KWINK GROEP

Strategy to facilitate EV infrastructure on local level

Using technological changes, preferences of municipalities and the expected demand of EV infrastructure in 2020 on neighbourhood level

Master Thesis

Freek Kuipéri

TU Delft Delft University of Technology

Faculty of Technology, Policy and Management

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Freek Kuipéri

Chair:
Prof.dr. Cees van Beers

Supervisors:
Prof.dr. Marina van Geenhuizen
Dr. Jan Anne Annema
Janine Mulder MSc(KWINK groep)

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Master Management of Technology
Department of Economics of Technology and Innovation
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Preface

This thesis is written for my graduation for the master Management of Technology at the TU Delft. I started the process of looking for an internship place in an early stage, and am very glad KWINK groep offered me a position. I enjoyed the research very much, because the subject allowed me to combine my theoretical and analytical knowledge from my TU Delft background, with practical considerations about stakeholder interests and the transition to a sustainable means of transportation. I liked it to be part of an innovative group heading towards a transportation system based on electric vehicles. This inspired me a lot in taking additional steps in my research.

I would like to say thanks to a couple of persons, without whom I would not have been able to achieve this result. To my first supervisor: Prof.dr. Marina van Geenhuizen, helping me with feedback in many sessions at her office. To my second supervisor: Dr. Jan Anne Annema for his fruitful comments and his faith in my capabilities. To my company supervisor: Janine Mulder for her help in structuring the report and sharing her knowledge and experience. To Rogier van Schelven for all his valuable information and knowledge on projects and researches to the subject of electric vehicles. To my other colleagues at KWINK groep, showing interest in my graduation project and giving me feedback on my presentation. To my dear girlfriend Gwendolyn Pronk, supporting me with positivity and love. And last, to my parents: Arnold Kuipéri and Ciska van der Plaat, for their continuous support and believe during my educational career, which provided me the possibility to develop myself to the person I am today.

Additionally I would like to thank the persons, whom I have spoken for this research: Harm Welleweerd and Gijs van der Poel of the municipality of The Hague, Alma de Jong of the municipality of Oegstgeest and Suzan Reitsma of the Dutch Enterprise agency. I would also like to thank all the municipalities who responded to my survey through email.

I hope you will enjoy reading this thesis!

Freek Kuipéri
Delft, July 2015

Executive summary

The importance to switch from our embedded energy system based on oil to a more sustainable system is emphasized by various research institutes in the past decades. Governments have translated this desirability into strategies and policies targeting to reach this change. One of the technological innovations, which could contribute to achieve a turning point, is electrical transportation. Policies are implemented to support this technology resulting in an increasing in the amount of electric vehicles on the road. The Netherlands is one of the leaders in marketshare of electric vehicles and is therefore seen as a testing ground by car manufacturers. The major shift, which is needed to be able to use the technology of electrical transportation is the way in which refuelling, i.e. charging in the case of electrical vehicles, is organized. Potential drivers of electric vehicles are limited by the availability of a charging infrastructure, which ensures them to be as flexible as with a conventional gasoline vehicle. Municipalities are a key actor in the implementation of a charging infrastructure because they are responsible for the public space on local level and the government designated them as the responsible authority.

However, establishing and implementing a strategy to facilitate a charging infrastructure is difficult for municipalities, because it is unclear which strategy works best for them. Three reasons can be identified for this ambiguity:

1. Uncertainty about the expected demand for charging infrastructure in neighbourhoods.
2. Uncertainty about the technological developments in charging electric vehicles.
3. It is not clear what the preferences of municipalities are in comparing strategy alternatives.

Therefore this thesis researches these uncertainties to come to an advice for municipalities on strategies they could implement to facilitate or stimulate the charging infrastructure and deal with the responsibility of the infrastructure on local level.

Research question

The research question, which is used for this, is: What strategy could municipalities implement to facilitate or stimulate the implementation of a charging infrastructure taking developments in the expected demand and in the technology into account?

Methods

The thesis uses a research framework based on a combination of the three different ambiguities identified above. Each research flow is researched by a tailored methodology. These methods, corresponding to the numbers above, are:

1. To identify the expected demand for charging infrastructure in neighbourhood an a model is used based on an energy balance. This model is finalized by analysing 400

different neighbourhoods in the Netherlands. To deal with the uncertainty in the future amount of electric vehicles, different scenarios for the amount of electric vehicles in 2020 and 2025 are identified. These scenarios are identified by analysing the political situation, the pattern of market adaptation and developments in the implementation by car manufacturers.

2. Technological developments in charging electric vehicles are research by analysing literature. More precisely analysing numbers and subjects of publications in academic journals.

3. The preferences of municipalities towards facilitation and stimulation strategies are research by a survey. 30 out of 45 municipalities responded, equally divided between large, medium and small municipalities, in terms of the amount of citizens. A weighted product model is used to compare the different strategy alternatives according to the preferences given by municipalities.

Different strategy alternatives and their theoretical effects are identified by analysing literature and existing strategies in municipalities. These strategy alternatives are identified in two levels:

- Level one, facilitation strategies: models which can be used to facilitate charging infrastructure; including licensing model, commission model, concession model, regional cooperation, ownership and no facilitation.
- Level two, stimulation strategies: policies which can be implemented to stimulate the implementation of a charging infrastructure; including subsidizing, parking advantages, enabling reservation of charging places, providing information and doing nothing.

The facilitation strategies are assessed on the results of the three research flows (expected demand, technological developments and preferences of municipalities). The preference of municipalities towards stimulation strategy alternatives is investigated.

Results

1. Expected demand for charging infrastructure on neighbourhood level
The facilitation strategies identified above are assessed on their ability to deal with the expected demand for a charging infrastructure on neighbourhood level. The four different types of neighbourhoods, which are identified in significantly differing in the amount of charging places, are used to calculate the expected demand on neighbourhood level in 2020 and 2025. The ranges become large in 2025 because of the higher uncertainty on the longer term.

- High-income residential neighbourhood: in 2020 between 9 and 14 charging places per square kilometre and in 2025 between 25 and 40 charging places per square kilometre.
- Low-income residential neighbourhood: in 2020 between 6 and 10 charging places per square kilometre and in 2025 between 18 and 35.

- Commercial neighbourhood: in 2020 between 20 and 30 charging places per square kilometre and in 2025 between 50 and 90.
- Working neighbourhoods: in 2020 between 12 and 20 charging places per square kilometre and in 2025 between 25 and 70. The range for working neighbourhoods is larger because of the large individual differences between working neighbourhoods.

The differences between the different types and between individual neighbourhoods are large. This means that dealing with these individual differences is included as requirement for the facilitation strategy advised to municipalities. Identifying the specific demand characteristics is therefore important before advising a municipality about a facilitation strategy.

2. Technological developments
Two developments are identified:

- Currently the possibility for fast charging is being deployed. An increasing amount of electric vehicle types is able to use fast charging. An increased demand for this charging method is expected at commercial and in some cases working neighbourhoods, where visitors park for a relative short amount of time (in the case of working neighbourhoods company visitors). The case of Fastned along the Dutch highways shows that the market is perfectly able to implement this themselves.
- A promising technology to use for charging is a method called inductive charging. This wireless method is expected to be implemented as option besides wired charging by car manufacturers between 2018 and 2020. When this technology start to enter the market it is recommended to provide the option for inductive charging as well in the charging infrastructure.

3. Preferences of municipalities
Regional cooperation and concession model scored highest in the comparison of facilitation strategies. In the comparison of stimulation strategies no clear preferred strategy is found. However subsidizing charging places is less preferred by municipalities because of the costs. Other strategies like providing the possibility to reserve parking places or informing citizens score equally.

Conclusions
The answer to the research question is that municipalities are advised to use an adaptive strategy in facilitating the charging infrastructure. This strategy maximizes the flexibility to adapt to changes because the results of this thesis show that there are uncertainties about future developments in the demand and technology of charging places.

An adaptive policy framework is developed to be able to implement a facilitation strategy, which is able to adjust to changes because of uncertainties about future developments. This framework can be used to monitor technological developments and the demand for charging infrastructure on neighbourhood level. The function of this policy framework is to support the implemented strategy and enable rapid adjustments when developments in demand or technology occur. Especially the amount of electric vehicles in the Netherlands and the implementation of inductive charging are developments, which are recommended to monitor closely.

This thesis also shows that municipalities prefer to cooperate on regional level with other municipalities in implementing facilitation strategies and that they are in favour of a similar model to the concessions for regional public transportation to implement charging facilities. This policy choice would enable municipalities with the possibility to formulate requirements about amounts, locations, types and implementations times of charging places. In the formulations of these amounts, types and locations emphasis should be given to the diversity and especially the uncertainty in the demand for charging infrastructure between and in neighbourhoods, as this thesis shows. For this reason the term of a concession agreement should not exceed 3 to 5 years, to enable for adjustments. Four general types of neighbourhoods, which fundamentally differ in the demand, were identified: high income, low income, commercial and working neighbourhoods. Besides the differences in demand between these types of neighbourhoods, individual differences for the expected demand in 2020 are recommended to monitor. The model identified in this thesis can be used for this.

The role of the municipalities in facilitating the infrastructure can also differ between the different types of neighbourhoods. The demand in commercial neighbourhoods is identified to be fast charging places. The market has shown to be perfectly able to implement this without any (financial) support of the municipalities. In working neighbourhoods the initiative in implementing charging places can be left to another stakeholder in this situation, companies. In residential neighbourhoods a facilitating role for the municipality is recommended. Stimulating the charging infrastructure by enabling the possibility to reserve charging places could be implemented in order to improve the currently not profitable business case of charging places. Emphasis should be given to parking pressure in this case to exclude the risk of abuse.

Future research and reflection

Further research is recommended on the practical implications of different strategy alternatives on criteria in the evaluation of the preferences of municipalities. Additional research is also recommended for the division of electric vehicles in different neighbourhoods. The data is based on the amount of electric vehicles in municipalities but a division of the amount of electric vehicles in neighbourhoods could increase the accuracy of the model.

In the development of this thesis the original plan was to explain the future demand for charging places by a regression analysis of demographic factors. However, data about the current charging places in neighbourhoods is not normally distributed. Therefore an alternative plan had to be developed. This process to develop and adjust to a new execution plan taught me a lot in being open minded besides the direction I have in mind.

Being forced to change my planning and deviate from the developed path helped me to realize that I had to execute my research step by step. At a certain moment I wanted to gather results too fast without considering the alternatives and searching for the most optimal method. This taught me to update my planning along the execution instead of retaining to the original deadlines.

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Nomenclature

List of Acronyms

BSS Battery-Switching Station

CBS Statistics Netherlands

EU European Union

EV Electric Vehicle

FEV Full Electric Vehicle

NKL National knowledge center charging infrastructure

OAD Area per Address: is the amount of addresses in a circle with a diameter of 1 kilometre.

PHEV Plug-in Hybrid Electric Vehicle

RandD Research and Development

RVO Netherlands Enterprise Agency

VWE Dutch vehicle information and registration office

WPM Weighted Product Model

Chapter 1

Introduction and research methodology

The amount of Electric Vehicle (EV)s on the Dutch roads is growing and an increasing amount of people is considering to switch from their conventional gasoline powered car to an electric car. This change has consequences for multiple actors in the society. This thesis will elaborate on the role for municipalities in the facilitation of EVs. This chapter will first identify the problem, which municipalities face. Second the problem will be fitted in an academic framework. Then the remainder of the chapter will be used to identify the core question, the research approach and the concepts of this thesis.

1-1 Problem statement

The usage of conventional gasoline cars is no longer seen as sustainable because of the environmental impact and the future shortage of resources [Kotter and Shaw, 2013, Catenacci, Verdolini, Bosetti, and Fiorese, 2013]. One of the options is to switch from our embedded system of gasoline vehicles to a system, based on electrical powering. Sierzchula et al. [2014] analysed the influence of financial incentives and other socio-economic factors on the adoption of EVs. They stated [Sierzchula, Bakker, Maat, and van Wee, 2014]:

"*The societal/economic benefits are not included in the price of electric vehicles and government stimulus policies are therefore desired*"

A lot of especially European governments have translated this desirability in the implementation of policies stimulating the usages of electric cars [van Kerkhof and Boonen, 2013]. For example on national level, the Netherlands subsidized the purchase of EVs until 2013 and stimulated leasing using a discount in the monthly tax to be paid for electrical powered vehicles [Maarsen, 2014]. However, a continues policy on the implementation of especially the infrastructure of EVs on local level is lacking [Buitelaar, 2015]. The lack of focus on the infrastructure is also emphasised in a research on stimulation policies for EVs [van der Steen, van Schelven, van Deventer, and van Twist, 2015].

In January 2015 a study was published in a news article which showed that more than 50% of the Dutch municipalities did not have a policy for the implementation of charging infrastructure [Buitelaar, 2015]. Because of the rising demand for a charging infrastructure it is important for municipalities to know what policy alternatives they have and which they could implement to facilitate and stimulate the infrastructure for EVs. This study will try to advice municipalities in the development of these strategies.

The current implementation strategy of Dutch municipalities for the facilitation of EVs is often reactive. When a request from a citizen for an charging place for an EVs (charging place fin the remainder of this thesis) is received by the municipality, it reacts by analysing the neighbourhood and providing a charging place as close as possible to the location of the received request [Netherlands Enterprise Agency: Environment, 2012]. It could be useful to investigate if there are other strategy options for municipalities for a couple of reasons:

- The rising air pollution in cities is an additional incentive for cities to stimulate the usage of EVs. Currently a lot of Dutch cities are not complying with European norms, risking fines [ANP, 2015]. According to Steinhilber et al. [2013] the transition to EV transportation is beneficial for air and noise pollution on local urban scale [Steinhilber, Wells, and Thankappan, 2013]. Therefore it is of interest to municipalities to stimulate the usage of EVs in order to reduce the air pollution and comply to the European norms.
- The Dutch government is aiming at 200.000 EVs on the road in 2020 and 1 million in 2025 [Ajanovic, 2014]. Using current data of the amount of cars sold and the amount of cars on the road (without correcting for the growth in the amount of cars on the road) would mean that approximately 150 electric cars a day would be sold [CBS, 2015b, RAI Agency, 2015]. For a city like The Hague this would implicate that 4 requests a day would be received for EV charging places. That would be 120 requests a month only for charging places around houses and not including places around offices or commercial areas yet. Processing this would mean an enormous amount of work. This is currently already taking more than 3 months in 22 out of 125 municipalities [APPM, 2015]. To increase the efficiency it might be useful to be able to construct the parking places for EVs in advance, using a model predicting the amount of EV charging places demanded.
- The current reactive strategy is vulnerable to mistakes and hasty decisions. This entails the risk of the selection of charging places which are actually not suitable because of trees or other practical issues and the creation of an infrastructure for electric vehicles without any overview. To prevent this it would be useful for municipalities to create charging places for electric vehicles in advance, allowing them to implement a network which is optimal chosen in the current infrastructure. Second, it is questionable if the current strategy of developing charging places is the optimal strategy in terms of future technological development and cost efficiency. If changes are expected in the technology of EVs, the current charging methods could become redundant.
- Steinhilber et al. [2013] researched the viewpoint of stakeholders in the automotive and energy industry. One of the barriers they mentioned was the missing regulation for the location selection for public charging spots [Steinhilber, Wells, and Thankappan, 2013]:

  "*It requires new challenges for urban planners.*"

Besides the problems of the current strategy there is another advantage of a proactive implementation of the infrastructure for EVs. The creation of charging places for EVs before they are actually used is an additional incentive for car owners to switch to EVs [Namdeo, Tiwary, and Dziurla, 2014]. Reasons like:

"There is already a spot where I can place my electric car or"

"my old parking place is changed in a parking place for electric cars"

could be an incentive for the systemic switch, which governments desire.

The municipality of The Hague confirmed this description in an interview. They recently changed their policy and are now targeting towards a proactive construction of 25% of the charging places for EVs. To ensure that the construction of these places will not harm the existing public parking places with high parking pressure, a decent analysis should be performed on the expected demand for charging places [Welleweerd, 2015, interview][1]. The question is however; is the proactive implementation strategy of an infrastructure for EVs on local level the best way, or could municipalities leave the implementation to the market, or could they remain as reactive as possible? This problem consists of two parts:

1. Knowledge question: what is the expected demand for charging places?

2. Policy question: what could municipalities do to facilitate this demand?

This master thesis will try to find an answer to these problems.

1-2 Academic framing

The problem identified in the previous sections needs to be framed as an academic problem to be able to conduct academic research. Therefore, the contribution of this research to the existing literature is identified here in the identification of a knowledge gap.

Literature review

To identify the position of this research in the existing literature a meta-analysis has been used [van de Wijngaert, Bouwman, and Contractor, 2012]. This meta-analysis is presented in appendix A. The network of concepts, which are used in the existing literature, is provided there. The conclusion of the meta-analysis is that the combination of characteristics of a neighbourhood is not related to the demand for an infrastructure for EVs in the academic literature before. It is researched for the demand for EVs itself but not for the infrastructure [Namdeo, Tiwary, and Dziurla, 2014, Wirges, Linder, and Kessler, 2012, Hidrue, Parsons, Kempton, and Gardner, 2011].

However, the major addition of this research to the existing literature is the policy strategy advice it tries to provide. A couple of researchers have identified policies to stimulate the usage of EVs but only Wirges et al. [2012] did this for the infrastructure, in the specific case of Stuttgart, Germany, not taking public charging places into account. For the

[1] Interview with Harm Welleweerd at Municipality of The Hague on February the 23^{th} 2015. Harm Welleweerd is responsible for the implementation of the infrastructure for EVs in The Hague.

Netherlands this public charging places are important and therefore this research contributes to the existing literature.

To be able to use predictions for an advice it is important to identify the uncertainties in the predictions. Another important contribution of this research to the existing literature is the identification of uncertainties that exist for the development of an infrastructure for EVs in the future and the consequences of these uncertainties for policy strategies for the facilitation of a charging infrastructure for EVs. These uncertainties can consist of multiple levels and there are multiple ways to deal with uncertainty according to previous scientific studies [van Geenhuizen and Nijkamp, 2003, Manzo, Nielsen, and Prato, 2015]:

- Blueprint thinking: idea of a makeable society with targets that can be reached through instruments.
- Normative thinking: idea that society may evolve according to normative criteria.
- Nested thinking: some parts of future can be predicted with sufficient accuracy.
- Fiction thinking: without limits of past constraints.
- Scenario thinking: design of meaningful future possibilities.
- Evolutionary thinking: assumes a mechanism in behaviour which drives systems to continuity in change, which also includes path-dependency.
- Learning thinking: based on positive and negative feedback loops in a dynamic choice environment.

The uncertainties for the future demand for an charging infrastructure are identified in this research. These uncertainties will be categorised in the categories to deal with uncertainties identified here. Based on this categorization, methods will be selected to deal with the uncertainties. The generic uncertainties which will be covered in this research include:

- Demographic characteristics: possibly the current demographic characteristics in neighbourhoods will change over time because of development plans or other factors. Chapter 4 will try to find methods to deal with this.
- Policy development: future policy which are taken to stimulate EVs are not known and the current policy can change. Chapter 3 will identify possible future changes in policies. Besides, the effects of policies are not known in advance and are therefore uncertain.
- Technological development: the development and influence of future technologies is not known and can only be predicted to a certain extend. Chapter 5 will try to map the predicted technological development.
- Market preferences: together with these technological uncertainties, uncertainties about the future demand of the market are difficult to estimate. Chapter 3 will develop possible methods to deal with this uncertainty.

Marchau et al. [2010] developed strategies to deal with different types of uncertainties in policy making. These strategies include mitigating -, hedging - and shaping actions, identified by possible signposts [Marchau, Walker, and van Wee, 2010]. These strategies will be taken into account when a policy strategy is formulated.

1-3 Research objective and core questions

The aim of the research is captured by the research objective. A research objective is the product; the researcher is aiming to deliver in the end.

The aim of this master thesis is to use predictions of the demand for charging infrastructure to identify a set of strategies that Dutch municipalities could follow to facilitate the development of an infrastructure for electric vehicles in 2020 and 2025 on a neighbourhood level taking uncertainties into consideration.

The charging infrastructure is in this case defined as the amount and type of EV charging places, and the location of these places. The timeframe of 2020 is chosen because the aim is that the results are relevant for municipalities at this moment. Current strategy plans are based in relative short term expectations. To be able to provide an advice, longer term developments are taken into account as well. The timeframe of 2025 is chosen for this because of the uncertainty in the developments in electrical transportation. It would be to speculative to provide predictions for 2030 or later. The level of neighbourhood is chosen because the characteristics of the analysed areas should be as specific as possible to be able to provide specific advice for local governments. Neighbourhoods are the smallest area for which data is gathered about demographic characteristics. Municipality districts are larger than neighbourhoods and therefore in most cases areas with different functions (shopping, residential etc.) will be located in districts, which reduces the specificity.

1-3-1 Scope

To make clear which subjects will and which won‘t be dealt with in this thesis, the scope is explained. This thesis explicitly does not include the stimulation of electrical driving itself. It tries to find demographic factors, amidst other factors to indicate the amount of EVs to be charged in a neighbourhood in 2020 and 2025 and strategies for municipalities to facilitate this. Therefore the research does not include an identification of the demographic characteristics that exist.

In the development for an infrastructure for electrical driving a lot of research is done to the network for electricity, called: smart grid [Jargstorf and Wickert, 2013, Kotter, 2013]. This research specifically does not include the relation between EVs and smart grids.

