Waardebepaling kleine ondergrondse infrastructuur. Vervangingswaarde van kabels en leidingen in Nederland.* Houten: Grontmij Nederland B.V. / Stichting Pipeline

Hadley, S.W. (2006). *Impact of Plug-in Hybrid Vehicles on the Electric Grid.* Oak Ridge National Laboratory Tennessee: 2006

Hadley, S.W., Tsvetkova, A. (2008). *Potential Impacts of Plug-in Hybrid Electric Vehicles on Regional Power Generation.* Oak Ridge National Laboratory Tennessee: January 2008

Hanschke, C.B., Uytrelinde, M.A., Kroon, P., Jeeninga, H., Londo, H.M. (2009). *Duurzame innovatie in het wegverkeer – een evaluatie van vier transitiepaden voor het thema duurzame mobiliteit.* ECN: January 2009

Harberger, A.C. (1984). *Basic Needs versus Distributional Weights in Social Cost-Benefit Analysis*. Economic Development and Cultural Change Vol. 32 no. 3 pp. 455-474.

Have, F. ten (2006). *Good governance: aanbevelingen voor Vennootschappen.* Deloitte: 2006

Helmer, S. (2011). *The Contribution of Gaming Simulation to Market Model Design.* Master Thesis Project: TU Delft: April 8, 2011

Hodgson, G.M. (2006) *What are institutions?* Journal of Economic Issues 2006 vol. 40 no.1, p. 2-4

Hunthington, S.P. (1968). *Political Order in Changing Societies.* p.12 New Haven, Conn.: Yale University Press.

Husain, I. (2011). *Electric and Hybrid Vehicles – Design Fundamentals. Second Edition.* CRC Press - Taylor and Francis Group: Boca Raton

IEA (2009). *Technology Roadmap – Electric and Plug-in Hybrid Electric Vehicles.* International Energy Agency: 2009

Jansen, R.J.P. (2003). *Besluit van de directeur-generaal van de Nederlandse Mededingingsautoriteit als bedoeld in artikel 37, eerste lid van de Mededingingswet. Betreft zaak:3282/Eneco – Remu.* NMa: Februari 25, 2003

Jansen, V., Lycklama, D. (2011). *Martmodel voor EV laaddienstverlening. Een roadmap.* Innopay: May 16, 2011

Karatay, E., Verhees, L., Bloemhof, G.A. (2010). *Betrouwbaarheid van elektriciteitsnetten in Nederland in 2009.* KEMA Consulting Arnhem: June, 2010

Karnama, A. (2009). *Analysis of Integration of Plug-in Hybrid Electric Vehicles in the Distribution Grid – Thesis from School of Electric Engineering at Royal Institue of Technology.* Stockholm: 2009

Keeney, R.L. (1994). *Value-focussed thinking – A path to creative decision making.* Digital Printing. Londen: Harvard University Press

Knigge, J (2011). *Smart Grids & Elektrisch vervoer.* Enexis: January 2011.

Koppenjan, J., Groenewegen, J. (2009). *Course 2 , 4131 Actor perspective and institutional design; NIE and OIE.* November 9, 2009

Koppenjan, J. and J. Groenewegen (2005). *Institutional design for complex technological systems.* International Journal for Technology, Policy and Management 5(3): 240-257.

Lehtinen, J. (2010). *Electric Vehicle Charging Systems in the Helsinki Region.* Aalto University: October 25, 2010

Liander (2009). *Kwaliteits- en capaciteitsdocument elektriciteit 2010-2016.* Liander Arnhem: December 2009.

Liander (2011). *Landelijk netwerk snellaadstations voor elektrische auto's in 2011.* http://www.liander.nl/liander/over_liander/2011/landelijk_netwerk_snellaadstations.htm Last revisited: June 20, 2011

Lysen, E., Duijvestein, C. (1996). *Trias Energetica.* Novem, TU Delft: 1996

Mayor of London (2009). *An Electric Vehicle Delivery Plan for London.* London: May 2009

McKinsey (2011). *Boost! Transforming the powertrain value chain – a portfolio challenge.* Advanced Industries Sector/Automotive&Assembly. January 2010

Meer, v.d. T. (2011). Theo.vandermeer@stedin.net. *Vragen naar aanleiding van document.* Message to Eline Kleiwegt (eline.kleiwegt@movares.nl). Sent July 14, 2011

Microwatt (2011). *Regionale Netbeheerders Elektriciteit*. http://www.microwatt.nl/netbeheerders-elektriciteit Last revisited July 17, 2011

Ministry of Economic Affairs (2008). *Energierapport 2008.* June 6, 2008

Ministry of Transport, Public Works and Water Management (2009). *Mobiliteitsonderzoek.* www.mobiliteitsonderzoeknederland.nl Last Revisited July 22, 2011Last revisited

Möller, A. (2011). *Nieuws: Bestuur 'Het Nieuwe Rijden Elektrisch Vervoer Centrum' compleet.* Elektrischvervoer-centrum. June 3, 2011

Nemry, F., Brons, M. (2010). *Plug-in Hybrids and Battery Electric Vehicles – Market penetration scenarios of electric drive vehicles.* JRC-ipts: June 2010

NetbeheerNederland (2010). *Op weg naar een duurzame en efficiënte energievoorziening – Roadmap Smart Grids.* August 26, 2010

NetbeheerNederland (2011). *ToekomstVisie Smart Grids 2025.* Arnhem: NetbeheerNederland

NextGenerationInfrastructures (2011). *About Next Generation Infrastructures.* http://www.nextgenerationinfrastructures.eu/index.php?pageID=23 Last revisited September 5, 2011

Nibud (2011). *Energie en water.* http://www.nibud.nl/uitgaven/huishouden/gas-elektriciteit-en-water.html Last revisited August 14, 2011

Nicolescu, C.L., Gorghiu, G., Dunea, D., Buruleanu, L., Moise, V. (2008) *Mapping Air Quality: An Assessment of the Pollutants Dispersion in Inhabited Areas to Predict and Manage Environmental Risks*. Scientific Research Centre for Improving the Quality of Life Valahia University Târgovişte: Issue 12, Volume 4, December, 2008

NieuwAmsterdamsklimaat.nl (2009). *Programma Klimaat en Energie.* http://www.nieuwamsterdamsklimaat.nl/achtergrond/klimaat_en_energie/ke/programma/ Last revisited May 16, 2011

NMa (2010). *Zorgen voor optimal energiedistributienetten. Visie van de toezichthouder op het reguleringskader.* Enegiekamer Nederaldnse Mededingingautoriteit The Hague: February 2010

NMa (2011). *Codes.* http://www.nma.nl/regulering/energie/codes/default.aspx Last revisited July 26, 2011

Normcommissie 364 069 (2010). *Commissieplan Elektrische Voertuigen.* NEN: Oktober 22, 2010

NSL (2009). *Nationaal Samenwerkingsprogramma Luchtkwaliteit.* Ministry of Infrastructure and Environment: November 1, 2009

Nuon (2011). *Amsterdam gunt plaatsing nieuwe oplaadpunten elektrisch vervoer aan combinatie Nuon/Heijmans en Essent.* Nuon: April 15, 2011

NY ISO (2009). *Alternate route: electrifying the transportation sector.* NY: June 2009

Ottens, M., Franssen, M., Kroes, P., Poel, I. van de (2006). *Modelling infrastructures as socio-technical systems.* International Journal of Critical Infrastructures, Vol. 2, No. 2-3, p.133 - 145

Passier, G.L.M., Driever, J.P.M., Langer, R. de, Ligterink, N.E., Smokers, R.T.M. (2009). *Electric vervoer in Amsterdam – Onderbouwing van ambitie en doelstelling en adviezen voor een effectieve aanpak.* TNO Delft: November 9, 2009

PBL (2010). *Beleidsdossier lokale luchtkwaliteit (webdocument 0072, versie 01, 09-09-2010)* www.pbl.nl/balansvandeleefomgeving PBL, Den Haag/Bilthoven.

Peças Lopes, J.A., Soares, F.J., Almeida, P.M., Moreira da Silca, M. (2009). *Smart Charging Strategies for Electric Vehicles: Enhancing Grid Performance and Maximizing the Use of Variable Renewable Energy Resources.* In: EVS24 Stavanger: May 13-16, 2009

Peças Lopes, J.A., Soares, F.J., Almeida, P.M. (2011). *Integration of Electric Vehicles in the Electric Power System.* Proceedings of the IEEE. In: Vol. 99, No. 1, January 2011.

Phase to Phase (2001). *Newton-Raphson loadflow.* 01-131 PMO. May 1, 2001

Phase to Phase (2011). *User Manual Vision 7.3.* 11-141 PMO. August 26, 2011

Philips (2011). *1,6 l, 2400 W temperatuurregeling geborstelde metalen waterkoker.* http://shop.philips.nl/store/rpeeub2c/nl_NL/DisplayProductDetailsPage/productID.216291500 Last revisited May 30, 2011

Pieltain Fernández, L., San Román, T.G., Cossent, R., Domingo, C.M., Frías, P. (2011). *Assessment of the Impact of Plug-in Electric Vehicles on Distribution Networks.* IEEE Transactions on Power systems, Vol. 26, No.1: February 2011.

PrestigeGreencab (2011). *GreenCab opent grootschalig oplaadstation.* http://www.prestigegreencab.nl/nieuws/greencab-opent-grootschalig-oplaadstation/ Last revisited July 18, 2011

Provincie Brabant (2011). *Regling Elektrisch Rijden en Slimme Decentrale Netwerken.* http://www.brabant.nl/dossiers/dossiers-op-thema/economie-en-werk/energie/elektrisch-rijden/regeling-elektrisch-rijden.aspx Last revisited: May 23, 2011

Provincie Utrecht (2011). *Project Op Kop. http://www.provincie-utrecht.nl/onderwerpen/milieu-klimaat/project-kop/* Last revisited May 23, 2011

Prud'homme, R. (2010). E*lectric vehicles : a Tentative Economic And Environmental Evaluation Discussion Paper No. 2010-22.* In: International Transport Forum 2011, 25-27 May Leipzig, Germany

Raju, P.L.N. (2003). *Fundamentals of Geographical information systems.* Indian Institute of Remote Sensing: March 13, 2003

RCI (2011a). *Programma Stroomstoot: impuls aan elektrisch vervoer in Rotterdam.* http://www.rotterdamclimateinitiative.nl/nl/50_minder_co2/projecten/programma_stroomstoot_impuls__aan_elektrisch_vervoer_in_rotterdam?portfolio_id=25 Last revisited May 16, 2011

RCI (2011b). *Over het programma 50% minder.* http://www.rotterdamclimateinitiative.nl/nl/50_minder_co2/over_ons/over_het_programma Last revisited May 16, 2011

Rekenkamer Rotterdam (2011). *Een slag in de lucht – effecten van beleid luchtkwaliteit.* June, 2011

Renault.com (2011). *The electric vehicle: A global strategy.* http://www.renault.com/en/capeco2/vehicule-electrique/pages/vehicule-electrique.aspx Last revisited April 14, 2011

Reitsma, S., Steinmetz, R., Sloten, R. van. (2010). *WATT en hoe in elektrisch vervoer – de startgids voor gemeenten.* Policy Research Corporation, EV Consult. Commissioned by AgentschapNL: December 2010

Rijken, K. (2011). *Iedereen zijn eigen oplaadpunt*. In: Binnenlands Bestuur 2011:30, p.24.

Rijksoverheid (2011a). *Elektrisch Rijden.* http://www.rijksoverheid.nl/onderwerpen/auto/elektrisch-rijden Last revisited July 13, 2011

Rijksoverheid (2011b). *Slimme meter.* http://www.rijksoverheid.nl/onderwerpen/energie-en-kleinverbruikers/slimme-meter revisited August 22, 2011

RIVM, PBL (2010). *PM10 concentratie 2010.* 0023-004g-lba10. 2010

Roland Berger (2010). *Onderzoek naar visie op regional netbeheer onder aandeelhouders. Stuurgroep Visie Netbeheer.* Amsterdam: Roland Berger November 1, 2010.

Sage, A.P., Armstrong, J.E. (2000). *Introduction to Systems Engineering.* New York: Wiley Series in System Engineering.

Siemens (2011a). *WT44E173NL - E 44.17 - Luchtcondensatie droogautomaat*. http://www.siemens-home.nl/producten/wassen-en-drogen/wasdrogers/WT44E173NL.html?source=browse Last revisited May 30, 2011.

Siemens (2011b). *WM12A160FN - A12.16 - Wasautomaat* http://www.siemens-home.nl/WM12A160FN.html?source=search Last revisited May 30, 2011

Siemens (2011c). HB11AB520 - *Roestvrij staal - Inbouw bakoven - Klapdeur met kijkvenster.* http://www.siemens-home.nl/producten/koken/ovens/HB11AB520.html?source=browse Last revisited May 30, 2011

Slater, S., Dolman, M., Taylor, P., Trichavis, P., Shine, J. (2009). *Strategies for the uptake of electric vehicles and the associated infrastructure implications.* P.9 and 10-13 For Committee of Climate Change: October 2009.

Sluijs, v.d. P. (2009). *Elektrisch vervoer & elektrische netten.* Liander Arnhem: December 16, 2009.

Smokers, R. (2010). *Elektrisch rijden als onderdeel van de transitie naar duurzame mobiliteit.* TNO: Juli 2010

Spier, M. (2010). *Elektrisch vervoer Amsterdam goed voor bijna twee rondjes om de wereld.* Amsterdam.nl: November 11, 2010.