Finally the financing of the charge facilities themselves is only touched upon shortly in this research. Current projects and subsidies show that there are a lot of possibilities to finance the construction of charging places. Theoretically it would even be possible for the local municipality to exploit the places to electricity companies which sell the electricity to users of the facility, like a conventional gasoline station. The part of the cost, which is included in this study is the cost of the development of different types of charging facilities to be able to identify the optimal strategy for municipalities, being as cost efficient as possible.

1-3-2 Core questions

The aim of this thesis is captured in the research objective, to achieve this objective a set of questions is developed. The following research question is formulated:

What strategies could be advised to municipalities to facilitate or stimulate the infrastructure for electric vehicles in neighbourhoods, given future expectations and uncertainties of the demand for - and technology of - the charging infrastructure?

This research question consists of three parts. First the actual differences between neighbourhoods in the amount of charging places for EVs requested are estimated. Second, demographical factors are used to explain these differences and provide the local government with a tool to predict the amount of charging places for EVs. Third, this tool is used to translate the different scenarios in future demand for EV infrastructure to a policy advice for municipalities using a multi-criteria analysis. To deal with this research question a couple of core questions need to be answered. Section 1-4 will explain more about the methodology used in this research. The research flow which the thesis and the questions follow is shown in figure 1-1. The first question is used to investigate the demographic characteristics of drivers of EVs.

1. *Which demographic factors, to explain the demand for electric transportation, exist in the literature and which demographic factors should be included in a model for an infrastructure for electric vehicles in neighbourhoods, taking uncertainty into consideration?*

   The first core question focuses on the demographic factors in neighbourhoods, which could explain the demand for parking places for EVs. These are factors like the income distribution, average household size, origin and average age in the neighbourhood. The purpose of this question is to identify the factors that should be included in the model. This question will include the characteristics of owners of EVs according to theory and the demographic characteristics currently used in policies by municipalities. The demographic characteristics of geographical areas are dynamic and therefore include uncertainties which are identified.

   Chapter 4 will try to find an answer to this question. Besides uncertainties in demographic characteristics, there are other uncertainties, which probably influence the future demand for parking places for EVs. An example of this is the possible (stimulation) policies of governments. A separate question is formulate to cover the influence of these uncertainties:

2. *What political uncertainties have an effect on the future demand for the infrastructure*

for electric vehicles and what is their influence?

These factors are important to take into consideration to be able to make a reliable prediction. These questions will be answered in chapter 3. Another dynamic variable influencing the demand for EV infrastructure is technological progress of charging methods. The following question will be used to predict to the expected change in charging technologies and map the uncertainty in technological progress:

3. *What is the expected technological progress in EV charging methods (inductive charging, switching batteries and increasing capabilities of batteries)?*

This question will be answered in chapter 5. The fourth question is formulated to identify possible strategies for municipalities to facilitate a charging infrastructure and their characteristics:

4. *What are possible strategies, and their characteristics, for municipalities to facilitate or stimulate an charging infrastructure?*

The answer of this question will be used to identify a strategy advice in the end. The fifth question is used to explain and predict the demand for a charging infrastructure in neighbourhoods.

5. *What is the current and future demand for an infrastructure for EVs in the different types of neighbourhoods, taking the uncertainties of different influential factors into account?*

To answer this question target neighbourhoods are selected and the demographic characteristics of these target neighbourhoods are gathered. This is done in appendix D together with a description of the relation between the demographic characteristics of neighbourhoods and the demand for parking places for EVs in these neighbourhoods.

The future demand for an infrastructure for EVs is calculated in chapter 9. A distinction will be made between 2020 and 2025. The data found and methods used in the previous questions will be validated to increase the reliability of the model. The validation consists of various sensitivity analyses and discussions with municipalities. This validation will be included in the chapters in which each question is answered.

When the model is validated it can be used to advice municipalities on their strategy/policy to facilitate the infrastructure for electric vehicles. This is done in the final question:

6. *What are the preferences of municipalities towards facilitation and stimulation strategy alternatives for the infrastructure for electric vehicles?*

After this question the future demand is fitted in the expected development of charging technologies and the costs for the construction of charging facilities to arrive at a decent advice. As part of this, the strategy alternatives for the facilitation of an EV infrastructure are evaluated. To be able to perform a multi-criteria analysis between these policies, criteria should be identified and the multi-criteria analysis itself should be made. The advice for strategies will take to timeframes into account, 2020 and 2025.

When these questions are answered the main research question can be answered in the conclusion.

1-4 Research approach

The methodology which will be used for the data collection and result parts of this research will be given in chapter 2. This section will shortly introduce the approach which will be followed during this research. A more detailed explanation of the sequence, used in this thesis is shown in figure 1-1. This figure will be included in every chapter to show the relevance of the chapter for the research and can be seen as the research framework.

First, existing literature will be used to identify existing theories, which are needed for the research. In these theoretical part the influence and development of major uncertainties is explained. The uncertainties which are included are:

- Uncertainty in future policies and other factors, including market preferences, influencing the future demand
- Uncertainty in development of demographic characteristics
- Uncertainty in technological developments

The theories which will be used to predict the amount of charging places are also introduced in this theoretical part. The fifth theoretical chapter will identify the different strategy alternatives for municipalities to facilitate a charging infrastructure for EVs, and their characteristics. It will also identify the stakeholders. Finally, the theoretical part will identify the conceptual model based on the theoretical chapters.

Before the results are presented the methodology which is used to arrive at these results is explained. This methodology and the uncertainties about the future demand are used to identify different scenarios to deal with the uncertainty in the future demand for EVs. The identified demographic characteristics are used to identify differences between different types of neighbourhoods depending on these demographic characteristics. These different types of neighbourhoods and the different scenarios are used in a model to predict the future demand for a charging infrastructure in the different types of neighbourhoods and districts in Dutch municipalities. To timeframes (2020 and 2025) will be used for this.

The different strategies which are identified in the theory are evaluated using a multi-criteria analysis. For this multi-criteria analysis weights are gathered in a survey at municipalities, so the weight is based on their experience. The scores for each strategy are based on their characteristics. To validate this interviews with policy makers at municipalities will be used. The methodology in chapter 2 will explain this method in detail.

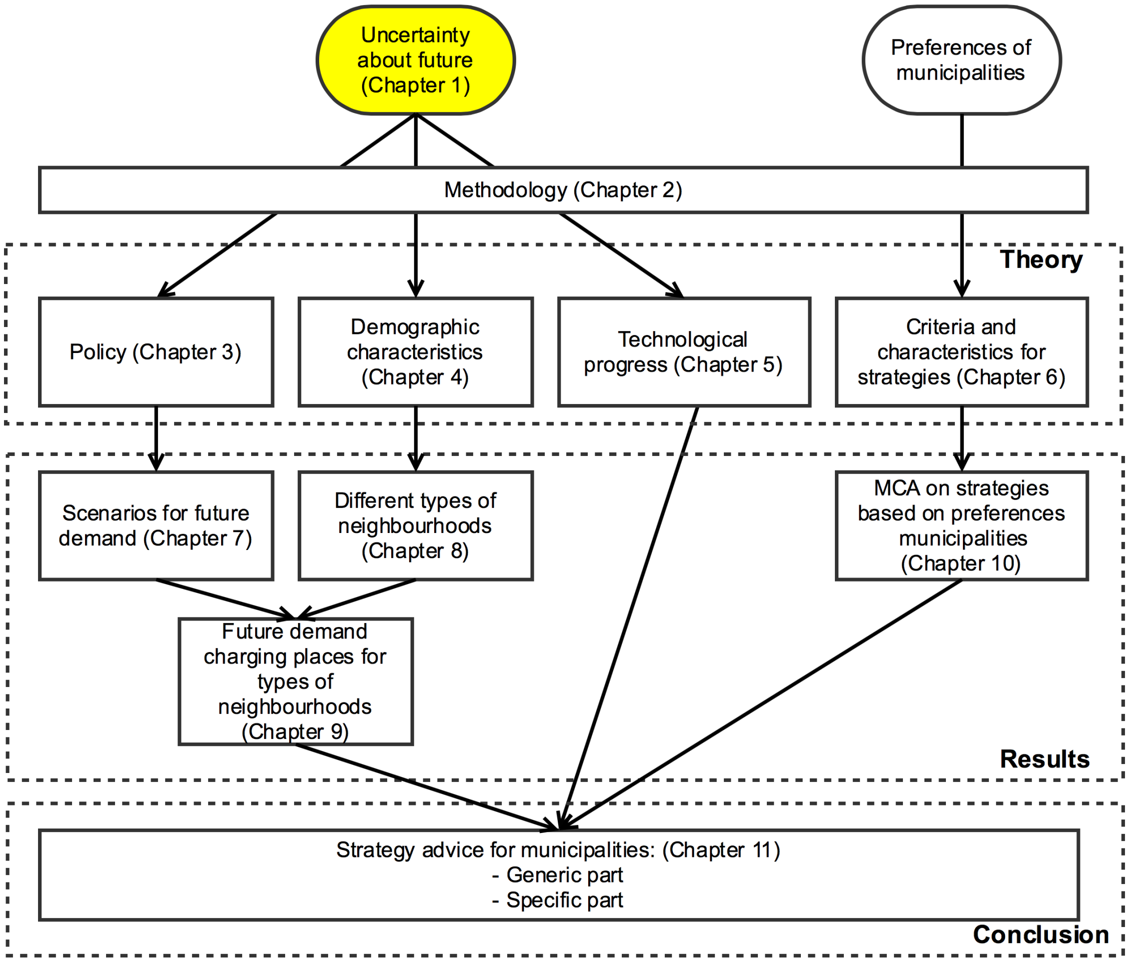

Figure 1-1: Sequence of steps taken in this thesis.

The final step uses the information found in the three columns to evaluate the different policy strategies and identify possible strategies for municipalities. The strategy advice will consist of a generic part which will be of general importance and of specific parts which are based on specifics types of neighbourhoods or specific scenarios, taking uncertainties into consideration.

1-5 Concepts

The concepts, which are part of this research will be explained and defined briefly here.

Uncertainty
Uncertainty is already introduced in section 1-2. In this thesis multiple categories of uncer-

tainty are used. This categories are used to determine the strategy that is used to deal with an uncertainty. The uncertainties that are identified in each chapter will be categorized and dealt with according to the definitions in section 1-2.

Demographic factors/characteristics
Demographic factors are defined as socioeconomic characteristics of a population expressed in statistics. Examples of this are age, gender, average size of households, average income, etc. The literature review in chapter 4 will identify demographic factors, which should be included to explore the demand for a charging infrastructure.

Infrastructure electric vehicles
The infrastructure for EVs is basically any device, which delivers electricity/power to the EV and the location of this device. There are different technologies available to do this and chapter 5 will elaborate more on this.

Besides the technology used it is important to make a distinction in the location of the charging places for EVs. There are three different types of locations possible [Netherlands Enterprise Agency: Environment, 2012]:

- Public places: are locations in public areas, which are not in private possession. Parking places along streets are an example of this.
- Semi-public places: are locations in areas with private ownership but with public access. Garage parking's at shopping malls are examples of this.
- Private places: are privately owned and privately accessible parking places. A driveway of a home is an example of this.

The municipality is not involved in the creation of private places, but because of competitative advantages these should be taken into account. More on this in section 2-1-1.

Future demand for electric vehicles
To be able to analyse the demand for the charging infrastructure in 2020 the future demand for EVs is needed. This future demand depends on different developments which can be simulated through different strategies. Most likely the future demand will be estimated in different scenarios. The literature review in chapter 3 will identify influential factors for the future demand and a way to deal with this uncertainty.

Demand for infrastructure for electric cars
The third concept is the demand for infrastructure for EVs. This concept is closely related to the demand for EVs itself and the prediction of this is a complex process. This thesis will not develop a growth model for the demand for electric vehicles as described in the previous section but it will try to connect the existing growth model used by the Dutch government to the geographical location of charging places for EVs needed [Environmental Agency, 2009].

Type of neighbourhood
Different types of neighbourhoods can be identified depending on the function of the neighbourhood in the society. In appendix B a more detailed description of the differences is given.

Technological progress
This thesis will identify possible developments in the technology of charging EVs. These developments depend on the technological progress that is made. A lot of literature is written on the characteristics of technological progress. In this thesis technological progress is seen as the introduction of new methods or products which will change the demand and/or current methods or products that are used. Chapter 5 will explain the expected developments in the technology of charging EVs.

Strategies for municipalities
In this thesis strategies for municipalities are defined as a set of policies, regulations and goals. The strategies are identified in chapter 6 and they are selected because they are used or possible to use for municipalities in facilitating a charging infrastructure for EVs.

1-6 Project overview

In the remainder of this master thesis the following structure will be used. In the first part I the data collection methods and reliability for the actual data measuring part is explained. This part also includes an explanation of the process which is followed to define the different scenarios, to predict the future demand and to evaluate the different strategies in a multi-criteria analysis.

The second part will consist of a description of the theory, to answer the questions based on theory. Chapter 3 will use literature to indicate the influence of other factors on the demand for EV infrastructure. Chapter 4 will identify demographic characteristics used in theory. Chapter 5 will indicate the predicted technological progress in EV charging methods, by evaluating publications. Chapter 6 will identify different strategies which are used by municipalities to facilitate a charging infrastructure. Part one will be concluded by the conceptual model which follows form the theory. The information resulting from the theory is processed in the conceptual model in appendix B.

In the third part the results are presented. First different scenarios for the expected developments in the amount of EVs on the market will be defined in chapter 7. Second the data of the neighbourhoods is gathered in chapter 8 and used to identify different types of neighbourhoods. The scenarios are used to predict the future demand for EV infrastructure for the different types of neighbourhoods in chapter 9. The founded results of a survey at municipalities and the criteria found in chapter 6 are used to conduct a multi-criteria analysis between the different facilitation and stimulation strategies alternatives using the preferences of municipalities.

In the methodology a section is written to explain the validation of the thesis. Multiple measures are taken to validate the research. In each chapter in the result part a section will be written about the validity of the results, using sensitivity analysis or interviews with policy-makers at municipalities. The conclusion and recommendations will be given in part IV, which also includes a reflection of the research.

Part I

Methodology

Chapter 2

Methodology

The research approach is introduced in section 1-4. The methodology, which will be followed during the data collection and result development is introduced in this chapter. Figure 2-1 shows the position of this chapter in the research flow, before the theoretical part and the results. This chapter is written to ensure the academic validity of the research. First the research design, including the unit of analysis will be explained. Second the methods used in the three research flows is explained. As is shown in figure 2-1 this starts with a method to calculate the expected demand for charging places will be explained. Then a method to investigate the technological developments in charging infrastructure is explained and for the third research flow the method used to arrive at a policy strategy advice from multiple options is explained. Finally the reliability will discuss measures taken to increase the validity and robustness of the research. This includes an explanation of the methodology used in interviews to validate the research.

2-1 Research design

To ensure the academic validity of the research the data gathering and analysis should be conducted in a structured way. This section describes the methodology that is followed throughout the research. The methodology explains the way in which the data is collected and processed to find the results. The first decision in the research design that needs to be made is the selection of the unit of analysis. Second, the research design will be described, including data collection approach, sampling and design of study.

2-1-1 Unit of analysis

The unit of analysis is the level on which the research focuses. In this thesis the unit of analysis is the level of neighbourhoods. The demographic characteristics of neighbourhoods are used to predict the amount of charging places for Electric Vehicle (EV) needed. Neighbourhoods are chosen in this case because it is the smallest level on which municipalities and the Statistics Netherlands (CBS) collects demographic data. There are arguments in favour and against the selection of neighbourhoods as the unit of analysis. To start with the arguments in favour:

- An analysis on the level of neighbourhoods would mean that the samples are large enough to reduce the possibility of extreme values without making the size to big which would mean that the distance to the nearest charging point would become too big.

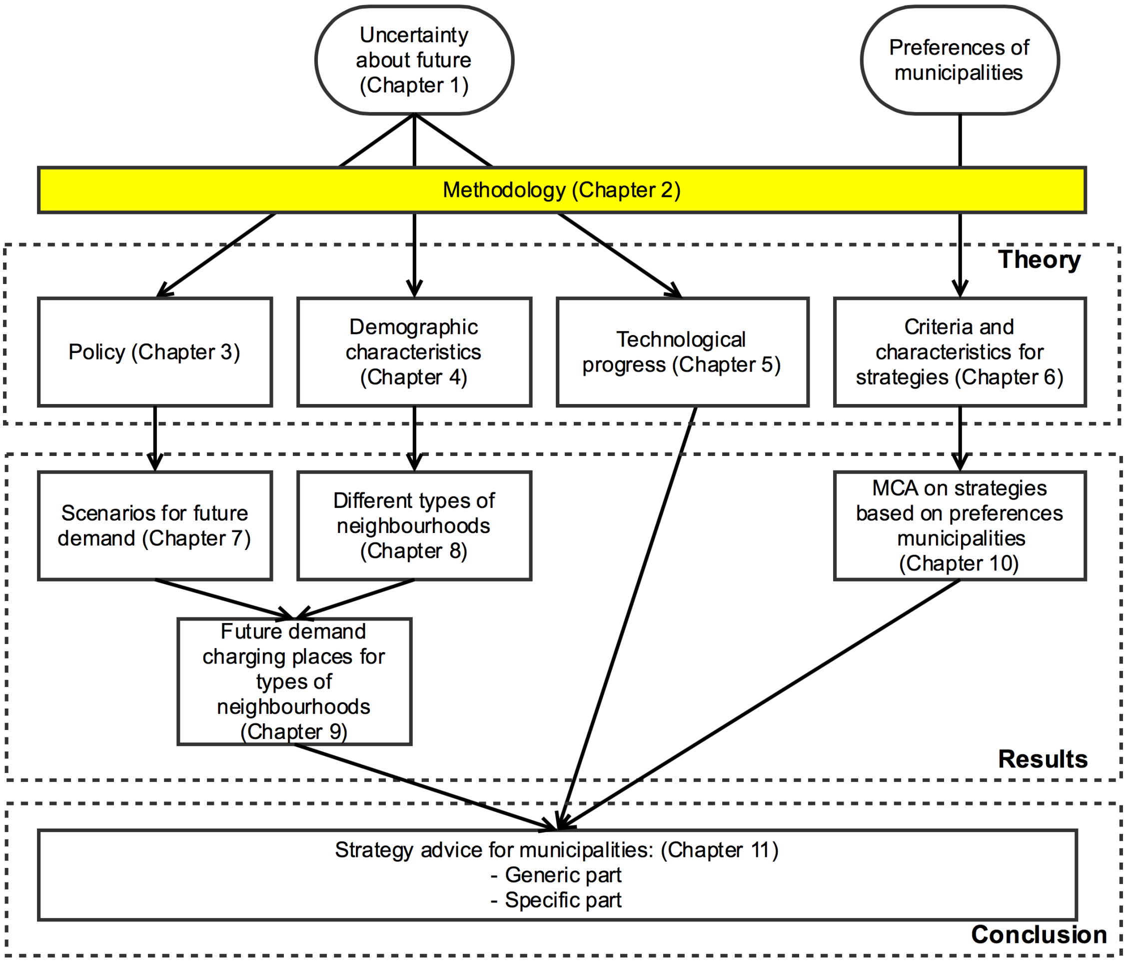

Figure 2-1: Sequence of steps in research, currently at chapter two in which the methodology to come to the results is explained.

- The data is collected by the municipalities and CBS and is open source and therefore freely available. This reduces the amount of data that needs to be collected.
- It is possible to identify differences between commercial, residential or working at the level of neighbourhoods without too much combinations.
- Neighbourhoods are small enough to have large differences in characteristics like income or household type.

Arguments against neighbourhoods as unit of analysis are:

- The distances within neighbourhoods can be too big for citizens to park their EV at parking place three or four streets further. This is a temporary problem because when the adoption of EVs increases the amount of parking places for EVs increases as well and the distances between places will reduce, reducing the possibility of a parking place for an EVs 3 or 4 streets further.

- The statistical office in the Netherlands has some delay in updating the demographic factors of neighbourhoods. They are up-to-date for 2012 now and 2014 is half empty [CBS, 2014]. Therefore it is possible that the data regarding demographic factors should be collected at municipalities. To ensure that all required data is collected the possibility to contact municipalities themselves should be considered.
- There is a risk that neighbourhoods are to small and not enough charging places are found per neighbourhood to be able to find results in the regression analysis. To reduce the impact of this risk the amount of EV charging points in municipality districts is collected as well.
- A lot of neighbourhoods are needed to be able to arrive at valid conclusions. A decent calculation of the required amount of neighbourhoods to be able to arrive at valid conclusions is therefore needed.

However the cons of neighbourhoods as unit of analysis it is decide to be the best level to use because of the sample size within the neighbourhoods, meaning the amount of citizens in a neighbourhood. This means that the cons should be taken into account in the data collection methods explained in the next section.

2-1-2 Design of study

The research to develop the model will have the form of quantitative research in which quantitative data is used to develop explaining (demographic) factors. The part in which the model and literature is used to develop a strategy/advice for municipalities about their policy for an infrastructure for EVs has the form of qualitative research. The influence of the researcher in the study will be minimized. This will be ensured through the selection method for the sample based on probability as described above. The time horizon of the study is selected to be cross-sectional, this means that the measurements are taken from one moment in time. The time frame is 2020, this means that a strategy for municipalities is developed in which the steps to take in the development of an infrastructure for EVs between now and 2020 are explained. The study setting is natural. This means that the setting is a real life case and not created by the researcher.