Stedin (2009a). *Elektriciteit tarieven 2010 – Aansluiting en Transport voor kleingebruikers*. Stedin Netbeheer b.v.: Oktober 2009

Stedin (2009b). *Persbericht: Te vroeg voor publiciteit elektrisch rijden.* Stedin Netbeheer b.v. April, 27 2009

Stedin (2010a). *Kwaliteits- en Capaciteitsdocument 2010-2016 Elektriciteit.* Stedin: 2010

Stedin (2010b). *Model om EV interesse per wijk te voorspellen.* March 2, 2010

Stedin (2011a). *Antwoord op uw vraag: Hoe vraagt u een (nieuwe) aansluiting aan?* http://www.stedin.net/Contact/Pages/Veelgestelde_vragen.aspx Last revisited July 19, 2011

Stedin (2011b). *Gesubsidieerd project elektrisch rijden.* http://www.stedin.net/Informatie_voor/Pers/Persberichten/Pages/Gesubsidieerdprojectelektrischrijden.aspx Last revisited: May 23, 2011.

Stokkum, van H., Broek, van den K. *Watertoetsproces op weg naar bestemming. Landelijke Evaluatie Watertoets 2006.* November 2006

Stuurgroep Visie Netbeheer (2011). *Professioneel aandeelhouderschap: nu en straks.* Commissioned by the ministry of economic affairs: March 2, 2011

Tan, M.L. (2011). *The Economic Impact Model for Smart Distribution Grids.* Thesis Project TU Delft / Enexis: June 2011

Taskforce Intelligente Netten (2010). *Op weg naar Intelligente Netten in Nederland.* Juli 2010.

Tatsumi, K. (2010). *Aspects of Technology Developments of Lithium and Lithium-ion Batteries for Vehicle Applications in National R&D Projects of Japan.* Journal of Asian Electric Vehicles, Volume 8, Number 2, December 2010

Taylor, K. (2010). *Landelijk netwerk snellaadstations voor elektrische autos in 2011.* http://www.thenewmotion.com/de-overstap/landelijk-netwerk-snellaadstations-voor-elektrische-auto%E2%80%99s-in-2011/ Last revisited May 23, 2011.

Taylor, J., Maitra, A., Alexander, M., Brooks, D., Duvall, M. (2010). *Evaluations of plug-in electric vehicle distribution system impacts.* in IEEE Power and Energy Society General Meeting, 2010, pp.1 –6.

TenneT (2011). *Nederlands Transportnet.* Arnhem Tennet TSO B.V.: January, 2011

Thenewmotion (2011). *Oplaadpunten.* http://www.thenewmotion.com/elektrisch-rijden/oplaadpunten/ Last revisited May 20, 2011

Valentine-Urbschat, M., Bernhart, W. (2009). *Powertrain 2020 – The Future Drives Electric.* Roland Berger Munich: September 2009

Verhagen, M.J.M. (2011). *Regeling van de Minister van Economische Zaken, Landbouw en Innovatie van 27 mei 2010, nr. WJZ / 11034132, tot wijziging van de Subsidieregeling energie en innovatie in verband met proeftuinen intelligente netten.* Staatscourant: June 7, 2011

Verwater-Lukszo, Z. Bouwmans, I. (2005) *Intelligent Complexity in Networked Infrastructure.* In: Systems, Man and Cybernetics, 2005 IEEE International Conference. Issue Date: 10-12 Oct. 2005, Volume: 3

Verzijlbergh, R.A., Lukszo, Z., Slootberg, J.G., Ilic, M.D. (2011a). *The Impact of Controlled Electric Vehicle charging on Residential Low Voltage Networks.* In: ICNSC'2011, 11 April 2011

Verzijlbergh, R.A., Lukszo, Z., Slootberg, J.G., Ilic, M.D. (2011b). *Deriving Electric Vehicle Charge Profiles from Driving Statistics.* Submitted to IEEE Power & Energy Society General Meeting 2011.

Verzijlbergh, R.A., Lukszo, Z. (2011). *System Impacts of Electric Vehicle Charging in an Evolving Market Environment.* In: ICNSC'2011, 11 April 2011

Vision Network Analysis (2011). *Input data Vision.* Derived May 11, 2011

Vliet, O. van, Brouwer, A.S., Kuramochi, T., Broek, M. van den, Faaij, A. (2011). *Energy Use, Cost and CO_2 emission of electric cars.* Journal of Power Sources 196 (2011) 2298–2310

Vries, L.J., Correljé, A.F., Knops, H.P.A. (2008). *Electricity and Gas Markets.* TU Delft: Oktober, 2008

Wiederer, A., Philip, R. (2010). *Policy options for electric vehicle charging infrastructure in C40 cities*. Clinton Climate Initiative: 2010

Wieringa, H., Beek, T. Van. (2010). *Brabantse overheden en industrie: samenwerken voor elektrisch vervoer.* APPM: 2010

Williamson, O. E. (1998). *Transaction cost economics: How it works; where it is headed*. Economist 146(1): 23-58.

Zaanstad.nl (2010). *Elektrisch Vervoer.* http://www.zaanstad.nl/mv/milieu/voor_bedrijven/elektrisch_vervoer/ Last revisited July 14, 2011.

Zaghib, K., Dontigny, M., Guerfi, A., Charest, P., Rodrigues, I., Mauger, A., Julien, C.M. (2010). *Safe and fast-charging Li-ion battery with long shelf life for power applications.* Journal of Power Sources. 196 (8): 3949-3954

Regulations and Legislation

Electricity Act (1998). *Chapter 3: Transport of Electricity. § 2. Art 16, § 4. Art 23, §6. Art 41b.* July 2, 1998.

Line Regulation Rotterdam (2006). *Leidingenverordening Rotterdam 2005.* March 2, 2006

Net code Elektricity (2011). *Chapter 3: Transport Service §3.2.1 and Chapter 4: Conditions with regard to planning. §4.1.4.5-4.1.4.6.* February 16, 2011

Interviews and Meetings

Municipality of Rotterdam: Akkerhuis, J. *Engineer at Gemeentewerken Rotterdam*. June, 6 2011.

Municipality of Amsterdam: Casteren, van M. *Project Manager Electric Mobility Municipality of Amsterdam.* May 12, 2011

Meeting network operator Stedin: Fidder, H., Meer, T. van der *Expert Asset Management and Senior Specialist Stedin*. May 11, 2011 and June 30, 2011.

Meeting network operator Liander: Klein Koerkamp, M. *Program Manager Electric Vehicles Alliander.* May 3, 2011

Municipality of Delft: Coremans, B. *Policy Advisor Noise and Air Municipality of Delft* .July 13, 2011

Municipality of Utrecht: Meijles, A. *Project Manager Sustainable Mobility Municipality of Utrecht.* May 20, 2011

NMa (Dutch Competition Authority): Ochu, E., Buys, M. *Technical Specialist and Economist at Energiekamer NMa* July 5, 2011

BAM Group: Oort, F. *Chief Procurement Officer BAM Group.* April 18, 2011

Enexis: Postma, A. *Manager MSG Development Enexis.* July 20, 2011

Municipality of the Hague: Puij, de L. *Policy Advisor Environment and Licensing.* July 20, 2011

EV Consult: Steinmetz, R. May 13, 2011

Meeting validation grid impact calculation: Verzijlbergh, R. *PhD* June 23, 2011

APPENDICES

APPENDIX I DESCRIPTION EXPERIENCES AND FUTURE EXPECTATIONS

I.1 EXPERIENCES ELECTRIC MOBILITY

Electric mobility is still in an early implementation phase; only a limited number of electric vehicles are currently being used. A withholding factor for electric vehicle adoption of consumers and companies is in many cases vehicle availability. Although many car manufacturers have announced electric vehicles, most releases were delayed. In addition, when vehicles are introduced to the market, their availability is very limited [Lehtinen, 2010]. Some countries or municipalities have, however, already taken a frontrunner role, and have deployed charging infrastructure. The table below shortly describes the experiences of electric mobility of three front running municipalities.

Table 9 Experiences of electric mobility in Amsterdam, London and Tokyo.

Municipality	Start of pilot	Current number of electric vehicles and charging stations	Policy	Lessons learned
Amsterdam [Spier, 2010; Rijken, 2011]	2009	Vehicles: 260 (including scooters and motorcycles) Charging stations: 250 (in august 2011)	Installing charging stations, subsidy for vehicle purchase and free parking spots.	• Charging peaks in the pilot occurred between 11AM and 7PM and after 10PM; • Network operators are interested in actual real time charging behaviour data to estimate the impact of charging on the grid.
London [Mayor of London, 2009]	2009	Vehicles: 1.700 (including scooters and motorcycles) Charging stations: 250 (in 2009)	An infrastructure plan aiming at 25.000 charging stations in 2015 is created, the municipality car fleet is partially replace by electric vehicles, electric vehicle parking spots are subsidised and exemptions to congestion charges are granted for electric vehicles.	• Access to infrastructure is a critical factor. The type of charging system can be selected based on the location where it is located (slow charging near shopping malls, fast charging near main road); • Niche markets are important for economies of scale. For EV to become suitable for bus, taxi and car rental companies, barriers concerned with driving range still need to be overcome.
Tokyo Pilot by TEPCO (Tokyo Electric Power Company) [Anegawa, 2008]	2007	*Unknown*	TEPCO started a pilot to substitute their service vehicles for electric vehicles. At the start of the pilot, six charging stations were installed. In 2008, fast charging stations were installed.	• Electric vehicles can be suitable for service purposes with a limited driving range; • The presence of fast charging stations reduces the psychological effect of range anxiety; • Fast charging stations were rarely used, reducing the profitability of the stations.

I.2 EXPECTATIONS ELECTRIC MOBILITY

Several Dutch and international organisation have written roadmaps or scenario studies about how a transition to electric mobility can or will occur. These studies describe ways and means to make electric mobility a success. The organisations agree on the fact that electric mobility will play an important role in sustainable mobility. They do however, not completely agree on the pathway towards this future and the exact role and share of electric vehicles in the future. The next section provides a short description of a number of roadmaps, showing the key factors, drivers and actors identified in the roadmaps and scenarios. The list of roadmaps and scenarios is not meant to be exhaustive, but to provide insight in the spectrum of studies.

The roadmaps and scenarios propose a wide range of possible futures for electric mobility. In 2020 the expectations differ from 1% [Nemry, Brons, 2010; McKinsey, 2011] to 10% [van den Berg et.al.,2009; Hanschke et.al., 2009]. For 2050, 50% [IEA, 2009] to 100% [Boekema et.al., 2010] of all newly sold vehicles are expected to be electric.

The next section also shows the underlying drivers for the penetration rates. For instance the C'MM'N roadmap [van den Berg et.al., 2009], which has the optimistic expectation to reach one million electric vehicles in 2020, assumes extensive involvement of governments. This involvement entails reducing barriers for people to switch to an electric vehicle, to develop new business models, to provide subsidies and to initiate pilots. In addition, when looking at technology, the C'MM'N roadmap states that significant improvement of battery technology is required in order to come to one million in 2020. A roadmap by TNO [Smokers, 2010] is sceptical about achieving one million electric vehicles in 2020. TNO looks at the course of product innovation and thereby expects that electric vehicles are simply in an early phase of product innovation, meaning that scaling and cost reductions, which are required for consumer adaptation, will take some time. In addition, TNO identifies a second problem with electric vehicle adoption, which is related to the consumers' willingness to switch to sustainable applications. TNO states that, while a lot of innovative technologies directly provide better quality to consumers, sustainable innovations often do not. There is a matter of split incentives, where consumers (at least for some time) will have to pay higher prices, while they do not directly benefit from the advantages (clean air and CO_2 reduction are a social and not an individual benefit).

From these roadmaps and scenarios, not simply one expectation for market penetration can be derived. There is a large variety of both the long term market potential for electric mobility and the speed of adoption of electric vehicles. This variety reflects the uncertainties related to electric mobility. The uncertainty is both related to technology development (mainly battery technology development), and social (consumers' willingness to switch, influenced by governmental policies) factors.

I.3 DESCRIPTION ROADMAPS AND SCENARIOS

The description of future expectations is based on several roadmaps and scenarios. The table below shortly summarises these roadmaps and scenarios by their perspectives, expected future, drivers and challenges, actors involved and measures proposed.

Table 10 Summary description roadmaps and scenarios.