2-2 Research flow 1: expected demand in neighbourhoods

To different types of data needs to be analysed. In this section the method to analayse the data to predict the future demand for charging infrastructure is explained. Different scenarios are defined for this following from the uncertainty in the future developments, which will be explained in chapter 3. First demographic characteristics which are available are defined, these demogrpahic characteristics will be studied in the theoretical part in chapter

4. Second the data collection method in order to develop a model is explained. Finally the methodology to analyse the collected data and come to an expected amount of charging places in neighbourhoods is introduced.

2-2-1 Demographic characteristics available

To minimize the probability of missing data it is important to check which data is available for all neighbourhoods, which are in the target group. The target group is defined to be neighbourhoods with 2000 or more citizens per square km. Most of the data on demographic characteristics of neighbourhoods in the Netherlands can be found in the data of the CBS in the Netherlands [CBS, 2014]. Data on the current charging infrastructure can be found on open data platforms and in apps [Oplaadpunten.nl, 2015].

Most difficult demographic characteristic to identify is the user type because this data is not collected. Other difficulties are the parking pressure, competitive advantages of other suppliers and visitors of neighbourhoods because these depend on the individual local characteristics of a neighbourhood. An indication of the parking pressure can be obtained by including the density of houses. The CBS has defined the variable Area per Address: is the amount of addresses in a circle with a diameter of 1 kilometre. (OAD) [CBS, 2014]. The amount and type of visitors can be characterized in general by the type of neighbourhood (commercial, working or residential). Finally the competitive advantage of other suppliers is mostly of importance in neighbourhoods with the availability of (semi) public parking garages. It is difficult to include this because of the dependence on specific local characteristics. However, it is important to include this factor in the final strategy advice.

2-2-2 Sampling for charging infrastructure

To be able to arrive at valid conclusions for the entire amount of neighbourhoods in the Netherlands a decent calculation of the sample size is needed. To be able to define the sample size a couple of elements should be defined [Sekaran and Bougie, 2009]:

- Population is defined as the neighbourhoods in the Netherlands. According to the statistical office the amount of neighbourhoods in the Netherlands is 12005 [CBS, 2015b]. However, because of detached houses with drive lanes which will not be included in the research only the neighbourhoods with a density of 2000 people per square km or more will be included. This results in a selection of 4876 neighbourhoods.
- Sample frame: will be this list of 4876 neighbourhoods of the CBS.
- Sampling design: will be probability sampling in which the neighbourhoods have a known, equal and non-zero chance of being chosen. The sampling method will be randomized sampling. Which means that the neighbourhoods are randomly selected [Sekaran and Bougie, 2009]. The neighbourhoods are divided in the following regions to indicate differences between regions:
    - North: including the provinces Groningen, Friesland and Drenthe.

- West: including the provinces Noord-Holland, Zuid-Holland, Utrecht and Flevoland.
- East: including the provinces Overijsel and Gelderland.
- South: including the provinces Zeeland, Noord-Brabant and Limburg.

The sample size of each region is proportional to the number of neighbourhoods in each region and should be at least 30. Using the table to determine sample size defined by Krejcie and Morgan (1970) the minimum amount of subjects needed in the sampling is 352 for a population of 4876 elements [Sekaran and Bougie, 2009]. To be able to check if the assumption to exclude neighbourhoods with a population density of less than 2000 citizens per square km is correct 30 neighbourhoods on the countryside are selected with a population density of less than 2000 citizens per square km.

One additional remark needs to be made: the neighbourhoods are divided in commercial neighbourhoods, working neighbourhoods and residential neighbourhoods as explained in chapter three. There should be at least 30 subjects in each of these groups to be able to conduct valid research. It is likely that these 30 subjects will be selected but to make sure an additional check in which the neighbourhoods are divided between the different categories will be included in the selection phase. In the selection phase neighbourhoods will be analysed using amount of shops and workplaces in a neighbourhood.

It is possible that the selection of neighbourhoods with more than 2000 people per square km is not feasible or accurate when the research is conducted. A possible switch to municipalities and neighbourhoods in the G32 (37 largest municipalities in the Netherlands excluding Amsterdam, Rotterdam, The Hague and Utrecht) or to municipality districts will therefore be considered during the research. To minimize the impact data for districts is gathered together with neighbourhood data.

2-2-3 Data collection methods for charging infrastructure

The methods used to collect the data in the research depend on the data that is needed. To make sure the data collected is objective and reliable, the preference is to collect secondary data from independent institutions. An example of this is the CBS. The data of the CBS is not fully up to data for 2014, therefore municipalities should be contacted to request for the missing data or the data of 2012 should be used.

Besides the demographic factors, there should be data collected about the infrastructure for EV in each neighbourhood. Basically the amount of parking places for EV is needed. There are several possibilities to collect this:

- Open data: there is open data available about the location for parking places for EV in multiple municipalities. When the neighbourhoods that are selected are know it can be observed which open data is available and which is not. In principle the data of the CBS is selected because of the independent position. The data should be selected from one CBS database to avoid conflicts between different datasets. Therefore the dataset of 2012 is taken because the data of 2014 is not complete yet. If any data is missing in the dataset of 2012 it is directly gathered at the municipality. This implies that an assumption is made that the changes in demographic characteristics in neighbourhoods between 2012 and 2015 can be neglected. This seems valid because of the small change in the years before 2012, as explained in chapter 3.

- Apps: there are applications available which show the locations and availability of parking places for electric vehicles. These apps could be used to identify the locations. The different apps will be tested on completeness and accuracy to select the most reliable one as data source.
- Contact municipalities: for open data which is not available municipalities should be contacted to obtain the required information.
- Interviews: for practical information at the start and the validation of the founded results in the end interviews with employers of some municipalities will be conducted. These interviews have the form of a semi-structured interview in which the subjects are known before the start of the interview. The selection of the municipality of The Hague as being interviewed is because they are one of the first municipalities in the Netherlands to implement an proactive policy strategy to facilitate EV infrastructure. Besides the municipality of Oegstgeest is selected because it is a small municipality. The interviews in the end will also include the collection of criteria for the multiple-criteria analysis. This will be explained in the data collection for municipality strategies below.

The data needed for the policy advice for municipalities consists of a mix between the model and data found and existing literature about developments in the infrastructure for EVs. Another source of data can be existing projects or research institutes. An overview of a couple of those projects is given in appendix A.

2-2-4 Prediction of future demand for charging infrastructure

The first problem which is identified in the problem statement in section 1-1 is the problem that the future demand for charging places is not known. This problem will be solved in three steps:

1. Developing scenarios for future demand
2. Define different types of neighbourhoods which are relevant for the charging infrastructure
3. Calculate the demand for charging places in the different types of neighbourhoods for the different scenarios

The methodology which will be used in the different steps is explained below.

Developing scenarios

The scenarios for the future amount of EVs are based on the uncertainties which are identified in chapter 3. Each scenario will be defined stating the assumptions on which the scenario is based and presenting the calculation for the amount of EVs in the Netherlands in 2020 and

2025. This process is described and the outcomes are presented in chapter 7.

Different types of neighbourhoods

Different types of neighbourhoods are defined using data about the demographic characteristics of these neighbourhoods and the amount of charging places in these neighbourhoods. The methodology which is used to identify the different types of neighbourhoods consists of several steps:

- Step 1: the data is gathered using the process described in section 2-1.
- Step 2: the data is checked for normality, and equal distribution using the procedure described in appendix E.
- Step 3: the data is categorized for the different demographic characteristics identified in chapter 4.
- Step 4: the different categorizes are compared using a Mann-Whitney U test, in which mean ranks are compared [Sekaran and Bougie, 2009].
- Step 5: factors which differ significantly are used to determine different types of neighbourhoods.

For the different neighbourhoods a calculation is made which depends on the characteristics of the neighbourhoods. In this calculations a value for R_n is determined, which is needed for the calculation explained below.

Calculation of demand for charging places

To calculate the amount of charging places a model introduced in the theory in chapter 4 is used. The information collected using the data collection method explained above, in combination with formula 2-1 is able to predict the amount of charging places needed [Wirges, Linder, and Kessler, 2012]. Wirges et al. [2012] used this formula to predict the amount of charging places in Stuttgart. Wiederer and Philip [2010] used a similar approach. This approach is based on energy balance, it states that the amount of energy used by EVs should be equal to the amount of energy charged:

$$(e * d * R_N) * EV_N = (P * 24h * U_N) * C_N \tag{2-1}$$

In this formula the following symbols are used:

- C_N is the amount of charging places in neighbourhood N.
- e is the amount of energy used by an EV per km.
- d is the average daily driven distance.
- R_N is the percentage of energy charged at public places in a neighbourhood.
- P is the amount energy transferred from a charging point to an EV per hour.

- U_N is the utility rate of a charging place per day.
- EV_N is the amount of electric vehicles in the different types of neighbourhoods.

This thesis will first use the current data to estimate the percentages of energy charged at public places by EVs in the different types of neighbourhoods. This percentage is used to calculate the future amount of charging places needed based on the amount of EVs in a neighbourhood and the utility rate in a neighbourhood.

$$C_N = ((e * d * R_N)/(P * 24h * U_N)) * EV_N \tag{2-2}$$

Because the analysis will focus and predict for an average neighbourhood, a correction for the size of a neighbourhood should be included. This is done by dividing the amount of charging places and the amount of EVs in a neighbourhood by the area land of that neighbourhood in km squared. This gives the following formula:

$$C_N/A_{LAND} = ((e * d * R_N)/(P * 24h * U_N)) * (EV_N/A_{LAND}) \tag{2-3}$$

The correctness of the formula can be checked by an unit analysis. In an unit analysis the units of all the variables in the formula are compared and the remaining unit at both sides of the equation are compared. If the units are taken we can check if the unit of the answer (C_N) is as expected, and so the units of the input variables are equal:

$$((kwh/km * km * \%)/(kw * h * \%) * amount/km2 = amount/km2 \tag{2-4}$$

According to this test the unit of the answer is correct and so the formula is correct. The result of the formula will be the average amount of charging places in a type of neighbourhood per square km land.

To be able to calculate the efficiency for the different types of neighbourhoods the averages of the charging places (function of income, amount of households and address density) and the average amount of EVs in the different types of neighbourhoods is needed. These data is calculated by using the gathered data for the random selected group of neighbourhoods. Besides the same information is calculated for districts. The factor R_N becomes a factor which consists of multiple influential terms:

- The percentage of energy charged at public places in a neighbourhood or district is part of R_N.
- R_N includes a correction factor for the amount of visitors in commercial and working neighbourhoods or districts. Theoretically the percentage for the amount of energy charged at public places can become more than 100% when a neighbourhood or district has a lot of visitors.
- The influence of the level of income on the amount of charging places is partly captured by a change in R_N.

2-3 Research flow 2: technological developments in charging infrastructure

An important uncertainty influencting the development in charging infrastructure is the technology. When technological progress is made and new charging methods are developed, the current charging technology could be no longer necessary or profitable. To map the expected developments in technology the second research flow is used. This research flow uses a theoretical study using literature to identify developments. For this literature study Scopus is used [Scopus, 2015]. Different promising technologies will be identified and investigated. Chapter 5 will show the results of this literature study.

2-4 Research flow 3: evaluate municipality strategy alternatives

To evaluate the preferences of municipalities in the third research flow a multi-criteria analysis is used. However, first the alternatives should be collected and developed. Second, the method used to evaluate the alternatives is introduced, including the sampling method used for a survey at municipalities.

2-4-1 Data collection methods for municipality strategy alternatives

To be able to translate the founded results in a policy strategy for municipalities, different strategy alternatives need to be evaluated. To select these alternatives a research commissioned by the National knowledge center charging infrastructure (NKL) for the G32 (37 largest municipalities in the Netherlands) is used [NKL, 2015, G32, 2015]. The policy alternatives are completed by alternatives found in literature and the one of doing nothing. The interviews with the municipalities in the validation phase are used to gather information on criteria and the importance of these criteria to evaluate the policy alternatives. These criteria are used in a multiple-criteria analysis to compare the different policy alternatives. The model used is the Weighted Product Model (WPM) [Triantaphyllou, 2000]. These interviews have a structured form in which subjects will be known before the interview starts. The selection of interview partners is based on a representation of the target group of the research. A large city, a medium sized city and a municipality with a couple of neighbourhoods with relatively high population density are therefore selected.

An interview is used to gather the strategy alternatives at the NKL. This interview included a data analysis of the gathered data by the researchers of the study. This interview had an open form because the goal for the interview was to analyse the data. The results of this interview and alternatives are shown in chapter 6.

2-4-2 Multi-criteria analysis to evaluate strategy alternatives

The second problem which is identified in the problem statement in section 1-1 is a policy problem to identify what municipalities could do to facilitate the demand for a charging infrastructure calculated above. The strategy advice in the facilitation of a charging infrastructure will be based on this multi-criteria analysis. The input variables for this multi-criteria analysis are the different strategies identified in chapter 6. The purpose of a multi criteria analysis is to rank different alternatives based on their effects on certain criteria. Two characteristics are used for this:

- Weights: each criteria gets a weight of importance. The higher the weight the large the influence of a criteria. The weights are gathered by a survey amongst municipalities, which will be explained below.
- Scores: each alternatives gets an amount of points at a certain criteria, this is the score of an alternative on a criteria. The scores are determined by comparing the theoretical effects of the different alternatives on a criteria. So practical implications and side effects are neglected. These scores will be determined in section 6-2.

The type of multi-criteria analysis which is used in this thesis is a WPM, because the influence of the scores is minimized using a WPM [Triantaphyllou, 2000]. The influence of the weights, which are gathered at the municipalities, has most influence. The influence of the scores is minimized because of the assumptions made in the identification of the scores: alternatives are compared relative to each other without taking the value into account [Triantaphyllou, 2000]. The formula which is used to calculate the WPM-score is:

$$WPM - score = A1_{C_1}^{weight_{C_1}} + A1_{C_2}^{weight_{C_2}} + ... + A1_{C_N}^{weight_{C_N}} \tag{2-5}$$

In this formula the following symbols are used:

- $A1_{C_N}$ = score an alternative gets for a certain criteria C_N. This score is identified in chapter 6 and appendix G.
- $weight_{C_N}$ = weight a certain criteria C_N gets. The weight will be determined by the municipalities, in a survey which will be explained below.
- $WPM - score$ = the WPM-score which is calculated for an alternative. Based on this score the alternatives can be ranked.

In format of a WPM is a table in which the factors mentioned above are placed at the positions shown in table 2-1.

Role of multi-criteria analysis in this thesis
The role of the multi-criteria analysis in this research is to make a comparison between different strategies using the opinion of both municipalities as theoretical knowledge. The multi-criteria analysis provides a selection of strategies, which is favoured by municipalities on the theoretical effects of these strategies on different criteria. The assumption is made that the effects of the strategies are according to the theoretical outcomes, with no changes because of practical implications or side effects. However, to maximize the robustness a sensitivity analysis is conducted as explained in section 2-5-1. Second a WPM is used to

Table 2-1: Weighted product model for facilitation strategies.

Criteria	Weight	Alternative 1	Alternative 2	...	Alternative N
Criteria 1	$weight_{C_1}$	$A1_{C_1}$	$A2_{C_1}$	...	AN_{C_1}
Criteria 2	$weight_{C_2}$	$A1_{C_2}$	$A2_{C_2}$	...	AN_{C_2}
...	...	...	...	...	...
Criteria N	$weight_{C_N}$	$A1_{C_N}$	$A2_{C_N}$	...	AN_{C_N}

minimize the effects of this assumption. In a WPM the weights are used as powers, which minimizes the effects caused by the identification of scores for the different criteria. This selection is combined with the findings in the part of the expected demand for charging places and the technological developments to formulate a strategy advice for municipalities, as shown by the three arrows in figure 2-1.

Sampling for multi-criteria analysis

For this WPM criteria and weights should be identified. These criteria and weights are identified by interviewing multiple municipalities. Therefore the municipalities are divided in three subgroups:

- Large municipality: more than 100.000 citizens.
- Average municipality: between 50.000 and 100.000 citizens.
- Small municipality: less than 50.000 citizens.

From each group 15 municipalities are called for an interview in which the questions are fixed, because the gathered data should be comparable with each other. If an interview is not possible using the phone an email with the questions is send. The target is to reach 10 respondents in each group. For the group of large and average municipalities, this means that 25% of the population is inclueded in the response. For small municipalities this number is only 3%, but small municipalities are assumed to be less important because of the lower population density in those municipalities. This implies that the opinion of small municipalities will be included, but not proportionally. So the opinion of large municipalities will preponderate the opinion of small municipalities.

The municipalities are asked to score eight different criteria on a scale of 10 points. Besides they are able to identify additional criteria. The scores of the municipalities are levelled per criteria and divided by 10 to come to a weight for the WPM.

When the criteria and weights are known the policy strategy alternatives will be scored on each criteria based on the results found in the theoretical part and the regression analysis. This will be done for the different scenarios and the different types of neighbourhoods. The result will be an set of strategy advices for different types of neighbourhoods taking scenarios for uncertainty into consideration. The uncertainties will also be evaluated in the end to provide policy makers with a advice taking the future knowledge and known uncertainties into account.

Identified trends in the survey will be tested for significance using SPSS. For this test a non-parametric method will be used because the gathered data is measuring preferences. Preferences are non-parametric in most cases. The Kolmogorov-Smirnov test will be used to test this, as is also done above. The non-parametric test which will be used is an independent samples test with the Krustal Wallis as significance test for the difference between groups [Sekaran and Bougie, 2009].

Non-response
The non-response of the survey should be reported. For this survey a response of 10 was desired form each strata, so 30 in total. 15 surveys are dispatched in each strata, so 45 in total. In three cases a reaction was received that the municipality is not willing to answer the survey because of time pressure or the amount of surveys. In 12 cases no answer is received. In total 30 completed surveys are received. Of this 30 completed surveys, 10 are form a large municipality (30% of population), 12 are from a middle large municipality (30% of population) and 8 are from a small municipality (2,5% of population). The percentage of respondents in the population of small municipalities is argued above. The lower percentage of respondents of the amount of dispatched survey at lower municipalities can be seen as a confirmation of the argument that the relevance at small municipalities is less than at large or middle large municipalities. One survey, which is completed, had scores, which strongly varied, from the other municipalities, therefore it is excluded from the analysis because it is expected that they misunderstood the survey.

2-5 Reliability

To increase the value of the results of this research it is important to maximize the reliability of the research. Factors which are important for this are the validity and the robustness of the research and the model. Included in the validation of the research are interviews with municipalities. The methodology used in this interviews is explained here as well.

2-5-1 Validity

There are a couple of factors which should be considered regarding the validity of the research. First the sampling size and selection should be reliable. To ensure this the process described above is followed. Further the influence of other factors on the investigated relation is expected as being substantial. Therefore it is important to take other factors into consideration as is done in the construction of multiple scenarios in chapter 3. These scenarios can increase the reliability of the research because external factors influencing the outcomes are taken into account and are used in the multi-criteria analysis.

Another method to increase the reliability is to validate the model afterwards. This is an important instrument to check if the conclusions are actually true. In this case the model will be validated using existing studies concerning the demographic characteristics of drivers of EVs. Further the model will be validated by testing the applicability at different municipalities. At the start of the project a meeting with the municipality of The Hague was organised to test practical issues and the relevance of this research. Other meetings with municipalities at the end of the research are used to test the model in actual cases. This final meeting will also be used to gather information on the criteria to evaluate the different strategies for municipalities. The methods used in this interviews will be explained below. Finally a sensitivity analysis of the model will be included to indicate the consequences of other unknown external factors.

2-5-2 Methodology validation interviews

The purpose of the interviews at the end of the research is to validate the results. The reason to use interviews is because of the open-ended questions which are needed to validate the research. Part of the interview has an explanatory characteristic; i.e. to explain if the founded results seem valid. And part of the interview has an exploratory characteristic; i.e. to explore if there are new insights. A semi-structured type of interview is used to be able to deal with both of these characteristics of the research. This is advised by Saunders et al. [2009]. The structure of the interview is the following:

- First a qouple of questions are asked to introduce the role of municipality and the policy towards charging infrastructure in the municipality. This takes approximately 10 minutes.
- Second a summary of the finded results in the form of a presentation of approximately 20 minutes is given.
- Third open-ended questions are asked and about the results and feedback is gathered in the remaining 30 minutes.

No audio-records of the interview are made. During the interview notes are taken, which are processed in interview records. Results from the interviews are used to improve the applicability of the strategy advises.

The municipalities which are interviewed are chosen because of their size. One large municipality is interviews; i.e. The Hague. And one small municipality is interviewed; i.e. Oegstgeest.

2-5-3 Robustness

The robustness of the model to predict the demand for charging places is ensured by using a sensitivity analysis in which the input is changed to monitor the consequences of these changes. Besides the selection of the sample size to ensure the validity of the research, an additional measure is taken to ensure this sample size. When in the data collection part data of a selected neighbourhood is missing or another problem occurs for which a neighbourhood has to be removed, another randomly selected neighbourhood will be added.