	Description roadmap	Expected future	Drivers and challenges	Actors involved	• (Policy) measures required
IEA Roadmap *International* [IEA, 2009]	The IEA Roadmap about electric and plug-in hybrid electric vehicles in 2009 describes which governmental and industry actions are required to make electric mobility possible in 2020, 2030 and 2050.	1/2 of light duty vehicles sold in 2050 electric[56]	• Vehicle technology and offerings • Charging infrastructure • Understanding on consumer demand	• Economics/ finance ministries • Environment/ energy/resource ministries • Research institutes • Local governments • Battery manufacturers • Utilities • Consumer	• Cooperation between governments and companies; • Increase RD&D budget; • Governments should set targets; • Develop an infrastructure plan; • Establish codes and standards.
JRC Scenarios *Europe* [Nemry, Brons, 2010]	JRC wrote a scenario study from a policy maker point of view. The focus of the scenario lies on battery technology and charging infrastructure development. From these scenarios, sales shares and effects on environment are derived.	Dependent on which scenario, the share of EV in Europe is: 1-2% by 2020 and 7-27% in 2030	• Battery performance and costs • Access to infrastructure and efficiency of infrastructure • Business model • Consumer acceptance	• Car manufacturers • Governments • Consumers	• Financial and fiscal incentives for the purchase of electric vehicles; • Green purchase procurement procedures • Investments in charging infrastructure.
ECN Scenarios *Netherlands* [Hanschke et.al., 2009]	ECN developed four transition paths which describe technical developments to reach these sustainable mobility targets. The pathways are: intelligent transport systems, bio fuels, 'hybrid, plug-in hybrid and all-electric vehicles' and hydrogen vehicles.	10% EV in 2020 - 45% in 2040	• Vehicle technology • Battery technology • Infrastructure availability	• Governments • Niche markets • Energy sector	Depending on innovation phase 1. Stimulate R&D 2. Fiscal or other financial measures 3. Infrastructure development
TNO Back casting *Netherlands* [Boekema et.al., 2010]	TNO uses back casting in order to come to a transition pathway towards a system where CO2 emissions are reduced by 80% in 2050.	TNO back casts towards 100% newly sold EVs in 2050. According to TNO 1 mln EVs in 2020 is not realistic as it requires 50% of all newly sold vehicles in 2020 to be EV. ¼ mln might be realistic.	• Cost reduction • Consistent government strategies (charging infrastructure) • Business model	• National government • European government • Municipalities • Electricity producers, distributors and network operators • Industries	• Consistent governmental strategies especially on investment in charging infrastructure • To switch to electric vehicles, business models need to be designed to deal with split incentives.

[56] In the Netherlands on average 7% (between 1997-2010) of a total number of 10 mln vehicles is newly sold [CBS Statline, 2010a; CBS Statline, 2011d]

C,MM,N Roadmap *Netherlands* [van den Berg et.al., 2009]	C,MM,N (an open source initiative of an environmental organisation and technical universities) developed a roll-out strategy to describe the consistency between energy and car technology, consumer behaviour, electricity infrastructure, spatial planning and governance.	1 million EVs in 2020 (10% of all vehicles)	• Cooperation between actors • Technology experience • Reliable and cost effective battery technology • Combined strategy of EV with future electricity production • Ease of use for consumers • Embeddedness of EV in public space	• Municipalities • Governments • Research institutes • Car and battery industry • Fleet owners • Lease companies • Banks • Media	• Varying package of measures from financing pilots to tax and financial incentives and stimulating sustainable energy.
Roland Berger Scenarios *International*	The scenario study focuses on the business perspectives of EV and the roles which can be fulfilled in the coming years. The report also identifies governmental instruments from two perspectives, namely from a supply (target regulation, penalties, R&D incentives) and from a demand (taxes and incentives and local benefits) side.	The report states that the future for EV is hard to predict, partially because governments are involved in the market.	*Pull side:* • Mobility needs • Cost expectations • Image/comfort requirements *Push side:* • Regulation and targets • R&D support	• Car manufacturers • End customers • Governments • Battery industry • Charging infrastructure • Regional grid operators • Municipalities	• From the supply side: target regulation, penalties, R&D incentives • From the demand side: taxes and incentives and local benefits
McKinsey Scenario *International*	McKinsey focuses on the powertrain value chain changes due to CO_2 standard regulation. Based on different CO_2 restriction scenarios for vehicles, different shares of hybrid, electric and fuel cell vehicles are calculated.	Depending on the scenario, 2-5% in 2020 (incl. hybrids etc.) and 15-65% in 2050.	• Government regulation	• Governments • Vehicle (and component) manufacturers and suppliers	• CO_2 regulation

APPENDIX II LITERATURE GRID IMPACT CALCULATION - ASSUMPTIONS

This appendix will describe the assumptions of the literature grid impact cases. The assumptions are categorised into three groups: grid characteristics, charging characteristics and parameters.

Table 11 Assumptions literature grid impact cases

	Verzijlbergh et.al. (2011a)	Peças Lopes et.al. (2009)	Pieltain Fernández et.al. (2011)	Clement et.al. (2008)
		Grid characteristics		
Voltage level	Low voltage	Medium voltage (semi-urban, 15kV)	Medium and low voltage	Low voltage
Topology	Not specified	Meshed, operated radial	Not specified	Radial
Scale	18326 transformers (basic data), 145 cable, 31 detailed transformer data	±300 grid nodes 2 feeders	2 areas: - 6000 LV residential customers, - 61 000 residential and industrial customers	34 grid nodes
Real case?	Yes	Based on	Yes	No
		Charging characteristics		
Voltage station	±0,7kW	1,5kW hybrid 3kW medium EV 6kW large EV	Normal: 1,6-9,6kW Fast: 16-96kW (depending on vehicle type)	4kW
Charging pattern?	Yes	No	Yes, 40% of EVs connected during peak	Yes, randomly distributed over time period (18h-21h or 21h-6.00)
Number of EV	75% of all vehicles in 2040	1,5 EV per household	35% (2020) 51% (2030) 62% (2050)	10% 20% 30%
Energy demand	30kWh/day	3.3kWh/day hybrid 5,5kWh/day medium EV 11,2kWh/day large EV	Not specified	8,8kWh/day
PHEV included	No	20% hybrid 40% medium EV 40% large EV	Yes, different shares for different penetration scenarios	Only PHEV
Smart charging?	Scenario	Scenario	Scenario	Scenario
Vehicle to Grid?	No	No	Yes (always 10% of vehicles inject power)	No
		Parameters		
Parameter used	Thermal load Voltage deviation	Max amount of dumb or smart charging possible, based on: - Allowable voltage drops - Thermal load	Incremental investment due to EV compared to total investment and energy losses	Voltage deviation and power losses
Time scale	2040	Not specified	2020, 2030 and 2050	2030

APPENDIX III ACTOR ANALYSIS

This appendix provides background information on the actors presented in chapter 2.