In the determination of the scores for the multi-criteria analysis in chapter 6 the assumption is made that the effects of the different strategies on the criteria would be as theoretically expected. Practical implications or side effects are neglected. To be able to estimate the consequences of this assumption a sensitivity analysis of the WPM is included. The purpose of the sensitivity analysis is to analyse the consequences of the scores that are identified. To achieve this the scores which are used are transformed (1 will be 5, 2 will be 4, 4 will be 2 and 5 will be 1) to simulate a case in which the effects on a criteria are the opposite. The WPM will be conducted again for each criteria which is transposed. The rank in the results of these weighted product models will be presented to analyse the amount of times a strategy gets a certain rank. This provides a picture of the sensitivity of the strategies to changes caused by uncertain implications. This sensitivity analysis is done for both the facilitation level strategies and the stimulation strategies.

Finally, to check the robustness of the calculation for neighbourhoods the same process as explained in section 2-2 is followed for the districts in which the neighbourhoods are located. The results for the districts are compared with the results of the neighbourhoods and differences are identified and explained. The total amount of districts which will be analysed is 293. Which is a representative sample from a population of 1486 districts in which neighbourhoods with a density of more than 2000 people per square kilometre are located [Sekaran and Bougie, 2009].

2-6 Role of methodology in this research

This chapter explained the data gathering and analysis part of this research. This consists of several steps which will be summarized briefly below. The steps corresponds to the chapters in which the results will be presented and analysed.

- Scenarios for the future amounts of EVs: these scenarios will be based on developments identified in chapter 3. In the analysis the calculations will be explained.
- Types of neighbourhoods: based on demographic characteristics different neighbourhood types will be defined. The amount of charging places in 400 neighbourhoods will be used to analysed this. The selection of these neighbourhoods will be randomly from all neighbourhoods with more than 2000 citizens per square km. For the analysis SPSS will be used with the Kolmogarov-Smirnov test for normality and the Mann Withney U test to compare mean ranks of different categories of neighbourhoods based on demographic characteristics.
- Expected amount of charging places: for the different types of neighbourhoods an expected amount of charging places will be calculated using the model of Wirges et al. [2012]. This model includes multiple factors concerning technical features of charging, charging behaviour, energy usage and characteristics about neighbourhoods.
- Preferences of municipalities: municipalities will be asked to score different criteria according to their preferences in a survey. 45 municipalities will be approached in this survey in three different categories according to the amount of citizens of the municipality. The preferences of the municipalities will be used to conduct a multi-criteria analysis in the form of a WPM. This model is selected, because the influence

of the scores given in the ranking based on theoretical effects, is minimized in this method. The effects of this assumption are therefore minimized.

Part II

Theory

Chapter 3

The future demand for EVs

To be able to explore the demand for a charging infrastructure it is necessary to know the demand for Electric Vehicle (EV)s which are dependent on, and therefore will use, this charging infrastructure. In general it is difficult to predict the demand for a good or service because of uncertainties. A lot of studies have been done to be able to develop predicting demand models. In the prediction of the demand for EVs multiple factors are of influence. Identifying these factors contributes to the answer of the second and the fifth core question of this research: the political influences on the development of the demand for EVs will be identified and other influences and methods to calculate expected demands for EVs are defined. In this chapter factors influencing the demand for EVs will be treated, because of the complexity the possible influencing trends on the future demand for EVs will be analysed. This can also be seen in figure 3-1. Demographical factors influencing the demand will be treated separately in the following chapter.

In this chapter section 3-1 will identify different uncertainties in the demand for EVs. It will also identify methods to deal with these uncertainties based on the categories of section 1-2. The remainder of the chapter identifies the role and influence of the three main actors, influencing the demand. In section 3-2 the role of the central government will be explained. Section 3-3 will focus on the role of companies in the automotive sector. Then the behaviour of the customer will be analysed in section 3-4. Finally, section 3-5 will summarize the chapter and explain the scenarios which will be used in the remainder of the thesis.

It is useful to mention that EVs include all different types of vehicles with an electric power device installed because all these vehicles need a charging facility to make fully use of their ability to drive on electrical power. The different types of EVs and their acronyms they are explained here:

- FEV: Fully Electric Vehicle: this vehicle fully operates on electrical power.
- PHEV: Plug-in Hybrid Electric Vehicle: this vehicle has the possibility to drive on electrical power, using an electro engine, which can be charged in the same way as fully electric vehicles but they have also a conventional combustion engine which can be used when the batteries are empty.

3-1 Uncertainty in demand for EVs

There are a lot of factors which influence the future demand and a lot of these factors are likely to change. Examples of these uncertainties are:

- Government policy: it is uncertain if the current government policy will stay the same.

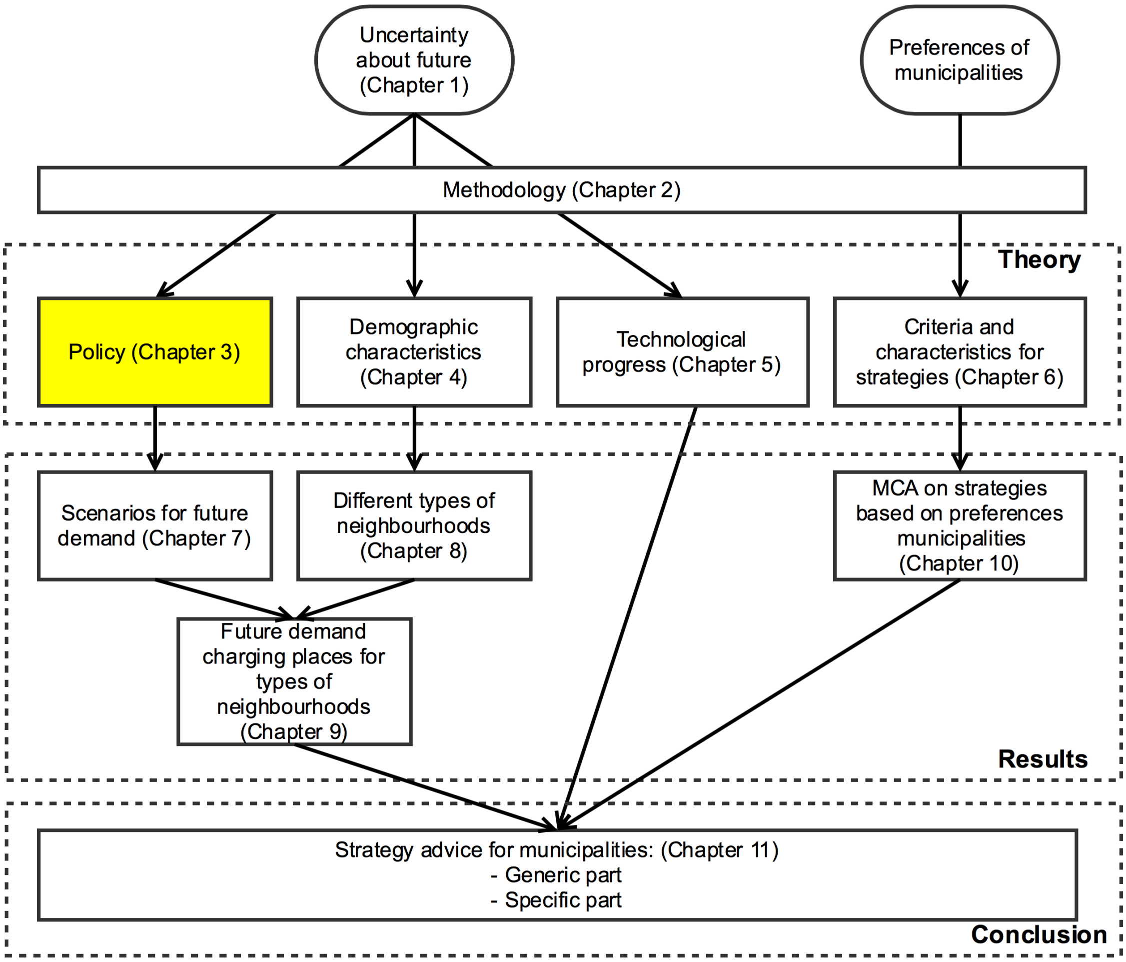

Figure 3-1: Sequence of steps in research, currently at chapter three in which uncertainties influencing the EV demand are define.

- Production automotive companies: the speed at which automotive companies will adjust their production plans and strategies to EVs is uncertain.
- Adoption of EVs in the market: the size of the market for cars is more or less stable, but it is uncertain how much and how fast EVs will penetrate this market.

The uncertainties in the future demand for EVs are large. The categories to deal with this type of uncertainty, defined in section 1-2, is scenario thinking. This category is able to deal with relative large uncertainties [van Geenhuizen and Nijkamp, 2003] and [Manzo, Nielsen, and Prato, 2015]. The method used is the definition of different meaningful scenarios, based on different possibilities. The three uncertainties identified above should be investigated more closely to be able to define scenarios. The following sections will elaborate on this.

3-2 Role of central government

Among others Sierzchula et al. [2014], Hidrue et al. [2011], Bosetti and Longden [2013] state the importance of government stimulation for EV adoption because of the societal/economic benefits of EVs which are not included in the price. Part of the reason for this is the knowledge spillover[1] externality causing a market failure [Rennings, 2000, Jaffe, Newell, and Stavins, 2005, Struben and Sterman, 2008]. These studies are part of the reason that a lot of governments have implemented stimulation policies, which influence the speed and amount of adoption of EVs. To be able to explore the demand for EVs it is necessary to know which policies are implemented and which will possibly be implemented in the Netherlands.

3-2-1 Current situation

The current ambition in the Netherlands is captured by the action plan electric transport of 2011 [Ministry of Domestic Affairs, Ministry of Economic Affairs, Ministry of Infrastructure and Environment, 2011]. The main target in this is 200.000 EVs on the road in 2020 and 1 million in 2025 [Environmental Agency, 2009]. The government uses policy instruments to reach the targets under continuous monitoring. An additional target in the action plan was 20.000 EVs on the road in 2015. As can be seen in figure 3-2 on the 31st of January 2015 the amount of EVs on the road was 48,500, more than twice the targeted amount [Netherlands Enterprise Agency, 2015b]. A remark has to be made that only 9.000 of these vehicles are full electric (Full Electric Vehicle (FEV)), and the rest is plug-in (Plug-in Hybrid Electric Vehicle (PHEV)) [Netherlands Enterprise Agency, 2015b].

Figure 3-2 shows the largest increase in EVs between August 2013 and December 2013, this can be explained by the stimulating policy that was in place during that time. This policy provided the option for drivers and companies who lease their car to be exempted from charges until 2018. This could potentially safe €10.000 for EV users between 2013 and 2018 [BNR, 2013]. When the short-term targets were reached the government stopped this policy, but it shows the effectiveness and commitment of the government to reach the goals set in its long-term action plan. Therefore it is likely that at least the amount of 200.000 EV will be on the road in 2020 as targeted by the action plan. The first baseline scenario will focus on this 200.000 EVs on the road. The uncertainty in this development is low because of the shown commitment of the Dutch government for the current policy.

3-2-2 Possible changes in policies

To identify possible future changes in the demand for EVs it is important to identify possible changes in the policy. As described in the previous paragraph the Dutch government developed long term targets and it has shown commitment to these targets. The likelihood of a long-term stable policy is even larger because it is developed by the previous cabinet and continued by the current one. This increases the likelihood that the next cabinet will

[1] Knowledge spillover relates to the ability of a firm to capture the benefits form technologies or expertise that it develops which reduces the change that the necessary Research and Development (RandD) investments are earned back [Sierzchula, Bakker, Maat, and van Wee, 2014].

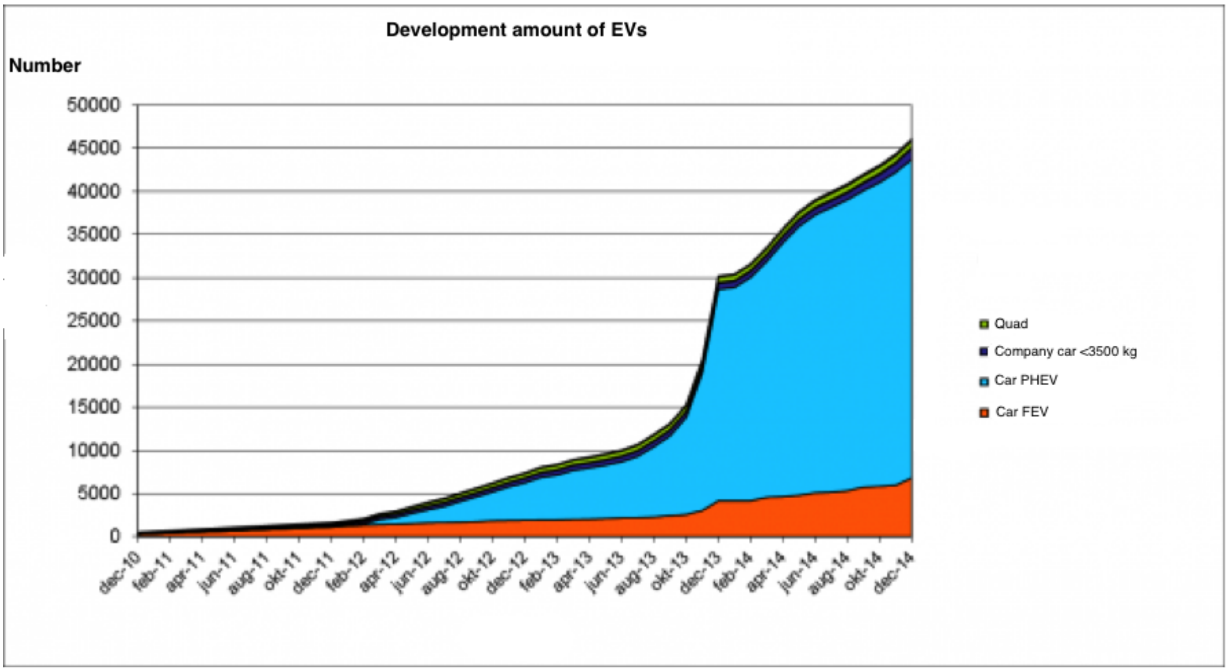

Figure 3-2: Amount of EVs on Dutch roads in between 2011 and 2014 [Netherlands Enterprise Agency, 2015b].

continue the current policy, also because of the European Union (EU) policy stimulating EVs [Ministry of Domestic Affairs, Ministry of Economic Affairs, Ministry of Infrastructure and Environment, 2011].

It is not likely that the Dutch government would do more than required to reach the stated targets because of the costs of stimulation policies. It would theoretically be possible that the Dutch government totally stops the stimulation of EVs, but as explained above not likely [Ministry of Domestic Affairs, Ministry of Economic Affairs, Ministry of Infrastructure and Environment, 2011]. Therefore this won't be included as a scenario.

What could cause a policy change is a changed target by the EU when it comes to the amount of EVs on the road. Most likely this European influence will only upgrade and not downgrade the amount of vehicles in the targets because the Netherlands does currently not comply to the European targets for 2020 on environmental aspects [European Environment Agency, 2014].

Effects of possible changes on types of users

The current stimulation policy focusses on lease drivers, which are in general workers with an above average income [BNR, 2013, CBS, 2015a]. This policy focusses on both FEVs and PHEVs. The government could change this policy to focus on only FEVs with no emission [Broekhuizen, 2014]. If the government stimulates the usages of the in general smaller FEVs and it uses a tax advantage on the price of the vehicles it is likely that also lower income groups will be able to buy FEVs. Especially when the current lease period of the PHEVs and

FEVs a lower income group will become attracted because they will be sold on the second hand market.

It is therefore a possible scenario that after 2018 (when current lease advantages end) new measures will be taken and lower and average income groups will be able to afford and electric car. As explained in chapter 4, studies already showed that it is not the income determining the willingness to drive EV but the affordability [Hidrue, Parsons, Kempton, and Gardner, 2011]. This would not be a scenario in which the amount of EVs changes but one in which the user groups, and therefore the characteristics of drivers of EVs change. This uncertainty will be used in chapter 7 as input for a scenario.

3-2-3 Export of electric vehicles

Numbers from the Dutch vehicle information and registration office (VWE) show that a lot of EVs bought in the Netherlands are exported. In previous years up to 20% of the new bought cars are exported within a year [Koot, 2015]. This can be used as an indication for the amount of EVs which will be exported, reducing the share of EVs in the Dutch fleet. It can be used as an uncertainty for a scenario in chapter 7.

3-3 Production automotive companies

An indicator of the future demand for EVs can be the RandD expenditures of automotive companies and governments through the principle of technology push [Nemet, 2009]. This is part of the blueprint thinking which automotive companies can follow. It is difficult to identify RandD budgets of automotive companies because of the competitive value of the information. However an interesting indication could be the new-presented electric cars because this provides and insight in the investments of an automotive company in EVs. This can be seen as an indication of their confidence in the technology and their expectations in the longer term. A difference is made between full electric vehicles and plug-in hybrid electric vehicles.

In table 3-1 it can be seen that almost every automotive company has presented an EV (FEV or PHEV), both FEV and PHEV are equal [ANWB, 2015]. A real difference can therefore not be identified in the technology in which the market has more confidence. An equal distribution between FEV and PHEV is therefore most likely in the short term. If the timeframe is extended to 2025 it would depend on the technological progress which category would be more likely to dominate. Since the range of FEVs is the main barrier the development of the battery capacity is most influential for this [Tsang, Pedersen, Wooding, and Potoglou, 2012].

3-4 Development along S-curve of technological innovation adoption

A frequently cited paper about the development of the market adoption for a technological innovation is [Ortt, Shah, and Zegveld, 2007]. This article describes the S-curve pattern for

Table 3-1: Focus of large automotive companies who have an EV on the market [ANWB, 2015].

Company	Both FEV and PHEV	Only FEV on market	Only PHEV on market
Audi			X
BMW	X		
Citroen		X	
Ford	X		
KIA	X		
Mercedes	X		
Mitsubishi	X		
Nissan		X	
Opel			X
Renault		X	
Smart		X	
Toyota			X
Volkswagen	X		
Volvo			X

the adoption of technological innovation. This is also mentioned by marketing books about the rate of diffusion in which 5 categories of user groups are identified (innovators, early adopters, early majority, late majority and laggards) [Mohr, Sengupta, and Slater, 2009]. Multiple researches have been done to see if the introduction of electrical vehicles fitted in these curves [van der Steen, van Schelven, van Deventer, and van Twist, 2015, Greene, Park, and Liu, 2014]. In general they state that the adoption of the electrical vehicle will follow this curve but with uncertainty about the period. According to van van der Steen et al. [2015] EVs are currently approaching or in the valley of death or trying to cross the Chasm as it is called in literature [Mohr, Sengupta, and Slater, 2009]. The research of van van der Steen et al. [2015] identified that additional investment of the government is necessary to overcome this. It would be interesting to fit the data of previous years in this S-curve pattern and expand the development to predict the future amounts. This would be a way to deal with the uncertainty, based on the S-curve theory, which is based on previous experiences with technological adoption, this is part of the category of evolutionary thinking as defined in section 1-2 [van Geenhuizen and Nijkamp, 2003] and [Manzo, Nielsen, and Prato, 2015]. An assumption in this is that the adoption of EVs will follow the same trajectory as previous technologies did. Chapter 7 will use this method to predict future amount in a model.

3-5 Scenarios used in thesis

The different influences and methods described above are used to determine scenarios. In chapter 7 the different scenarios will be explained and the values for the future demand will be determined. The scenarios which will be included, based on the previous analysis are:

- Baseline scenario: based on the current policy targets.
- Changing policy scenario: based on the assumption that the policy to stimulate EVs will change.
- Discontinuous policy scenario: based on the assumption that hydrogen will become the dominant technology and EVs will no longer be stimulated.
- Export scenario: based on the assumption that a substantial percentage of the EVs will be exported.
- Regression scenario: based on a regression based on the development in the S-curve theory of technological adoption.

Chapter 4

Demographic characteristics to explain EV usage

The policy advice for municipalities is partly based on the expected demand for Electric Vehicle (EV) infrastructure in neighbourhoods. Demographic characteristics will be used as indicator to define different types of neighbourhoods which will be used to calculate the expected demand. This chapter will identify the demographic characteristics that are included in the analysis using a literature analysis and taking practical considerations into account. These demographic characteristics will be used to find different types of neighbourhoods as the research flow in figure 3-1 shows. First the literature on this subject will be researched in section 4-1. Second, practical implications will be identified and future developments will be described in section 4-2. The third section will explain the uncertainty in the demographic characteristics. Finally a concluding section will be written in which the demographic characteristics included will be explained and literature will be research to identify models to calculate the amount of charging places.

4-1 Demographic characteristics in literature

Multiple studies try to find demographic characteristics of drivers of EVs. The characteristics that are identified focusses mainly on gender, age, income, number of cars per household and type of traffic [Orbach and Fruchter, 2011, Hidrue, Parsons, Kempton, and Gardner, 2011, Tal and Nicholas, 2013]. Other papers define groups of users of EVs. These groups are defined by characteristics, both demographic and other [Namdeo, Tiwary, and Dziurla, 2014, Wirges, Linder, and Kessler, 2012].

4-1-1 Literature based on specific demographic characteristics

Below the demographic characteristics that are mentioned in the literature are discussed.

Age and gender
Orbach and Fruchter [2011] found that in general EVs are bought by males between 25 and 40 years old with an above average income [Orbach and Fruchter, 2011]. Wirges et al. [2012], Namdeo et al. [2014] also use age as a characteristic as described in section 4-1-2. From the perspective of the willingness to pay for EVs Hidrue et al. [2011] have found that young people are the most promising group to target, gender is not mentioned in their analysis [Hidrue, Parsons, Kempton, and Gardner, 2011]. That Orbach and Fruchter [2011]

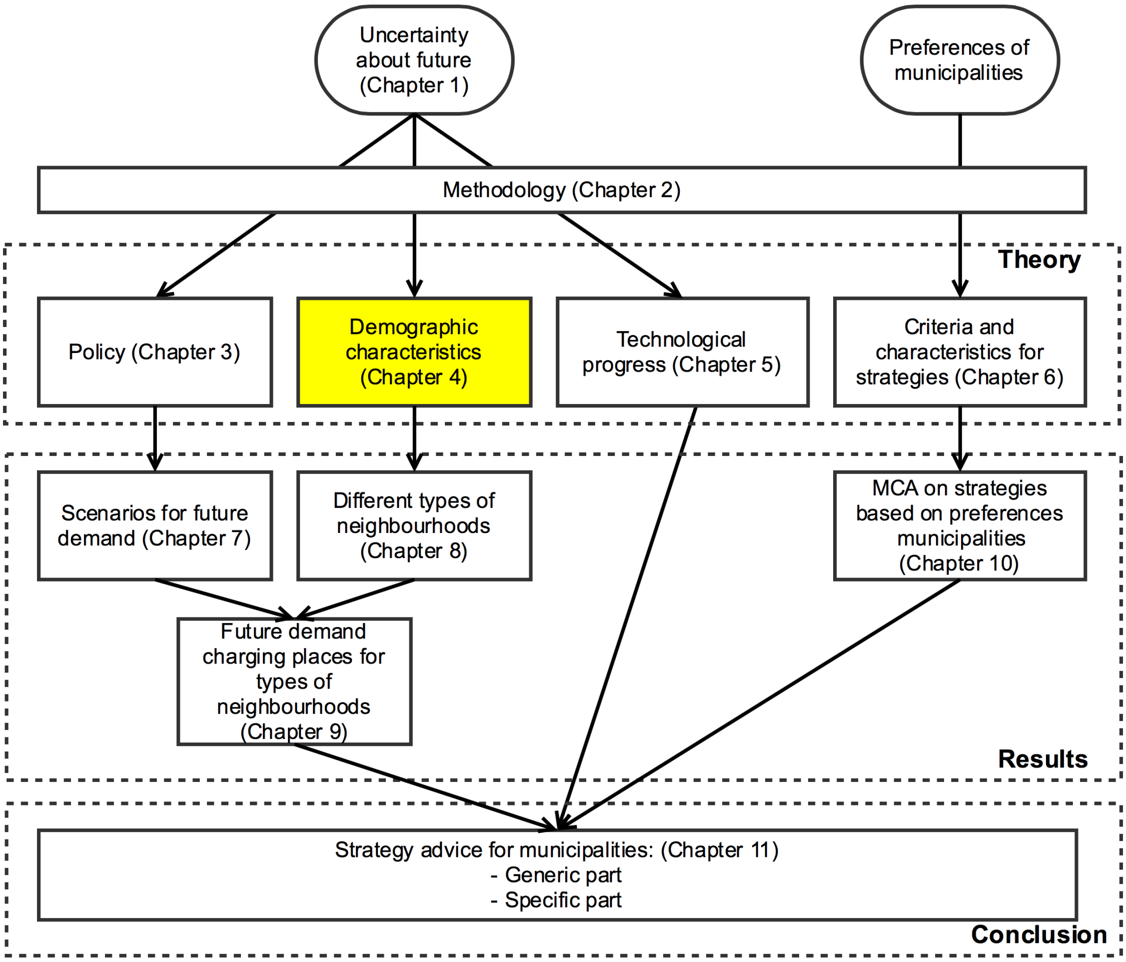

Figure 4-1: Sequence of steps in research, currently at chapter four in which demographic factors are defined.

identified males as the most prominent group of buyers of EVs is not surprising because in general more cars are bought by man and used by every member of the family.

Income and education level
Hidrue et al. [2011] state that:

"*educated people are the most promising group to target but that income is less important than expected. If the price of an electric car is competitive to a combustion engine car the demand will rise from all income groups*" [Hidrue, Parsons, Kempton, and Gardner, 2011].

According to them income is just of influence because of the higher price for EVs.

In a paper by Lieven et al. [2011] the higher price of an EV compared to a conventional gasoline car is mentioned as most important barrier [Lieven, Mühlmeier, Henkel, and Waller, 2011]. This confirms the viewpoint of Hidrue et al. [2011] in stating that income is no longer important when EVs becomes competitive to conventional cars.

Another reasoning can be included as well. It is evidential that people with higher income buy relatively more new cars than people with lower income, who buy relatively more second hand cars. Because there are no second hand EVs available yet, it is logical that the average income om drivers of EVs is higher, after all they have to buy a new EV [Pierre, Jemilin, and Louvet, 2011].

A research by Tal and Nicholas [2013] in California identified that the average income of buyers of EVs is higher than of buyers of conventional cars. They also show that a higher educational level also increases the percentage of EV buyers. As they mention as well, this is not surprising because income level and educational level are highly correlated [Tal and Nicholas, 2013]. It will therefore be hard to find differences in the explaining factor for income and education. There are two causal relations which can be used:

- People with higher income have more money to spend and can afford an EV. The higher educational level only helped them to earn this higher income.
- People with higher education care more for the environment and therefore buy EV. The higher income is only a consequence of the higher educational level.

The argumentation of Hidrue et al. [2011] above showed that in Europe the first causal relation is more likely to be the case.

Number of cars per household

The suggestion rises that EVs are often the second car in a household. However, no statements about this in the selected literature could be found, but it is mentioned in the second part of this section. Tal and Nicholas mention that in California most of the EV buyers, only buy a new EV. But they also state that 71% of the drivers are owners of an EV and only 29% are leasers of an EV. In the Netherlands however it is known that the percentage of EVs that is leased is a lot higher because of the financial advantages that where in place in 2013 [Steinbuch, 2012]. Practical implications of this will be discussed in section 3-2.

Type of neighbourhoods

The type of traffic is used to differentiate commuter traffic from leisure traffic and freight transport [Orbach and Fruchter, 2011]. This is only of importance when it comes to the type of neighbourhood which is the destination of drivers of EVs, because in general commuter traffic has as destination companies and leisure traffic commercial areas. Wirges et al. [2012] defines three different types of neighbourhoods:

- Commercial neighbourhoods: these neighbourhoods are characterised by a high amount of visiting 'shoppers' who want to park their electric car for a relative short amount of time. The commercial neighbourhoods will be defined using the amount of shops in a neighbourhood and an analysis of the map of a neighbourhood.
- Working neighbourhoods: these neighbourhoods are areas with a relative high amount of businesses. So the demand in this neighbourhood is for charging places during

daytime when the drivers are working. The working neighbourhoods will be identified using the amount of workplaces in a neighbourhood and an analysis of the map of a neighbourhood.

- Residential neighbourhoods: these neighbourhoods are residential areas. Basically, the demand for parking places for EVs in these areas is of people living there and parking/charging their cars overnight.

4-1-2 Literature based on groups of users

Using demographic characteristics, different groups of drivers of EVs can be defined as several studies showed. Namdeo et al. [2014] define the following groups [Namdeo, Tiwary, and Dziurla, 2014]:

- New Urban Colonists: Small households with children living in inner city, dependent on public charging facility.
- City Adventurers: young professionals living alone or in couples in inner city, dependent on public charging places.
- Corporate Chieftains: senior management professionals, residing in peri-urban locations, with multi-car ownership with own charging facility.

Wirges et al. [2012] describe the categories of EV owners in four groups [Wirges, Linder, and Kessler, 2012]:

- The urban trend-setter: younger persons in single or couple household with high level of education and high income.
- The multiple-car family: family households owning at least two cars and living in detached or semi-detached houses with own garage. They have relative high income and mostly their second car is replaced by electric one.
- The dynamic senior citizen: people between 60 and 75, owning high-capital. This group will increasingly become more mobile.
- The innovative fleet manager: enterprises adopting electric cars because of the environmentally friendly image.

In the definition of the categories a couple of demographic characteristics return. Both Wirges et al. [2012] and Namdeo et al. [2014] mention age and income as a demographic factor in most of their group definitions. Household size or type is mentioned in the New Urban Colonists and the City Adventurers of Namdeo et al. [2014] and in the urban trend-setter and the multiple-car family categories of Wirges et al. [2012]. Location of residence is mentioned as the inner-city by Wirges et al. [2012]. In the location also a distinction is made between detached and semi-detached housing by Wirges et al. [2012]. User type is related to a second car in multiple-car families or to business car ownership in both studies.

4-2 Practical implications of demographic characteristics

To be able to identify the demographic factors which are important to include in this research it is necessary to investigate which characteristics are of influence on the strategy for the implementation of an EV infrastructure for municipalities.

To identify practical characteristics, which are important to include, an interview with the municipality of The Hague was organised. The municipality of The Hague was chosen because it has established the policy goal to construct 25% of the charging locations proactively. These locations are selected using multiple criteria including income, parking pressure and location [Welleweerd, 2015, interview]. In this interview a couple of important characteristics to include were mentioned:

- Parking pressure: a critical factor in the development of a local EV infrastructure is the local parking pressure, because the availability of parking places determines the available space for charging places. An indication for the amount of parking pressure in a neighbourhood is therefore desired [Welleweerd, 2015, interview].
- Income: important characteristic but has to be combined with car ownership because people living in the centre in general have a high income but no car, so this could cause a conflict [Welleweerd, 2015, interview].
- Household type: the municipality of The Hague did not find a relationship between household type and the demand for an EV infrastructure in an analysis of the neighbourhoods in the Hague. However, it would be interesting to include [Welleweerd, 2015, interview].
- Density of houses: the municipality uses this as an important characteristic of the amount of vehicles in a neighbourhood [Welleweerd, 2015, interview].
- Competitive advantages of other suppliers of charging places: it is possible that semi-public locations are able to offer the same infrastructure for a lower price. In neighbourhoods where this is the case the relative expensive construction of an EV infrastructure by the municipality should be avoided [Welleweerd, 2015, interview].
- Visitors of neighbourhoods: there are two important types of visitors, visitors for leisure and commuters. Both groups should be included in the demand for an EV infrastructure [Welleweerd, 2015, interview].

Parking pressure is important for larger cities in general. The municipality of Amsterdam confirms this as well [Mun, 2015]. However, for smaller cities it is likely to be less of a problem because the population density is lower. Income and household type are also mentioned in literature as demographic factors to characterize EV usage [Wirges, Linder, and Kessler, 2012, Orbach and Fruchter, 2011]. Competitive advantage of other suppliers is something to take into account during the actual implementation of EV charging locations and could therefore be included in the advice. Visitors of neighbourhoods are also mentioned by Wirges et al. [2012] in the definition of different types of neighbourhoods.

4-3 Uncertainty in demographic characteristics

The demographic characteristics of neighbourhoods are also changing over time. It is not likely that the current composition (in terms of demographic factors) of neighbourhoods will stay the same between now and 2025. A couple of trends can be defined which will influence the future composition of neighbourhoods:

- Growing older: the population in the Netherlands is ageing. The consequence of this is a higher average age in neighbourhoods.
- Development area's: municipalities define area's which they refurbish to attract higher income groups [Driessen, 2015].
- City centres: the population of city centres changes relatively fast because most of the houses are for rent [Driessen, 2015].
- Neighbourhood effects: because of the relative small area of neighbourhoods it is possible that citizens park their car a couple of streets further in a different neighbourhood. Especially in neighbourhoods with high parking pressure, this is the case.

These uncertainties can be categorized according to the literature by van Geenhuizen and Nijkamp [2003] and Manzo et al. [2015], which is introduced in section 1-2. These categories are used to determine a strategy to deal with the uncertainty. The uncertainties which are mentioned above are categorized as nested thinking, because the changes within the uncertainties are relative small. The change in demographic characteristics over the past years was small as well [CBS, 2015a]. This means that the uncertainties can be predicted with sufficient certainty to make accurate predictions. In the case of 2025 ranges are added to remain the level of accuracy.

Another uncertainty is a change in user groups of EVs. This uncertainty is included in chapter 3 because it is an uncertainty about the demand for EVs.

4-4 Demographic characteristics for this research

Before the data is selected the availability of the data should be checked. The factors that are available for each neighbourhood and possibly of influence for the EV infrastructure should be included. The demographic factors, which are included are presented below with their unit:

- Age: according to Namdeo et al. [2014], Hidrue et al. [2011] young people are more likely to buy electric vehicles [Namdeo, Tiwary, and Dziurla, 2014, Hidrue, Parsons, Kempton, and Gardner, 2011]. This will be included in this research as well, using the data from Statistics Netherlands (CBS) [CBS, 2014].
- Average income: as explained by Namdeo et al. [2014], Wirges et al. [2012]. the average income is an important factor in the demand for electric cars. The suggestion rises that a higher income of a neighbourhood would result in a higher demand for

electric cars and so potentially a higher demand for parking places for electric vehicles [Wirges, Linder, and Kessler, 2012, Namdeo, Tiwary, and Dziurla, 2014]. These data are available in the CBS databases [CBS, 2014].

- Amount of citizens: to be able to estimate the demand for electric cars in a neighbourhood it is necessary to know the amount of citizens in this neighbourhood. The data about income is available in the CBS databases as well [CBS, 2014].

- Type/size of households: the composition of households is believed to have an influence on the demand for electric vehicles as explained by Hidrue et al. [2011]. The suggestion is that families and couples have a higher demand for electric vehicles [Hidrue, Parsons, Kempton, and Gardner, 2011]. It will be difficult to test this because of the wide range but it will be included, taking this range into consideration. Data about types of households is included in the CBS databases as well [CBS, 2014].

- Cars per household: the average amount of cars per household can give an indication of the type of car that is electric. If a lot of second cars are electric this will be found in the data in a high amount of charging facilities in neighbourhoods where the average amount of cars per households is high.

- Parking pressure: according to an interview with Harm Welleweerd of the municipality of The Hague the parking pressure in a neighbourhood is an important factor influencing the development of an infrastructure for electric vehicles [Welleweerd, 2015]. Therefore this will be included as a demographic factor in a neighbourhood (actually characteristic of neighbourhood). An indication of the parking pressure will be obtained by combining the amount of cars per area land and the density of houses (Area per Address: is the amount of addresses in a circle with a diameter of 1 kilometre. (OAD)).

Model to explain charging infrastructure demand based on demographic characteristics

Based on the demographic characteristics different types of neighbourhoods are identified in chapter 8. An expected amount of charging places is calculated for these different types using the demographic factors as indicators. The method which is used to calculate the amount of charging places needed is introduced by Wirges et al. [2012]. They developed a formula based on an energy balance, it states that the amount of energy used by EVs should be equal to the amount of energy charged. Wiederer and Philip [2010] used a similar approach. The formula and its role in this research is introduced in section 2-2.

The formula can be rewritten to calculate the amount of charging places to be able to cope with the demand for energy of EVs in a neighbourhood. This is what Wirges et al. [2012] have done for the analysis to predict the demand for a charging infrastructure in commercial areas. One of the assumptions they made is that no public places would be necessary at residential area's because drivers would be able to charge their EVs at a private charging place at home. This model will be used in chapter 9 to calculate the amount of charging places demanded in 2020 and 2025 in the different types of neighbourhoods which are based on the demographic factors introduced in this chapter.

Chapter 5

Technology developments

In this chapter technological progress in the Electric Vehicle (EV) infrastructure will be discussed. The function of this chapter is to identify if there are technological changes ahead which will influence the current charging methods or charging demand. The third core question will be answered in this chapter: what is the expected technological progress in charging infrastructure? Possibly these changes will have an impact on the way in which municipalities should organize or plan the facilitation of EVs. The location of this chapter in the research flow is shown in figure 5-1.

The technologies that can be used to charge EVs are [Netherlands Enterprise Agency: Environment, 2012]:

- Fast charging: using higher amount of power the batteries of electric cars can be charged faster. This form of charging is not possible on the normal 230V power supply locations in homes.

- Normal charging: enables users to charge a normal 230V power supply networks and is also possible on outlets in homes.

- Inductive charging: it is possible to charge EVs without wires. Through a primary coil in the ground and a secondary one in the EV energy is transferred through a small distance between the two coils. Currently this technology is only implemented in testing cases.

- Switching batteries: provides the option to switch the entire battery of an EV for a new one. It is not feasible in the electric vehicles, currently on the road, but technically it should be feasible.

This thesis will try to make a distinction between the demand for fast charging places and normal charging places to identify the kind of device municipality could facilitate in different neighbourhoods at this moment. For the future the technological developments of inductive charging [Zheng, Chen, Faraci, Zahid, Senesky, Anderson, Lai, Yu, and Lin, 2015, Eghtesadi, 1990], switching batteries [Amstrong, El Hajj Moussa, Adnot, Galli, and Riviere, 2013] and the development of the capabilities of batteries [Catenacci, Verdolini, Bosetti, and Fiorese, 2013] is analysed to enable a switch to those new technologies. Promising technologies are mentioned in literature, which will be discussed here.

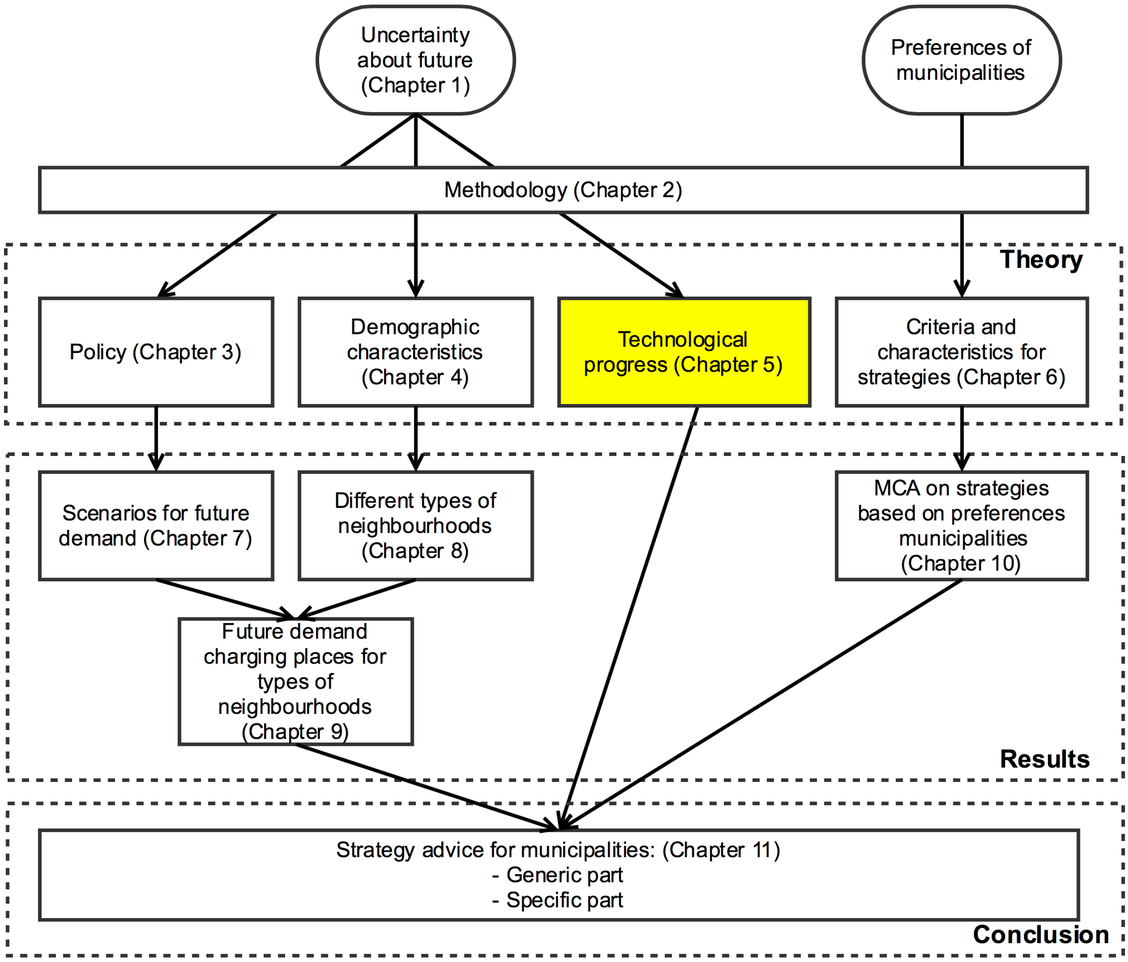

Figure 5-1: Sequence of steps in research, currently at chapter five in which technological developments are researched.

5-1 Uncertainty in technological development

Predicting the adoption of new technologies is difficult because there are a lot of uncertainties about the technology itself but also about the environment in which the technology enters the market. For example the fact that a technology is technically feasible does not mean that it is financial feasible and will be implemented [Ortt, Shah, and Zegveld, 2007]. It is difficult to categorize this uncertainty in one particular category, as defined in section 1-2, because of the different aspects influencing the technological development. From the perspective of automotive companies the uncertainty in technology can be defined as blueprint thinking, in which instruments can be used to reach a makeable society [van Geenhuizen and Nijkamp, 2003] and [Manzo, Nielsen, and Prato, 2015]. However, this thesis is written from the perspective of municipalities as policy maker and therefore a different category is used, namely evolutionary, in which path-dependency has an important role.