Table 12 Actor description

Actors	Description	Area of interest	Resources
		Policy makers	
National government *(Ministries of Economic Affairs, agriculture and innovation (EL&I) and Infrastructure and Environment (I&M))*	The ministries set targets for electric mobility and facilitate cooperation between governments and market parties.	Electric mobility reduces CO_2 emissions and helps achieving European emission reduction objectives. Because the municipality is the direct link with the car users, the ministries assign an important role to municipalities [Eurlings, van der Hoeven, 2010]. A downside of large-scale utilisation of EV for the national government is the loss of taxes and duties of gasoline and diesel.	Regulation, tax/subsidy schemes, lobby (cooperation with companies)
Provinces	Provinces are stimulating EV for economic development and air quality.	Often work together with municipalities on stimulating EV (fe. Province of Utrecht and Province of Brabant) [Provincie Brabant, 2011, Provincie Utrecht, 2011]	Regulation, tax/subsidy schemes, lobby (cooperation with companies)
Municipalities	There is a large difference between municipalities and their need to stimulate EV. Some actively stimulate, others merely facilitate or do nothing (yet). Most municipalities are positive to EV as a sustainable technology.	Municipalities were assigned a large role in stimulating EV by the national government, especially on infrastructure deployment. Some municipalities actively deploy charging infrastructure [Gemeente Amsterdam, 2010; Gemeente Utrecht, 2010]. Other municipalities are confronted with an EV demand for charging stations by their citizens.	Non-monetary incentives (parking spots etc.), charging infrastructure deployment, regulation, tax/subsidy schemes, cooperation with companies
Formule E-team	Cooperation between governments, companies an research institutes to realise a break-through in EV	Is founded to stimulate electric mobility in the Netherlands. The ambition of the Formule E-team is to come to standards and facilitate cooperation between governments and companies [AgentschapNL, 2011].	Knowledge
		Electricity sector	
Distribution network operator	Responsible for the reliability and capacity of the distribution network and to connect charging stations. But not allowed to actively influence charging station locations, charging behaviour and frequency [Pieltain Fernández et.al, 2011].	Electric mobility affects the reliability of the electricity network. At the same time network operators are investing in charging infrastructure and pilots [Enexis, 2011; Stedin, 2011b]. Most network operators cooperate in Stichting E-laad to deploy charging infrastructure throughout the Netherlands.	Money to invest in infrastructure, lobby
Electricity company *(producer and retailer)*	Will produce, deliver and remunerate the electricity for electric vehicles to	Will sell more electricity because of electric mobility - possible new business case. Will possibly have to increase the production park in the long run. The scale is expected to be	Money to invest in charging stations and to increase production

	customers.	small (EU average 1-4% [Nemry,Brons, 2010]	capacity, lobby
Charging station operator	*The role of a charging station operator/service provider is not yet defined* [Boekema et.al., 2010]		
Vehicle user			
Consumer	Consumers need to be convinced to switch to EV and receive tax and local incentives to do so. Consumers see the lack of charging stations as a barrier to switch to EV.	Customer needs: driving range, availability of infrastructure, costs, safety, reliability, comfort, image. Currently EV doesn't have much added value compared to conventional vehicles [Valentine-Urbschat, Bernhart, 2009, p.56].	Money to buy electric cars
Companies	Can purchase EV in exchange for national tax advantages and sustainable image.	Some companies already started a pilot with electric vehicles for a green image and to deal with new market opportunities. Companies can also invest in charging stations at parking lots to allow employees to charge during working hours.	Money to buy electric vehicles
Other actors			
Media	As image is an important success factor for EVs, media can make or break the brake through of EV. Media can also entail other social contacts influencing the attitude of vehicle users towards EV.	Media do not have a specific interest in EV, but will monitor development [van den Berg et.al., 2009].	Knowledge
Technology developer	Availability of charging station, battery and vehicle technology is a key factor for EV success.	The technology is still being developed. Standards for most technology is still lacking. Much research is thus still required [Valentine-Urbschat, Bernhart, 2009]. For the technology developer electric mobility is a new business case.	Knowledge, Money to invest in technology development
Oil companies	Oil companies and fuel station owners are competitors of electric mobility as wide scale adoption of EVs will reduce oil dependency.	Although EV might in the long term decrease oil demand and thus the dependency on oil companies, some have already shown an interest in charging stations at their fuel stations [Taylor, 2011]	Lobby

APPENDIX IV GRID IMPACT CALCULATION

This appendix provides background information on the grid impact calculation in chapter 2.

IV.1 CALCULATION APPROACH

The grid considered for the case study is a sub-grid in the city centre of Utrecht. The district considered is located in the North East of the city centre, including the neighbourhoods of Wittevrouwen and Zeeheldenbuurt.

This grid is selected based on the expectations that high income and property value corresponds to a large electric vehicle demand. The table below shows the data of the district and the corresponding number of electric vehicles.

The data is derived from CBS data [CBS Statline, 2011c] and the formula presented in section 3.1.1.

Table 13 Data input for grid impact calculation North East city centre Utrecht.

	Nr of nodes in district	Nr of EV T2	Nr. EV per household T2	EV per node T2	Total power ch.st. per node T2 (kW)
Wijk 04 Noordoost	70	10345	0,53	148	383
Vogelenbuurt	7	772	0,32	110	286
Lauwerecht	8	233	0,22	29	75
Staatsliedenbuurt	1	44	0,07	44	114
Tuinwijk-West	3	518	0,41	173	447
Tuinwijk-Oost	5	775	0,53	155	401
Tuindorp en Van Lieflandlaan-West	12	1890	0,56	158	408
Tuindorp-Oost	8	892	0,62	111	289
Huizingalaan, K. Doormanlaan en omgeving	2	420	0,71	210	544
Zeeheldenbuurt, Hengeveldstraat e.o.	8	920	0,46	115	298
Wittevrouwen	10	1710	0,46	171	443
Voordorp en Voorveldsepolder	6	1230	0,79	205	531

Grid characteristics

The grid is meshed and operated via the n-1 rule, as can be seen in figure 42. The loads are fed via one cable, with a grid opening which can be closed during a calamity, feeding the loads via another cable.

The grid is fully composed of 10,5kV cables and is connected to the 150kV network in Lage Weijde via a 50kV network [TenneT, 2011]. The grid does not contain transformers as these are located outside this grid (in case of the coupling with higher voltage grids) or simulated as loads (in case of lower voltage grids)

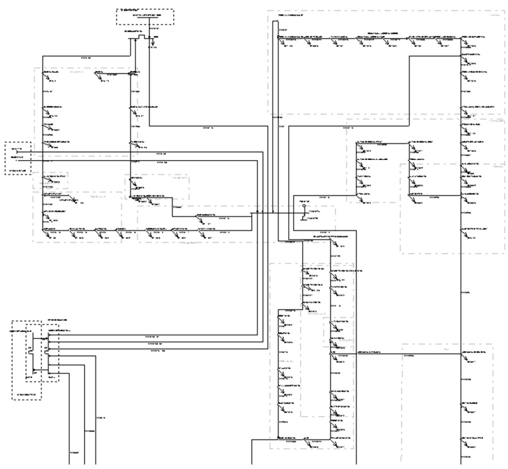


Figure 42 Grid topology

IV.2 UNCERTAINTY ANALYSIS APPROACH – CHANGING PARAMETERS

IV.2.1 TESTING FOR VARYING SHARES OF ELECTRIC MOBILITY

As described in appendix I.3, many different market penetration scenarios for electric mobility exist. It can therefore be concluded that the share of electric vehicles is uncertain. The share of electric vehicles does however directly determine the additional load on the grid and is thus expected to change the impact on the grid. The sensitivity analysis for varying shares therefore looks into shares of 10%-90% (0% and 100% are already included in the base scenario), with steps of 10%. This analysis makes use of the same assumptions and approach of the base case calculation. For each percentage, the amount of EVs per node is again calculated and added to a new grid model. Therefore nine additional copies of the Utrecht grid are created with different EV shares.