Based on this categorization a possibility to obtain an indication of the time before a technology enters the mass market is developed. By analysing the scientific publication timeline of a technology and compare it with other technologies it would be possible to get an indication of the moment of adoption of a technology [Ortt, Shah, and Zegveld, 2007]. In figure 5-2 an overview of the timeline of scientific publications for inductive/contactless charging and switching batteries is compared with the technology of fast/quick charging and charging EVs itself. The scale of the graph is limited to 20 publications to keep the overview, but the amount of publications for charging EVs after 2010 is higher. To get an indication of the amount of publications scopus is used to find the amount of articles published, using the words mentioned in the article title [Scopus, 2015]. This, combined with practical factors to consider will be used in this chapter to identify the expectations of these new technologies.

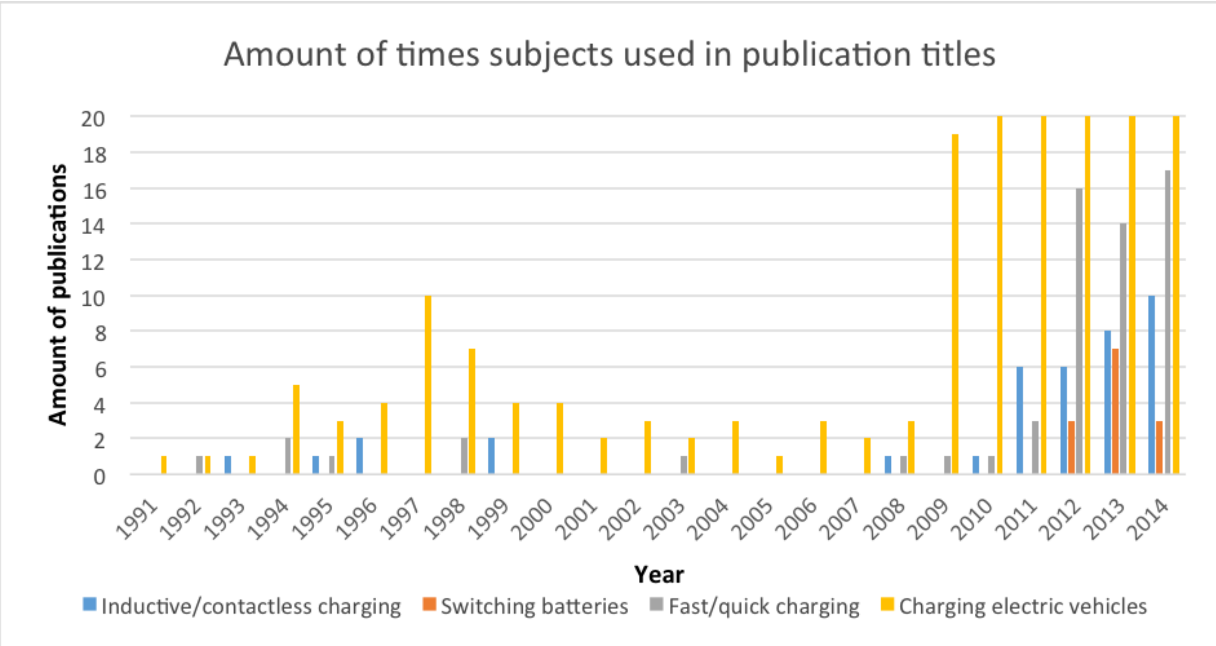

Figure 5-2: Amount of publications for each year on different technologies.

5-2 Capacity of batteries

Of influence for normal and fast charging can be developments in the capacity of batteries. In an expert survey in the European Union (EU) Catenacci et al. [2013] found that the investments in Research and Development (RandD) needed to overcome the price gap with conventional gasoline cars should be increased. On the current level, 50% of the experts predicts the gap to be disappeared in 2030. According to the other half a higher amount of RandD investment is necessary [Catenacci, Verdolini, Bosetti, and Fiorese, 2013]. Baker et al. [2010] did an similar expert analysis in the US. They founded a more optimistic view

[Baker, Chon, and Keisler, 2010]. So it can be concluded that the price of batteries will decline but not very fast [Catenacci, Verdolini, Bosetti, and Fiorese, 2013, Baker, Chon, and Keisler, 2010].

According to Adany et al. [2013] a lot of progress can be made in the extension of the lifecycle of batteries reducing the average cost of batteries. The proposed algorithms extend life duration by switching between a subsets of battery cells for each current demanded and control the discharge current from each battery cell, based on the electrochemical properties of the individual cells [Adany, Aurbach, and Kraus, 2013]. Other possibilities are more incremental improvements in software reducing the amount of energy needed, as Tesla is proposing [Tesla Motors Team, 2015].

Both methods discussed above are based on the current Lithium-ion batteries. But a promising Lithium-sulphur can change this. The capacity of this type of battery is five times higher and a recent breakthrough potentially solves the limited amount of charge cycles. The expectation is however that the new type of battery will not be implemented before 2023 because the research is currently in a fundamental stage [Abrams, 2013].

5-3 Inductive charging

Research to contactless charging of batteries started a long time ago [Eghtesadi, 1990]. In figure 5-2 it can be seen that inductive charging is the subject of publications on a regular basis. Only in the last three years fast/quick charging is used more often in publications. So based on the figure the development of inductive/contactless charging is expected to be ahead of fast/quick charging. Since fast charging is already implemented this would increase the likelihood that inductive charging will be implemented soon as well. A test with buses which are charged inductively during stops is an example of this [Proov, 2012]. However, inductive charging has a couple of technological barriers [Zheng, Chen, Faraci, Zahid, Senesky, Anderson, Lai, Yu, and Lin, 2015]:

- Efficiency of inductive charging: Zheng et al. [2015] showed that a theoretical peak efficiency of 96,6% for contactless charging is possible. This is still below the efficiency of wired charging and this will increase the electricity price of the transferred electricity because this loss has to be paid. A consequence of this is that people will still use the wired alternative because of the lower price [Zheng, Chen, Faraci, Zahid, Senesky, Anderson, Lai, Yu, and Lin, 2015].

- Ground clearance: for inductive charging the air gap between the primary coil on the ground and the secondary coil on the bottom of the car is important. For the efficiency of 96,6%, mentioned above an air gap of 8cm was used [Zheng, Chen, Faraci, Zahid, Senesky, Anderson, Lai, Yu, and Lin, 2015]. Current regulations in for example Australia state that the ground clearance between the bottom of the car and the road should be at least 10cm [Northern Territory Consolidation Regulations, 2015]. The likelihood that car manufactures will start producing vehicles which do not comply to regulations is low, resulting in lower efficiencies for inductive charging.

This barriers should be solved before inductive/contactless charging will be implemented. But according to the amount of research and the advantages of this technology it is expected that it will be implemented before 2020.

5-4 Switching batteries

The first time the possibility of fast charging of electric vehicles was mentioned in relevant literature was in 1998 [Nor and Vogt, 1998, Burba and Ochocinski, 1998]. The amount of publications about switching batteries in figure 5-2 shows that the academic interest for the technology of switching batteries is limited, possibly because it is not really a new concept (switching batteries is common in portable electronic devices).

Amstrong et al. [2013] researched the financial feasibility of battery switching stations Battery-Switching Station (BSS) for EVs. They found that BSS only generate revenue when a vehicle to grid method is used and the arrival of EVs is spread equally throughout the day, which is quite unlikely if we compare the spread with the demand at gasoline stations. The main reason for this is the high price for batteries [Amstrong, El Hajj Moussa, Adnot, Galli, and Riviere, 2013]. The lack of profitability can be a reason why battery-switching is not implemented yet and will probably not be implemented soon. The bankruptcy of Better Place in 2013 confirms this picture [McCormick, 2014].

Currently automotive companies do not provide the option to switch batteries. Of course this should be the first step in allowing the technology to enter the market but before they will do this the profitability should be improved and according to Amstrong et al. [2013] the price of batteries is an barrier for this. To overcome this barrier the price of batteries should decline, which is not likely on the short run according to Catenacci et al. [2013]. Therefore it is not likely that the technology of switching batteries will be largely implemented by 2020.

5-5 Summary research flow expected technological progress in charging infrastructure

The previous sections tried to identify expected changes in technology to minimize the technological uncertainty as mentioned in section 1-2. In the timeframe of 2020 the expected changes in technology are only in the implementation of inductive charging. In the strategy advice it should be taken into account that this technology will become largely available before 2020. If the timeframe is expanded to 2025, additional changes in especially battery capacity and duration should be taken into account [Abrams, 2013]. This can especially influence the market preference for EVs and can possibly cause an increase in the demand for EVs. However, it is difficult to make predictions about these changes at the current stage but it should be taken into consideration in the formation of a long-term policy advice. The considerations which will be included in the next steps of the research are:

- Fast charging is currently being implemented. Not every EV model currently on the market is able to use fast charging. It is expected that the new models which will be implemented, will be able to use fast charging. Therefore the demand for fast charging places along highways and commercial areas will increase. The demand for charging places at home or at work will remain for normal charging places because the parking time is longer and fast charging is more expensive.

- Inductive charging is likely to be implemented between 2018 and 2020. However, because of the changes needed in the composition of EVs it is likely that it will be provided as option at first. Like car manufacturers provide an option for air conditioning. They are likely to provide an option for inductive charging technology, because of the changes needed in the construction.

- Enabling charging point developers and operators to implement the possibility to use inductive charging should therefore be considered when the technology is implemented. This means that the same strategy car manufacturers use, can be used: provide the option to construct an inductive charging place.

- No breakthrough developments in the battery technology are expected in the near future. A lot of research is done in batteries with other compounds than currently used but experts expect no implementations of these technologies within five to ten years. The main improvements in battery technologies at the moment are initiated by software improvements.

These developments in the technology for a charging infrastructure are used in the general advice for municipalities.

Chapter 6

EV facilitation strategies for municipalities and conceptual model

In this chapter different strategy alternatives for municipalities will be investigated. The function of this chapter is to investigate the alternatives municipalities could use to facilitate an infrastructure for Electric Vehicle (EV)s. These alternatives are compared using a multi-criteria analysis in chapter 10, as can be seen in figure 6-1. Before the different alternatives are identified it is useful to know the stakeholders who are involved in the infrastructure for EVs. This is done in section 6-1. Section 6-2 will determine different alternatives. The alternatives are determined on different levels. First a general level will be investigated. This focusses basically on the question whether municipalities should take action or do nothing. Second different models to facilitate the installation of EVs are defined. Third different stimulation policies will be identified. These three levels will also be evaluated in chapter 10 to be able to advice municipalities. In section 6-3 the criteria to evaluate the alternatives are defined together with the scores of the different alternatives on these criteria.

6-1 Stakeholders

There are different types of stakeholders involved in the infrastructure for EVs. Table 6-1 gives an overview of the stakeholder types, their role and examples of them. The first 3.000 charging places which are constructed in the Netherlands are constructed by E-Laad, initiated by the national government [E-Laad, 2015]. These charging places are subsidized by the national government. At the end of 2013 E-Laad reached 3.000 charging places and they stopped the construction. Currently, E-Laad is split up in EVnetNL, responsible for the maintenance of the charging places constructed by E-laad and ElaadNL, responsible and allowed to use the data of the charging places. Besides E-Laad, other companies started to construct charging places. Fastned started to construct fast charging place along the highway, Allego focusses on the cooperation with municipalities and The New Motion started to construct charging places for individuals [Fastnet, 2015], [Allego, 2015] and [The New Motion, 2015]. Energy supply companies started to construct charging places as well because they want to sell as much energy as possible [Nuon, 2015]. The transportation of the energy towards the users is operated by the energy grid operators.

The municipalities are responsible for the local public area. This means they regulate the mapping of the public area and so should allow or allocate locations to construct charging places in the public space. The municipalities are cooperating in regions and provinces and because of compatibility issues provinces are a stakeholder. They want the same type of

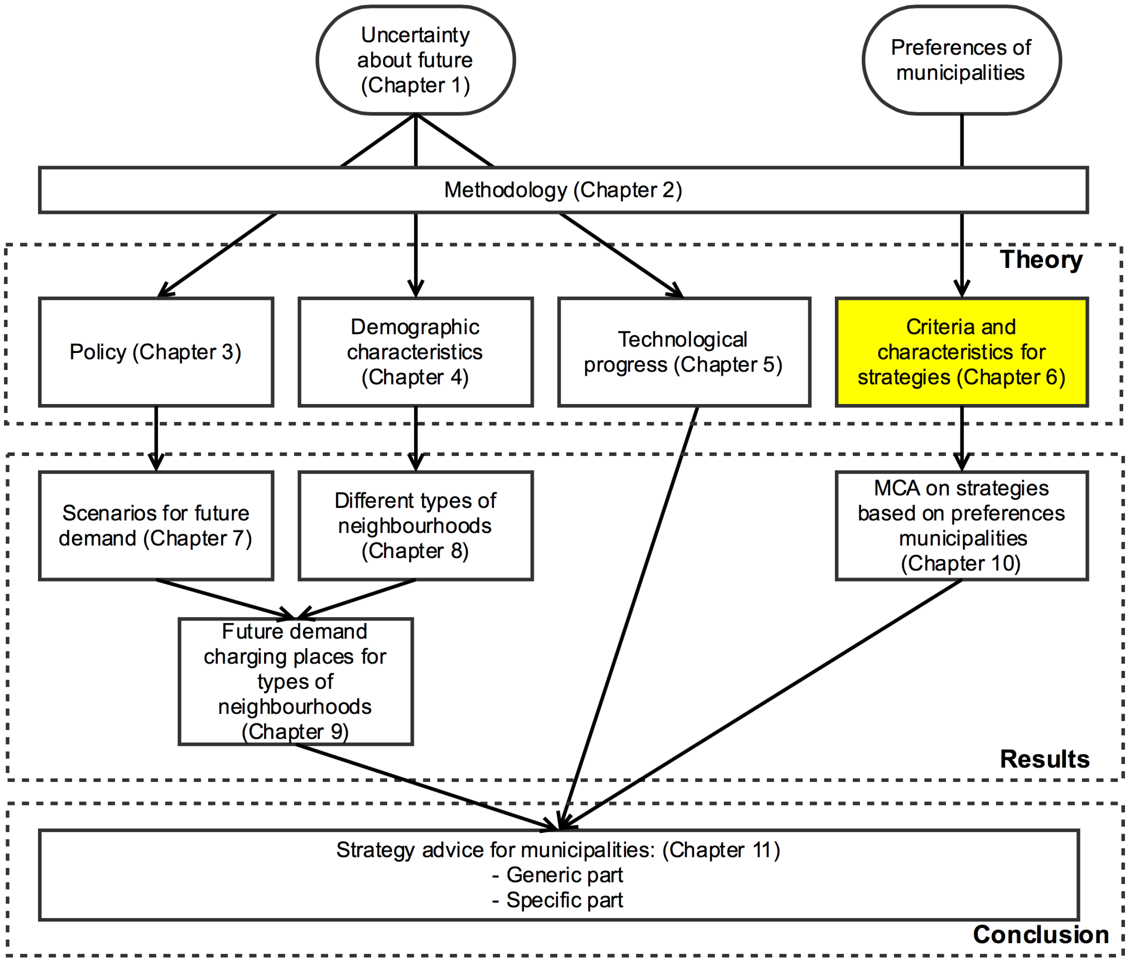

Figure 6-1: Sequence of steps in research, currently at chapter six in which possible strategies and criteria to evaluate the strategies are researched.

connection in the province so users are able to charge in the same way in each part of the province. Finally, manufacturers of EVs are targeting to sells as much EVs as possible. They are a stakeholder, because the EVs they sell need a charging infrastructure to be used. The drivers of EVs are therefore a stakeholder, as well.

Currently the business model for charging places is not profitable in general. Important reason for this is the limited electricity price charging place operators could charge because of regulations by the central government. These regulations aim to keep the price of electrical transportation sufficiently below the price of conventional gasoline [Vereniging Nederlandse Gemeenten, 2015]. Appendix J explains the business case of charging places.

Table 6-1: Stakeholders concerning infrastructure for EVs

Stakeholder type	Role	Example
National government	Original initiator, currently subsidizing	Ministries
Municipality	Responsible for local public area	Amsterdam, The Hague, etc.
Province	Compatibility of charging places	Flevoland, Limburg, etc.
EV manufacturers	Need charging places to increase sales	Tesla, Renault, Opel, etc.
EV drivers	Need charging places to charge their EV	Citizens
Charging place producer	Producing charging places	Allego, Fastned, The New Motion, Nuon, etc.
Charging place operator	Operating charging places	ElaadNL, Allego, Fastned, The New Motion, Nuon, etc.
Electricity supplier	Selling the energy	Nuon, Essent, Eneco, Oxxio, etc.
Electricity grid operator	Responsible for the transportation of energy	Alliander, Stedin, Tennet, etc.

6-2 Strategy alternatives for municipalities

As explained in the introduction above different levels of alternatives will be defined to be able to compare alternatives of the same level. Three different levels of strategy alternatives are defined, depending on their function. In figure 6-2 a schematic overview of the different levels is given. The first level consists of alternatives, which focus on the question if municipalities should facilitate EVs. The second level focusses on the model, which municipalities could use to facilitate EVs. The third level consists of a separate question: should municipalities take stimulation measures for an infrastructure for EVs?

Level 1: facilitation of infrastructure for EVs
The first strategy level focusses on the question if municipalities should facilitate an infrastructure for EVs. Different studies have emphasised the importance of the charging infrastructure for the large-scale introduction of electrical transportation. Sierzchula et al. [2014] made a regression analysis with data about the percentage of market adoption in different countries and explaining factors for this percentage of EVs on the market. They found the largest relation between the availability of a charging infrastructure and the amount of EVs [Sierzchula, Bakker, Maat, and van Wee, 2014]. However, this is a logical relation because if the amount of EVs increases, more EVs need to be charged and the amounts of charging places will increases. This does not say anything about the role the government should play

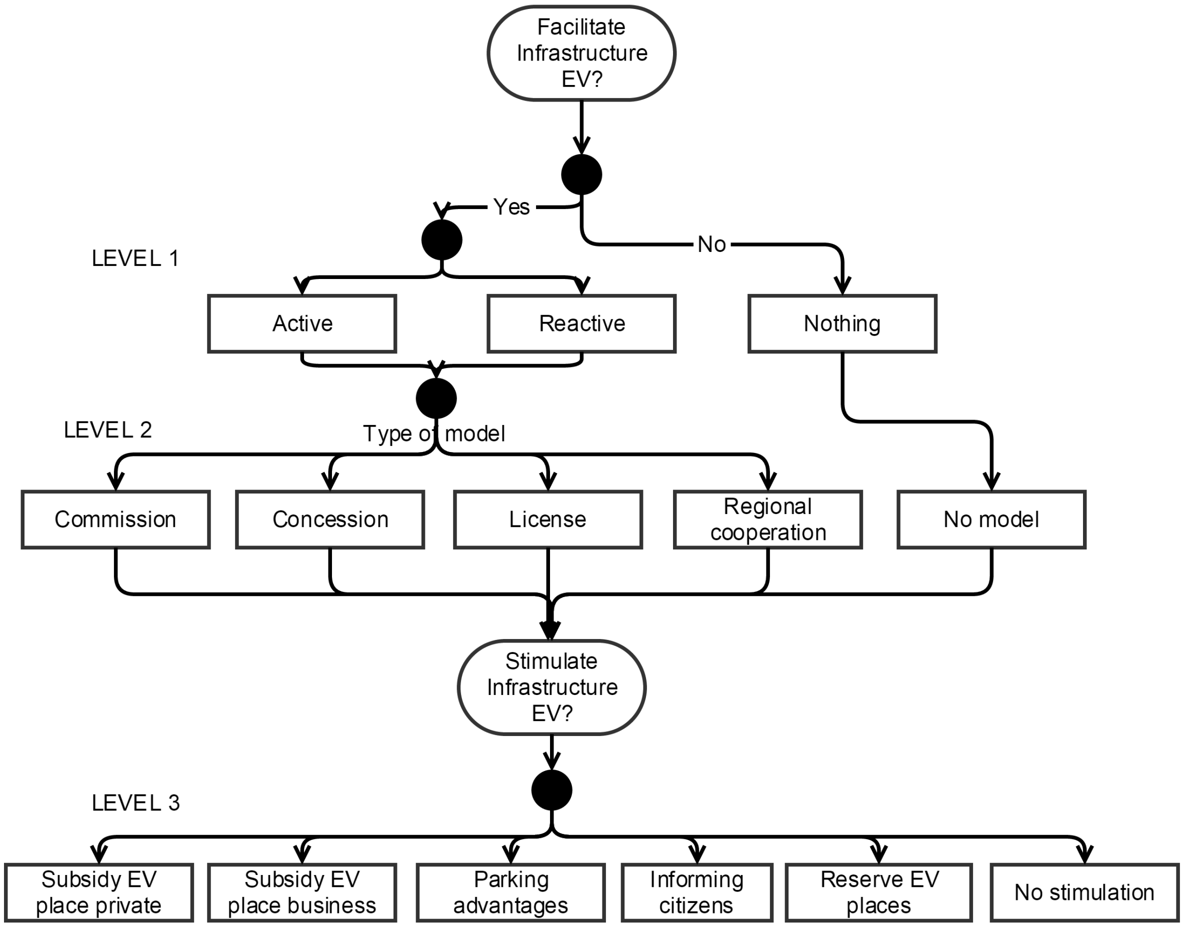

Figure 6-2: Overview of the strategy levels. which are determined in this thesis. Level one and two focus on the facilitation of an infrastructure for EVs and level three on the stimulation.

in this.