IV.2.2 TESTING FOR ORGANIC GROWTH

In current network planning, grid operators assume an organic growth of electricity demand, of mostly 1,5%. Electricity demand is however already changing for some years. Energy savings have become more important and electrical devices have become more efficient. At the same time the number of electrical devices has increased. The long term effect of on the one hand energy savings and an increasing number of electrical devices is difficult to estimate on the other hand. It is even possible that the growth will change to a decrease. The long term development of electricity demand is thus difficult to predict. From the literature cases, it could however already be concluded that there is a significant impact of organic growth on the grid. Therefore a sensitivity analysis will be done to see what the impact of different organic growth scenarios is. For these scenarios, the normal grid file was used. In the base case calculations already the existing loads were assigned with a load profile. These load profiles were changed by steps of 0,5%, varying from -1% to 2%. These percentages are chosen as, as said before, it can be possible that in the future electricity demand will decrease due to emphasise on energy savings.

IV.2.3 TESTING FOR ADDITIONAL VEHICLES

The personal vehicle market might change significantly up to 2040. Therefore the sensitivity analysis looks into a different number of personal vehicles in the city district. The analysis looked into -10% and +10% and in addition at a more extreme value of 50%, to see whether there would be a maximum impact related to the number of vehicles.

IV.2.4 TESTING FOR CHARGING CONCEPTS

In chapter 2, three charging concepts are introduced. These charging concepts illustrate the fact that it is uncertain what type of charging infrastructure will deploy in the future. The concepts are however not yet quantified, so the implication to the grid is difficult to calculate. Therefore the scenario analysis makes some additional assumptions.

1. For the *charge at home* concept it is assumed that every vehicle has the possibility to charge at home, even if it is not at private property. In that case a charger in public streets is used. For this case the normal base case outcomes are used;
2. *Charge everywhere* assumes that every vehicle user can charge at home. In addition, every district has a fast charging station of 50kW. The worst case scenario, where these stations are used during peak demand is considered. In the Utrecht sub-grid Vision model, the normal case is used, added by ten fast chargers of 50kW (one fast charger per neighbourhood);

3. In the *charge via a fast charging infrastructure* scenario, only those vehicles which can charge at private property charge at home, in this case assumed to be 10%[57]. All other vehicles have to charge via a fast charging station. The number of required fast charging stations is one fast charging station per forty vehicles;
    - Argumentation for 1:40 lies in the average 6kWh daily demand of a vehicle. For a fast charging station of 50kW, eight vehicles can theoretically charge per hour. It is assumed that vehicles are not able to charge exactly sequentially, especially since some vehicles will have to charge more than 6kWh, taking up to an hour. A changing time equal to the charging time per vehicle is therefore used as a correction factor. Assuming that vehicles will only charge during day time, between 8AM-6PM:

    Looking at the daily average power demand for an electric vehicle:

    $$\frac{50kW}{6kWh/vehicle} = 8\frac{vehicles}{hour}$$

    With the correction factor 2, the number of vehicles that can charge per hour equals 4. As it is assumed that the majority of the people will charge only during 10 hours per day, **40 vehicles** can charge per day per charging station. As this calculation looks at the daily average power demand, this number applies to every day. Thus it can be concluded that one charging station will on average be used for 40 vehicles.

4. *Smart charging* will change the load of each charging station and thereby impact the total amount of impact of charging stations on the grid. As mentioned in section 2.1.3.3, it is expected that always some vehicles will remain to be charged during peak hours. The smart charging calculation will therefore be based on numbers of electric vehicles which are still charged during peak demand. The amount of vehicles still charging at peak hours is assumed to be 10%, which is also corresponding to the correction factor in the Verzijlbergh case [Verzijlbergh et.al., 2011a].

IV.3 GRAPHIC REPRESENTATION RESULTS

Grid with no electric mobility, only 1,5% organic growth

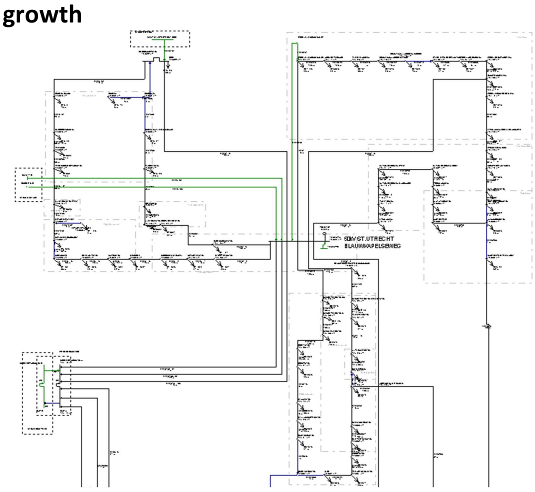


Figure 43 Grid representation in 2040 for no electric mobility.

Grid at 100% electric mobility

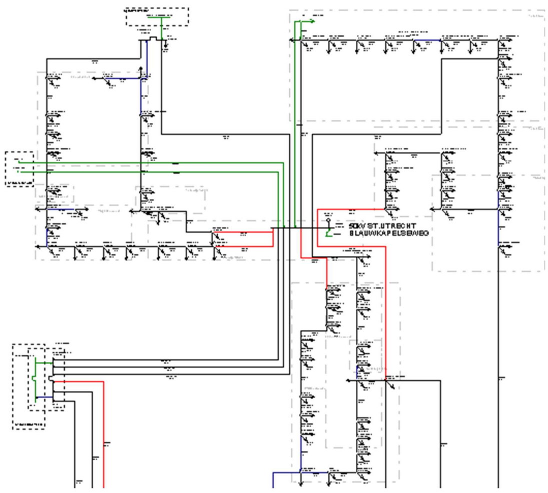


Figure 44 Grid representation in 2040 for 100% electric mobility.

57 Average percentage of houses with a private parking spot in the Netherlands is 14%. It is assumed that in urban areas this number is lower.

APPENDIX V DATAFILE GRID IMPACT CALCULATIONS

Table 14 Data file outcomes grid impact calculations

General data		
Average WOZ	241	
Average % higher income	20	
Average share EV market in 2030	30%	100%
Average nr of vehicles per household	1	
Normalised power charging station 3kW	0,7	

	CBS data						*Input from Vision*	*Derived from data*			*Input for Vision*	
	Nr of citizens	*Nr of house-holds*	*Personal vehicles total*	*Average house value*	*% households with higher income*	*Personal vehicle per household*	*Nr of nodes in district*	*Nr of EV 100%*	*Nr. EV per household 100%*	*EV per node 100%*	*Additional EV power per node 100%*	*Smart Charging 90%*
Wijk 04 Noordoost	35420	19540	10345	306	32	0,5	70	10345,0	0,53	147,8	103,5	10,3
Vogelenbuurt	3980	2450	1020	299	30	0,4	7	857,6	0,35	122,5	85,8	8,6
Lauwerecht	1900	1070	505	257	17	0,5	8	258,5	0,24	32,3	22,6	2,3
Staatsliedenbuurt	1050	610	250	190	11	0,4	1	49,0	0,08	49,0	34,3	3,4
Tuinwijk-West	2370	1260	675	260	28	0,5	3	575,8	0,46	191,9	134,4	13,4
Tuinwijk-Oost	2690	1460	775	313	33	0,5	5	775,0	0,53	155,0	108,5	10,9
Tuindorp en Van Lieflandlaan-West	6750	3370	1890	406	49	0,6	12	1890,0	0,56	157,5	110,3	11,0
Tuindorp-Oost	2610	1430	960	242	26	0,7	8	960,0	0,67	120,0	84,0	8,4
Huizingalaan, K. Doormanlaan e.o.	1110	590	420	291	28	0,7	2	420,0	0,71	210,0	147,0	14,7
Zeeheldenbuurt, Hengeveldstraat e.o.	3350	2020	920	381	32	0,5	8	920,0	0,46	115,0	80,5	8,1
Wittevrouwen	6310	3740	1710	304	32	0,5	10	1710,0	0,46	171,0	119,7	12,0
Voordorp en Voorveldsepolder	3300	1550	1230	282	30	0,8	6	1230,0	0,79	205,0	143,5	14,4

Data
Limit cable loading
60

Overview data					
1) Base case results		% cables overloaded	difference 0%		average load
0% EV		19%		0%	33
100% EV		29%		9%	41

Scenario analysis			
2) Varying EV share	Percentage above 60%	Difference with 0%	average load
0%	19%	0%	41
10%	24%	4%	35
20%	24%	5%	36
30%	*25%*	6%	*37*
40%	*25%*	6%	*38*
50%	29%	9%	38
60%	*29%*	9%	*39*
70%	*29%*	9%	*39*
80%	29%	9%	40
90%	29%	9%	41
100%	29%	9%	41

3) Varying organic growth	**-0,50%**	**0%**	**0,5%**	**1%**	**1,5%**	**2%**
0% EV	0%	0%	8%	11%	19%	26%
100% EV	9%	11%	16%	24%	29%	45%

4) Varying vehicle fleet			differences 0%	average load
-10%		29%	29%	40

0%		29%	29%	41
+10%		42%	42%	49
+50%		42%	42%	44

5) Fast and slow charging				
charging at home		29%	29%	41
charging everywhere		29%	29%	41
fast charging network		45%	45%	47
smart		24%	4%	35

	6) excluding correction factors		*7) differentiation per neighbourhood vs. average values per district*	
Market shares electric mobility	With correction factors	Without correction factors	Differentiation per neighbourhood	Average per district
0%	19%	19%	19%	19%
10%	24%	24%	24%	24%
20%	24%	24%	24%	24%
30%	25%	24%	25%	24%
40%	25%	24%	25%	25%
50%	29%	25%	29%	25%
60%	29%	28%	29%	30%
70%	29%	28%	29%	32%
80%	29%	32%	29%	33%
90%	29%	33%	29%	34%
100%	29%	37%	29%	37%

APPENDIX VI SHAREHOLDERS NETWORK OPERATORS

VI.1 STEDIN

Stedin is a subsidiary of Eneco Holding N.V.. The stocks of Eneco Holding N.V. are owned by 60 municipalities. The largest shares are for:

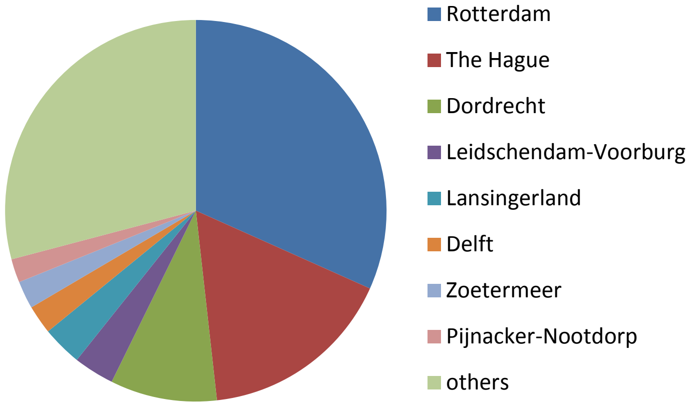


Figure 45 Shareholders Stedin

VI.2 ENEXIS

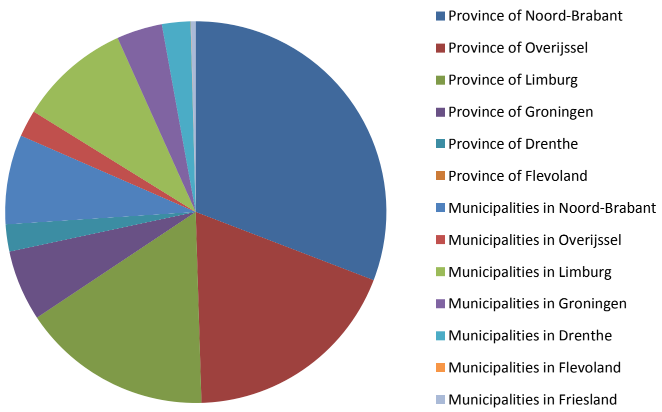


Figure 46 Shareholders Enexis

VI.3 LIANDER

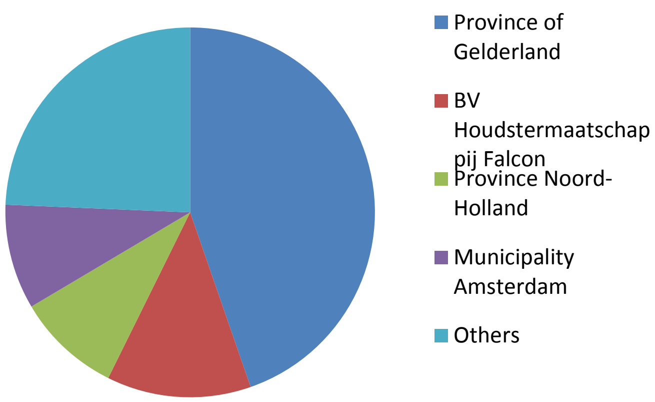


Figure 47 Shareholders Liander