A study by Bakker and Trip [2013] ranked different measures municipalities could take to stimulate the usage of EVs. Supporting and enabling a charging infrastructure scored second best in this study [Bakker and Trip, 2013]. The also identified the availability of charging places as the greatest barrier for citizens to buy EVs.

A more specific urgency for municipalities to facilitate the infrastructure in the Netherlands, or at least do something, is that the Dutch government is stimulating driving in EVs with tax preferences. However, when it comes to the infrastructure the government leaves the responsibility to the municipalities because they are responsible for the local public space.

In general there are three possibilities for municipalities as options to choose from when it comes to the question whether or not to facilitate a charging infrastructure [APPM, 2015]:

- Reactive: provide the possibility to create charging places but only after requests of citizens.
- Proactive: Implement charging places at locations where a demand for charging places is expected, without waiting for requests.
- Nothing: Do not facilitate charging places and leave the implementation to the market.

These three possibilities are combined with the possibilities in strategy level two below in the comparison of the different alternatives.

Level 2: Model to facilitate infrastructure for EV
There are different possibilities in facilitating an infrastructure for EVs. The different models are gathered by analysing a study of APPM. In their study they researched the policies that Dutch municipalities have to facilitate or stimulate EVs. As part of their research, information about the model that municipalities use to facilitate EVs was gathered. The different models are [APPM, 2015]:

- Commission: municipalities could give a commission for every charging place they want to construct. This model fits best in a reactive strategy where points are implemented one by one.
- Concession: in this model municipalities give a concession for the implementation and the exploitation of a certain amount of charging places for a certain period. This model can fit in both a reactive and a proactive strategy. The municipality can require a minimum amount of charging places in different areas in this model.
- License: municipalities could give a license to construct a charging place at a certain location without any investment. This model can be used in a reactive strategy but the initiative is left to the market about the actual placement of point and the municipality is not in charge of the amount of points that is constructed in this model.
- Cooperation (regional): it is possible for municipalities to cooperate with each other in the construction of charging places. In this case the scale of the concession or commission is increased, reducing the cost and reducing the risk for individual municipalities. This model is especially suitable in combination with a concession model, similarly to the model that is used for bus transportation in the Netherlands.
- No model: it is possible for municipalities to leave the implementation of a charging infrastructure to the market. This model, or actually no model corresponds to the strategy of doing nothing.

Level 3: Stimulation of infrastructure for EV
The third level focusses on different stimulation policies, which can be taken to stimulate an infrastructure for EVs. These policies are basically based on a study by Wiederer and Philip [2010]. In this study different policy alternatives for local government to stimulate the usage of EVs are identified. These alternatives are divided in different groups [Wiederer and Philip, 2010]:

- Monetary policies
- Regulatory policies
- Real-estate strategies
- Procurement of EVs in public fleet
- Advocacy/PR strategies.

These strategies focus on the stimulation of EVs in general. According to Wiederer and Philip [2010] monetary policy alternatives are less suitable for local governments because municipalities have a relative low budget with a lot of tasks. Regulatory, real estate or PR strategies would be more suitable for municipalities. Also the procurement of EVs in the public fleet could be useful. However this is not a strategy concerning the infrastructure of EVs but a strategies concerning EVs itself. Therefore only the strategies, which are relevant for the infrastructure of EVs are selected. In this selection a division is made between two types of subsidies for charging places: subsidies for private places and subsidies for places at businesses, similar to the division APPM [2015] has made. This gives a number of strategies concerning the question whether to stimulate the infrastructure for EVs [Wiederer and Philip, 2010]:

- Subsidy citizens charging location: in this alternative a subsidy is given to construct a charging place for public usage in a residential area.
- Subsidy for business charging location: in this case the subsidy is given to construct charging places for businesses for their employees.
- Information for citizens: municipalities could inform their citizens about the possibility to construct charging places and the procedure to construct charging places.
- Parking advantages at charging places: municipalities could provide charging advantages for EVs. For example no parking fee required at shopping malls.
- Provide possibility to reserve charging places: municipalities could provide possibilities to operators of charging places to reserve a charging place. This gives drivers of EVs the possibility to reserve a charging place in advance to ensure availability when they arrive. The operator could charge fees for this reservation, which increases the possible returns of a charging place.
- No stimulation: municipalities could also chose to do nothing and not stimulate the implementation of a charging infrastructure at their municipality.

6-3 Criteria and scores of strategies alternatives

To be able to compare the different strategy alternatives on the different levels criteria are needed. These criteria are determined using three different sources:

- Interview with policy maker at municipality of The Hague [Welleweerd, 2015].
- Criteria found in literature.
- Possibility for municipalities to add criteria[1].

The criteria, which are used together with the reason why, are:

- Low cost for municipality: because costs are an important measure for the municipality.
- Safety of charging place: because different alternatives can have different effects on the safety of charging methods used.
- Simplicity of procedure for citizens: because this is an important obstacle for citizens in implementing EVs.
- Simplicity of policy for municipality: because the municipality wants to have as less work as possible.
- Environmental image of municipality: because municipalities want to have a good image.
- Uniformity in charging places in municipality: because this is part of the local layout of the municipality.
- Reaching targets in air quality: because fines could be given to municipalities.
- Uncertainty about future demand for charging places: because municipalities do not want to facilitate places which are not used.

The different alternatives are scored on the different criteria. The weight of each criterion is gathered in a survey at municipalities. Chapter 2 will describe this procedure. The scores of the alternatives are determined by ranking each alternative relative to each other on the theoretical effects a strategy has on each criteria. It should be emphasised that these effects are theoretically and practical implications can influence the actual effects. So it is assumed in this multi-criteria analysis that the effects of strategies are according to the theoretical effects and no changes occur because of practical implications or side effects. For example a commission model uses a new commission for each charging place to be installed. This policy is more complex for the municipality than a concession model in which a long-term agreement with one company is made. However a commission is less complex than a cooperative model in which regional agreement should be reached on decisions, this adds an additional step for municipalities.

Each alternative is evaluated using this comparing method to come to a rank. The highest score in this ranking is 5 and the lowest is 1, a 5 is positive and 1 is negative. If two alternatives score the same, the same score in ranking is given. These scores are an input for the multi-criteria analysis in chapter 10 in which the different levels are evaluated.

[1] Municipalities have the possibility in a survey to add criteria to the already determined criteria

An example is given here for the determination of the scores for the different stimulation strategies on the criteria costs, scores on the other alternatives can be found in appendix G.

The scores for the costs for different strategies to stimulate a charging infrastructure are determined as follows:

- Subsidy for citizens: a subsidy costs a lot of money for the municipality therefore the score of this is the lowest: 1.
- Subsidy for businesses: the score is the same as a subsidy for citizens because both are a subsidy and no difference in the amount of places which will be requested by each group can be made in this stage.
- Parking advantages: this will cost the municipality some money because some income from parking fees is not earned. However it is considered to be less than subsidizing charging points and therefore the score is 3.
- Reserving places possible: this strategy does not require any investment from the municipality. The score is therefore 5.
- Information for citizens: the information has to be gathered and distributed. This will cost time and therefore some money. However, the update of a webpage with additional information on possibilities concerning a charging infrastructure is not expected to cost a lot of time and therefore this strategy has a score of 4.
- Do nothing: the final option for municipalities is to do nothing. This won't cost any money and therefore the score of this strategy is determined to be 5.

Part III

Results

Chapter 7

Scenarios to deal with uncertainty in future demand of EVs

In this chapter the scenarios are identified which are based on the identified uncertainties for the future demand for Electric Vehicle (EV)s in chapter 3. In the research sequence in figure 7-1 the link between the chapters is shown. In the definition of scenarios the methodology explained in section 2-2 is used. This means that the uncertainties of chapter 3 will be used to develop scenarios. In the definition of these scenarios the assumptions will be mentioned. Assumptions about specific values of variables in the calculation of the future demand for each scenario will be described in chapter 9.

7-1 Baseline scenario

The baseline scenario is defined as the scenario following the targets set by the Dutch government. These targets are 200.000 EVs in 2020 and 1.000.000 EVs in 2025 [Netherlands Enterprise Agency: Environment, 2012]. These targets were set in 2012 and until now the Dutch government has shown commitment to these targets. The target for 2015 has been reached and the current Dutch government has stated that it will continue the current policy until 2020. Only minor revisions will be made to adjust if necessary [Meinders, 2015]. This increases the likelihood that the targets for 2020 will be reached and the characteristics of drivers of EVs will continue to stay the same. The assumptions in this scenario are:

- The government will continue the current strategy.
- Only minor changes in stimulation policies will be made.
- The characteristics of EV drivers will stay the same.
- The government is able and willing to take necessary measures to reach the targets, it will continue to show commitment.

7-2 Changing policy scenario

The second scenario is based on the same numbers as the baseline scenario but the governmental policy changes in this scenario. A different type of stimulation is assumed for this scenario in which a subsidy is given for new cars. In this case mostly small Full Electric Vehicle (FEV)s will be bought and a different income group will become the driver of

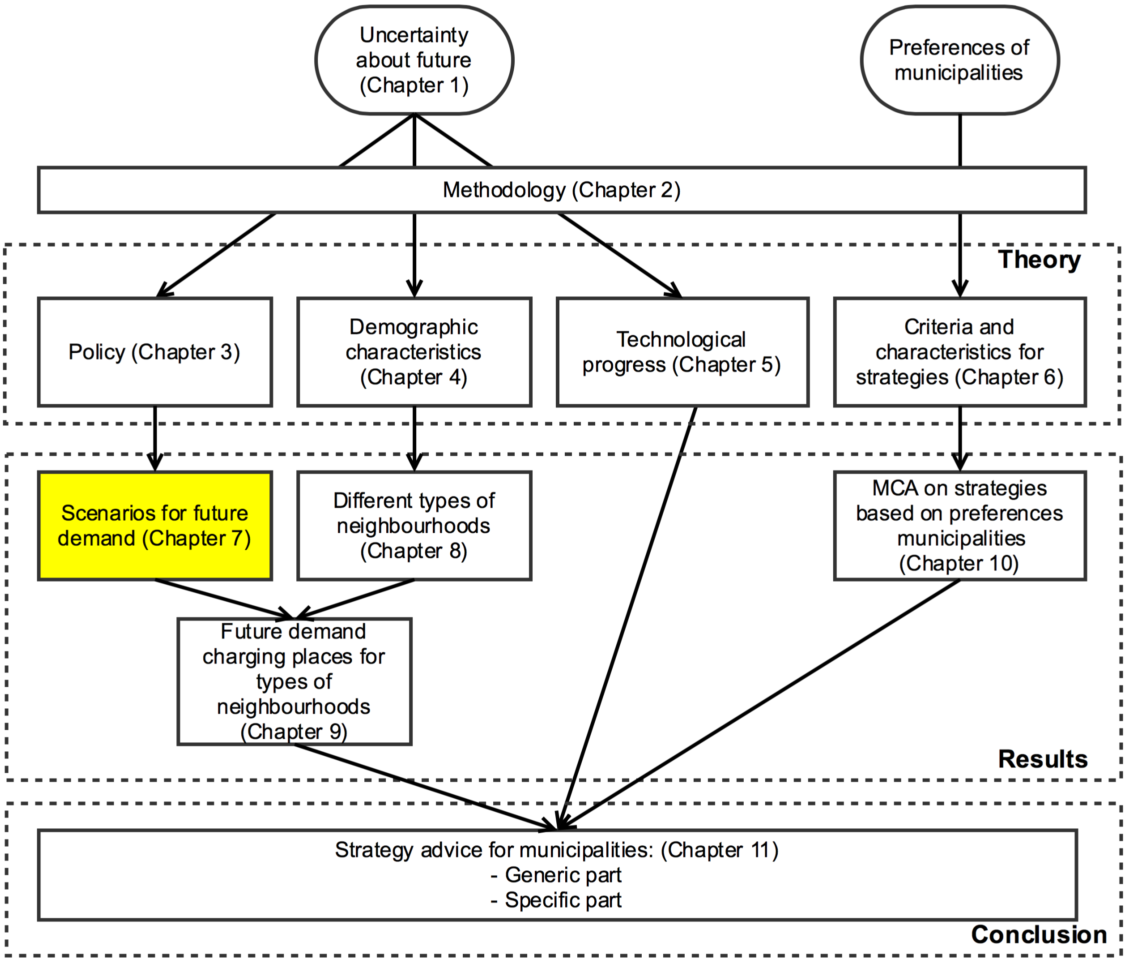

Figure 7-1: Sequence of steps in research, currently at chapter seven in which scenarios to for the demand for EVs are defined.

EVs. However, because of the commitment of the government until 2020 it is not likely that this scenario will be the case before 2020. The current stimulation policy should be totally rearrange for this. However, for 2025 the possibility of this scenario rises, especially in combination with decreasing EV prices, when the technology becomes more mature. The assumptions in this scenario are:

- The government is changing its policy towards a subsidy for new EVs which are bought.
- This new policy is still aiming at reaching the targets set for 2020 and 2025.
- The types of users will change which will have consequences for the average daily driven distance because the user group is no longer using EVs for commuter traffic.

- The drivers of EVs are still higher income groups because the cars sold are new and lower income groups are buying their cars more on the second hand market.
- In the long-term more second hand EVs will become on the market.

7-3 Discontinuous policy scenario

The third scenario is based on an extreme assumption. In this case the government does not continue with the current policy and no policy at all is implemented to stimulate the usage of EVs. As the previous scenario, this scenario is not likely to be implemented and effective before 2020. Especially because it does not comply with guidelines of the European Union (EU). However, this scenario is possible after 2020, for example because of a switch towards hydrogen vehicles. In this case a gap in the business case of EVs would rise, which will take additional time to overcome. In the scenario the following is assumed:

- The increase in EVs will stop in 2020 because the stimulation of EVs will not be continued and a switch to hydrogen vehicles will be made.
- The amount of EVs will decrease after 2020 because of the export of remaining EVs to other countries. This decrease will be based on the average percentage of cars which are exported and demolished every year in the age category of cars between 0 and 6 years old, because almost all EVs will be that age in 2020 [Statistical office in the Netherlands, 2015a].

The calculation for this amount is made in appendix C. There is a reason to assume that this would not be the case because hydrogen uses an electric engine. There is an additional step needed to transform hydrogen into electricity, which is used to power the vehicle. This makes the technology more complex and therefore more expensive then vehicles which are directly powered by electricity.

7-4 Export scenario

A newspaper in the Netherlands published an article in which a calculation was presented about the amount of EVs which are exported every year. This research showed that 20% of the newly sold EVs are exported within a year. So in this case every year 20% of the new EVs are removed from the market [Koot, 2015]. This leakage can be calculated based on the baseline scenario, resulting in a lower amount of EVs in 2020 and 2025. Other influential factors are assumed to be the same in this scenario because the exported cars will mainly be cars which are at the end of their lease term. And so the main usergroup in the Netherlands will remain lease drivers, also because the policy is assumed to stay the same in this scenario. The assumptions in this scenario are:

- 20% of the newly sold cars is exported from the Dutch market within a year.
- The user group of EVs stays the same, so the characteristics of stay the same.

- The policy of the government stays the same, so it will not react by implementing additional measure to make up for the exported EVs.

7-5 Prediction based on S-curve of technological adoption (Regression scenario)

A way to deal with the uncertainty about the market adoption is to learn from previous technologies, as explained in chapter 3. It would be interesting to analyse the current data and fit it in the existing model of the S-curve of technological adoption. The data used is about car sales in the Netherlands between 2009 and 2015 [BOVAG, 2013, Netherlands Enterprice Agency, 2015, Autoweek, 2013, RAI Agency, 2015].

The period between August 2013 and January 2014 is excluded because the stimulation policy at that time had a great influence on the amount of EV sales and it is not expected that a similar policy will influence the EV sales again before 2020 [Broekhuizen, 2014]. Other policies which were in place in the previous years are assumed to be more or less the same in the period between now and 2025. This can be safely assumed because of the governmental commitment explained in 3-2.

A trend line is fitted to the development of the market share of EVs. The least squares solution is found with an R^2 of 0,9867. The R^2 value is a measure for the similarity between the trend line and the data points. The trend line prediction and formula can be seen in appendix C. The first part of this trend line seems to have the characteristics of a S-curve, although very slow in time. Conclusions on these figures are preliminary but an estimation of the consequences of this trajectory for the demand for EVs in 2020 would be useful. Following the trend line, the market share of new car sales in 2020 would be 21%. With the current amount of car sales that would mean that in 2020 84.000 new EVs will be sold.

Based on this regression the total amount of EVs on the road in 2020 would be 340.000, significantly more than the 200.000 targeted by the government. In appendix C a detailed description of the calculation is given. The third scenario will use this 340.000 EVs on the road in 2020 as input in the regression scenario.

If the regression is followed up to 2025 it is found that the expected amount of cars on the road according to this model will be around 1 million, which is also the targeted amount by the government. There are a couple of assumptions made in this model:

- The policy of the lasts months of 2013 will not be implemented again. This seems valid because the costs for the government would be too high to implement this policy again.
- The current stimulation policy will be continued in similar construction.
- The data of previous years is representative for the future demand.
- The development of the adoption of EVs follows a similar pattern compared to other technologies.

7-6 Define scenarios for future demand EV

As described early different scenarios will be used in this study to be able to deal with uncertainty in demand. The scenarios are based on possibilities defined in literature, calculated with data from multiple sources. The scenarios and there development can be seen in figure 7-2.

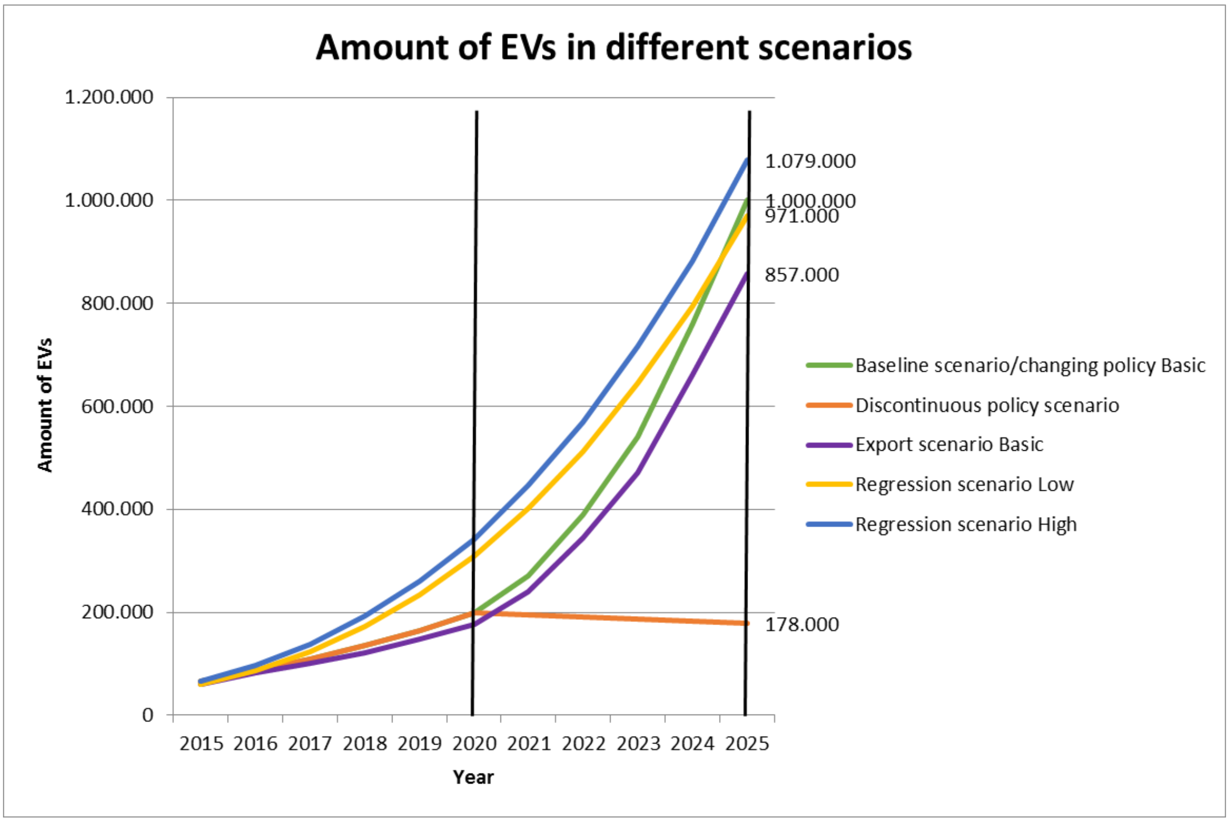

Figure 7-2: Amount of EVs on Dutch roads in different scenarios defined by author.

The three scenarios that will be used are described below. Values for the amount of EVs in 2020 and 2025 can be seen in table 7-1.

- Baseline scenario: The scenario following the targets of the government is defined as the baseline scenario. This scenario is expected to reach 200.000 EV on the road in 2020 and 1.000.000 EVs on the road in 2025.
- Changing policy: This scenario includes a changing policy in which different user groups are targeted. Part of this includes also the assumption that a lot of EVs, which are currently leased, will become second hand in 2018, targeting a different market. This scenario differs from the baseline scenario in the characteristics of drivers of EVs; the amount of EVs on the road is expected to be the same.

- Discontinuous policy scenario: In this scenario the amount of EVs decreases after 2020. Until 2020 the same trajectory as the baseline scenario is used. After 2020 hydrogen becomes the dominant technology and the EVs on the market are slowly removed because of export and dissembling. The average amount of cars which is retracted from the Dutch market in the age category of cars between the 0 and 6 years is 2,25% [Statistical office in the Netherlands, 2015a]. If this percentage is withdrawn of the amount of EVs on the market in 2020 an amount of 178.000 EVs is found for 2025.

- Export scenario: The scenario for export is based on the uncertainty in the amount of EVs being removed from the Dutch market. The scenario follows the estimation of Dutch vehicle information and registration office (VWE) that 20% of the sold cars are exported [Koot, 2015]. This leads to a scenario in which the amount of 200.000 EVs in 2020 is not reached.

- Regression scenario: The final scenario is based on literature, which identifies the adoption of new technologies along S-curves. Based on a extrapolation a prediction of the amount of EVs in 2020 and 2025 is made, resulting in a higher amount than the baseline scenario. The detailed calculation for this scenario can be find in appendix C. The range around the predicted line for this scenario has to do with the uncertainty about the amount of EVs that will leave the Dutch market before 2020 and 2025. This is calculated using the assumption that 10% of the new vehicles sold each year would be exported.

Table 7-1: Amount of EVs on the market in different scenarios

Year	**2020**	**2025**
Baseline/changing policy	200.000	1.000.000
Discontinuous policy	200.000	178.000
Export	176.000	857.000
Regression	309.000-343.000	971.000-1.079.000

Chapter 8

Different types of neighbourhoods based on amount of charging places

In this chapter different types of neighbourhoods, which will be used in the model to calculate the demand for Electric Vehicle (EV)s will be identified. This is done using the methodology explained in section 2-2. These types of neighbourhoods are used in combination with the scenarios of the previous chapter to calculate the demand for charging places in different types of neighbourhoods in 2020 and 2025, as can be seen in figure 8-1. This is used as one of the input variables to come to a strategy advice for municipalities in facilitating an EV infrastructure. In the first section different groups of neighbourhoods will be compared using demographic and other variables defined in chapter 4 and appendix E. Based on this comparison the types of neighbourhoods used in the model to calculate the demand for charging points in 2020 and 2025 will be defined. Part of this is the identification of the factor R_n for different types of neighbourhoods, which depends on different characteristics of neighbourhoods.

8-1 Comparing neighbourhoods and identifying types

To identify different types of neighbourhoods, categories of neighbourhoods are defined based on the demographic characteristics defined in chapter 4. All these categories of neighbourhoods are compared to identify significant differences. The results of all these tests can be seen in appendix E. An example for the difference between neighbourhoods with a residential, working or commercial function is given here:

- Step 1: The results for the Mann-Whitney U test for equal distribution are given in figure 8-2. The founded significance is 0,000, this means that an equal distribution cannot be assumed.

- Step 2: The test for significant difference with no equal distribution assumed is tested by comparing mean ranks. The results is shown in table 8-1. This shows a significance of less than 0,05 (significance level of 95%), which means that the difference between the mean ranks is significant and the groups do differ significantly.

An overview of the significant differences from all the comparisons between categories is shown in table 8-2.

The significant different variables which are identified in this test are neighbourhood function, average income per worker in a neighbourhood and the national regions west and

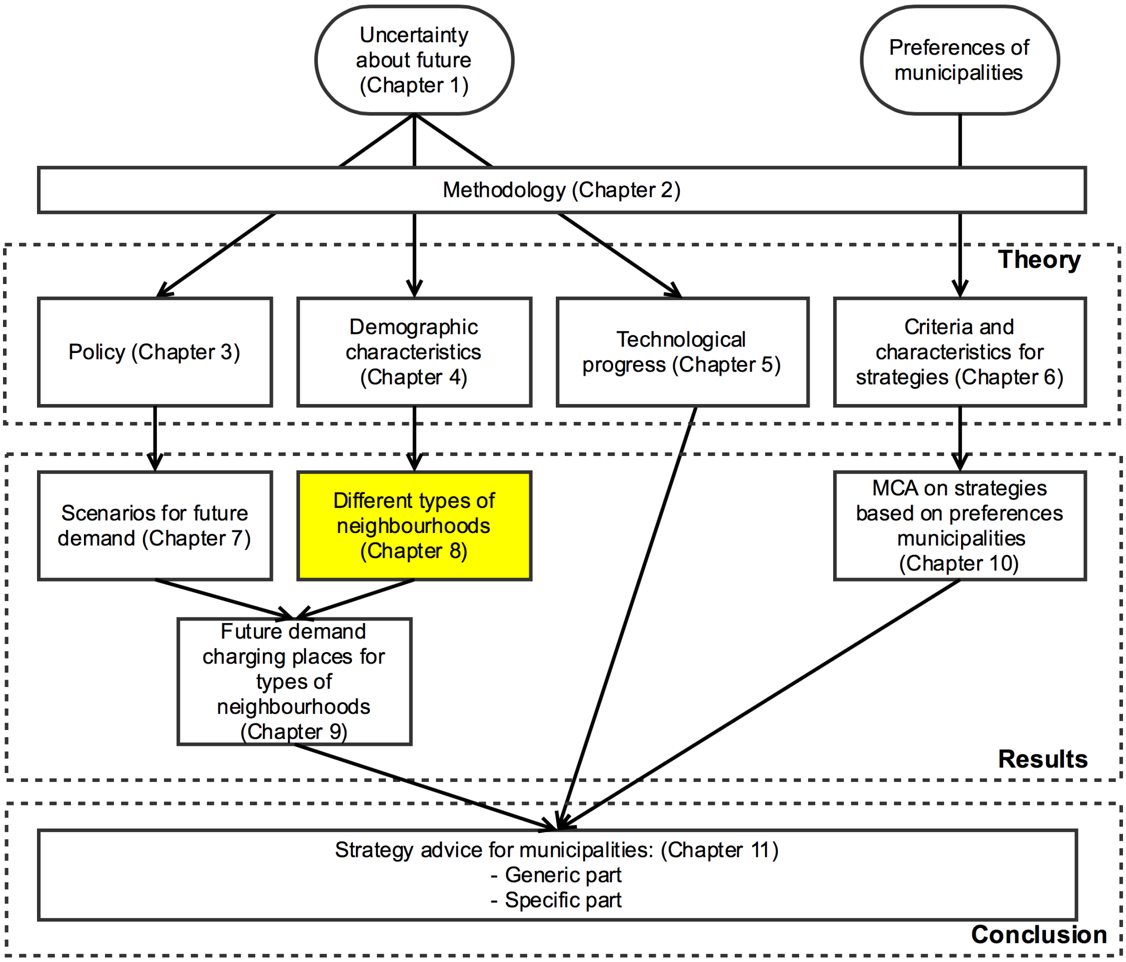

Figure 8-1: Sequence of steps in research, currently at chapter eight in which types of neighbourhoods are defined.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Cn is the same across categories of Type.	Independent-Samples Mann-Whitney U Test	,000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

Figure 8-2: Test for equal distribution of neighbourhood functions.

Table 8-1: Test for significant difference in mean ranks between neighbourhoods with different functions.

	C_N
Mann-Whitney U	2408
Wilcoxon W	53129
Z	-5,485
Asymp. sig (2-tailed)	0,000

north. These categories are used to identify the different categories of neighbourhoods for which the amount of charging places in the future will be predicted. As explained in appendix E the correlation between the national regions and the income level is high. Therefore only income is included in the definition of neighbourhood types and region is not taken into account. The following types of neighbourhoods are defined:

- Residential neighbourhoods:
  - High income
  - Low income
- Commercial neighbourhoods
- Working neighbourhoods

All these types will be used in the following section to identify the characteristics of these neighbourhoods. Besides, individual factors should be taken into account when individual neighbourhoods are analysed.

8-2 Difference in types of neighbourhoods

The previous section explained that the differences between different types of neighbourhoods are significant. Only one demographic factor is significantly influencing the amount of places: income. Appendix E gives more information on the figures about these relations.

The model used to predict the amount of charging places is explained in chapter 2. The model is shown in equation 8-1.

$$C_N/A_{land} = ((e * d * R_N)/(P * 24h * U_N)) * EV_N/A_{land} \tag{8-1}$$

The values for the different parameters in the model are explained and specified below:

- C_N is the amount of charging places in neighbourhood N. This is divided by the area land of a neighbourhood to correct for the size because an average is desired.
- e is the amount of energy used by an EV per km. This is 0,16 kwh/km for the EVs currently on the market [Hacker, Harthan, Matthes, and Zimmer, 2009] and [Dutch Enterprice Agency, 2015].

Table 8-2: Significant difference between different groups of neighbourhoods.

Variable	Category	Equal distribution	Significant difference
Neighbourhood function	Residential	No	Yes
	Commercial	No	Yes
	Working	No	Yes
	Countryside	No	Yes
Region of neighbourhood	North	No	Yes
	West	No	Yes
	East	No	No
	South	No	No
Category of income	High	No	Yes
	Low	No	Yes
Average age	High	No	No
	Medium	No	No
	Low	No	No
Cars per household	High	No	No
	Medium	No	No
	Low	No	No
Persons per household	High	No	No
	Medium	No	No
	Low	No	No
Commercial companies	High	No	No
	Low	No	No
Working companies	High	No	No
	Low	No	No

- d is the average daily driven distance. Statistics Netherlands (CBS) just pronounced numbers about the average distance driven by users of vehicles of different fuel types. The average distance of electric and hybrid vehicles is 17.743 km a year (48,6 km a day) [CBS, 2015]. This is higher than drivers of gasoline vehicles, mostly because electric and hybrid vehicles are used for business purposes and gasoline for leisure. Diesel drivers cover more kilometres a year. They use their car for business purposes as well but do not have the limited range of EVs [CBS, 2015]. For the different types of residential neighbourhoods based on income it is likely that the average daily driven distance will change as well. For neighbourhoods in the high income group it is expected that the daily driven distance is higher than for neighbourhoods in the low income group. Estimations based on the CBS data will be used to identify this. In residential neighbourhoods in the low income group it is expected that drivers of EVs drive the average distance of all drivers, which is 13.044 km a year (35,7 km a day).

- R_N is the percentage of energy charged at public places in a neighbourhood. This percentage is calculated for the different types of neighbourhoods based on the information gathered.

- P is the amount energy transferred from a charging point to an EV per hour. From efficiency measurements it is calculated that this is 7,5 kilowatt [Dutch Enterprice Agency, 2014].

- U_N is the utility rate of a charging place per day. Different values are used for different types of neighbourhoods based on estimated parking pressure. When the parking pressure is higher the utility rate of a charging place should be higher to be able to justify the construction of the charging place. As explained in chapter 5 the utility rate should be at least 8%. Wiederer and Philip [2010] investigated the internal rate of return (IRR) for a single charging point. They assumed a utility rate of 20% [Wiederer and Philip, 2010]. This seems to be unrealistic, because when data about the charging behaviour in Amsterdam is analysed a utility rate of 11,3% is found [Mun, 2015]. It can be assumed that this percentage is a little higher because of the high density of EVs in Amsterdam and the high parking pressure in Amsterdam. Therefore a utilization rate of 8% is taken as minimum amount. In neighbourhoods where the parking pressure increases this rate will be increased to 12%.

- EV_N is the amount of electric vehicles in the different types of neighbourhoods. The amount of EVs in a neighbourhood is based on the amount of EVs per municipality. This is also divided by the area land of a neighbourhood to correct for the size.

- A_{land} is the area land of a neighbourhood. This is included because the size of neighbourhoods differs in different municipalities. In this way an average value is used.

For the calculation of R_N the numbers explained above are used. It is possible to calculate R_N for each individual neighbourhood. In this thesis the calculation will be provided for the different types of neighbourhoods identified in the previous paragraph. Therefore the values will be an average value for a particular type of neighbourhood. This gives the results of table 8-3. To check the robustness of the model the same calculation is made for districts. For districts the results are shown in table 8-4.

In the calculation for R_N for districts less differences between the types are seen than in the calculated R_N-value for neighbourhoods. This can be explained by the fact that districts are larger and often consist of a combination of different types of areas. Part of a district can for example be commercial and another part residential. Therefore the values for districts are more an average value compared to the value for neighbourhoods which is much more specific for the different types. For the predictions about future amounts of charging places in the next chapter the focus will be on the different types of neighbourhoods.

Table 8-3: Calculation of R_N for different types of neighbourhoods

Neighbourhood	C_N per km^2 (average)	EV_N per km^2 (average)	e [kw]	d [km]	P [kwh]	U_N [%]	R_N [%]
Residential high income	2,1	17	0,16	48,6	7,5	8%	23%
Residential low income	0,9	20	0,16	35,7	7,5	8%	12%
Commercial	6,4	31	0,16	48,6	7,5	8%	39%
Working	3,9	14	0,16	48,6	7,5	8%	53%

Table 8-4: Calculation of R_N for different types of districts

District	C_N per km^2 (average)	EV_N per km^2 (average)	e [kw]	d [km]	P [kwh]	U_N [%]	R_N [%]
Residential high income	1,8	12	0,16	48,6	7,5	8%	28%
Residential low income	0,7	8	0,16	35,7	7,5	8%	24%
Commercial	4,1	21	0,16	48,6	7,5	8%	37%
Working	1,3	9	0,16	48,6	7,5	8%	27%

Chapter 9

Future amount of charging places per neighbourhood

With the scenarios from chapter 7 and the types for neighbourhoods form chapter 8 the expected future amount of charging places in the different types of neighbourhoods can be calculated. Amongst others, based on this expected future amount of charging places a strategy advice to facilitate a charging infrastructure is developed for municipalities. The research flow in figure 9-1 shows the location of this chapter in the research graphically. In order to calculate the future amounts, first the predicted amount of Electric Vehicle (EV)s in the different scenarios should be divided over the neighbourhoods. Section 9-1 will explain the method used for this. Second, section 9-2 discusses the change in variables. When this is done, the expected amounts for the different types of neighbourhoods for 2020 will be calculated in section 9-3. The expected amounts for 2025 are calculated in section 9-4. The expected change in variables in 2025 will be expressed in ranges to deal with the uncertainty. This means that the expected amounts will also be expressed in ranges. The robustness of the calculations will be tested by a sensitivity analysis in section 9-5.

9-1 Division of EVs over neighbourhoods

The calculation for the amounts of EVs is based on data about the current amount of EVs in each municipality in the Netherlands of the ministry of Infrastructure and Environment [Ministry of Infrastructure and the Environment, 2015]. The amount of EVs in each neighbourhood is divided by the total amount of EVs in the Netherlands to find the percentage of EVs in a neighbourhood. The predicted amount of EVs in the scenarios are divided over the neighbourhoods using this percentages. This implies the assumption that the division of the EVs over the neighbourhoods stays the same in the future. This seems valid because the same user groups are assumed to use EVs in the future. Only in the changing policy scenario a change in the user groups is expected and future research could be done to the consequences for the division of the EVs over the municipalities.

The amount of EVs which is found for each municipality is divided over the neighbourhoods using the following method. The amount of EVs in a neighbourhoods is divided by the amount of households in a municipality. This number is multiplied by the amount of households in a neighbourhood to find an approximate of the amount of EVs in a neighbourhood. Households are used for this because car ownership is more related to households than to the amount of people in a household. For example a household with 2 adults has most probably 1 or 2 cars and a household with 5 persons (2 adults and 3 children) has most

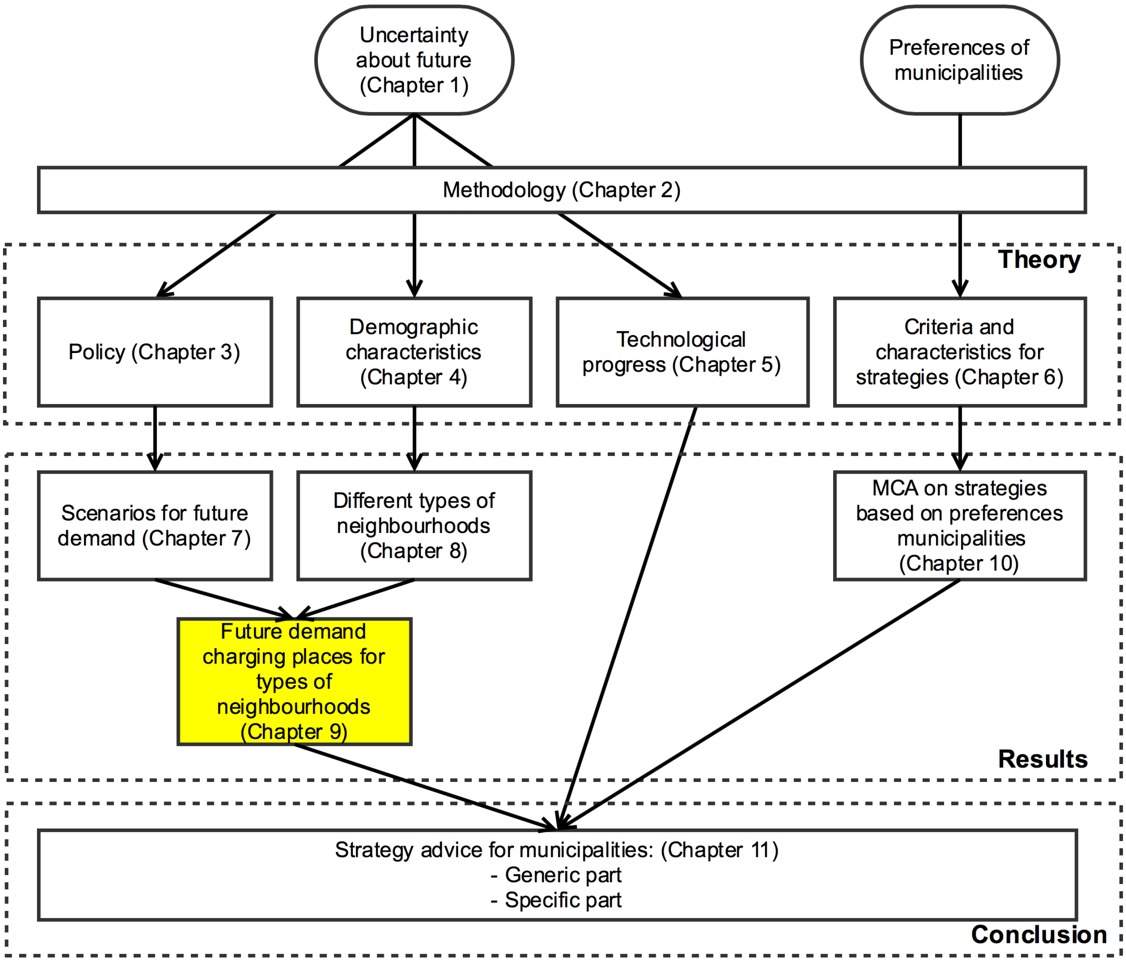

Figure 9-1: Sequence of steps in research, currently at chapter nine in which the future demand for charging places in the different types of neighbourhoods is calculated using the different scenarios for the future demand of EVs.

probably 1 or 2 cars as well.

9-2 Change in variables of model in future

Some of the variables introduced in the chapter 8 are likely to change in the different scenarios introduced in chapter 7. Uncertainty about the value of these variables is especially relevant in the calculations for 2025. Therefore ranges are developed to deal with this uncertainty, as explained in chapter 1. The assumptions which are made for the values of the variables in the scenarios are explained here. These assumptions are based on the assumptions about the scenarios made in chapter 7.

Baseline scenario

The change in variables for the baseline scenario is summarized in table 9-1. The assumptions which are made are:

- In the baseline scenario the division of the amount of charging places over different types of neighbourhoods stays the same because the specific demographic factors of EV drivers are not expected to change.
- However changes are expected in the efficiency of the power transmission (P) and the efficiency of the EVs (the energy needed per kilometre (e)), because of increasing efficiency due to technological progress. When the amount of fast charging places increases it is likely that the average amount of kwh charged (P) will increase. The power of fast charging places is 22kw with an average power transmission of 8,57 kwh [Dutch Enterprice Agency, 2014].
- The percentage of fast charging places is expected to increase until 2020. The implementation of inductive charging on a large scale can cause a change in this trend, as explained in chapter 5. The percentage of fast charging places as percentage of the total amount of charging places was 2,92% at the end of 2013 and 4,48% at the end of 2014 [Netherlands Enterprise Agency, 2015a]. If this development is extrapolated until 2020, about 10% of the charging places are assumed to be fast charging places. The fast charging places are mostly placed at commercial areas and around highways. The average power transmission at commercial areas (P) is therefore assumed to increase to 8 kwh in 2020.
- When the timeframe is shifted to 2025 it is likely that inductive charging will be implemented at a larger scale. The current power transmission of inductive charging is lower than wired charging [Zheng, Chen, Faraci, Zahid, Senesky, Anderson, Lai, Yu, and Lin, 2015]. However it is expected that the efficiency will increase before 2025 and the range is determined to be between 7,5 and 8,5 kw for most neighbourhood types and between 8,0 and 9,0 kw for commercial neighbourhood types, because of the demand for quick charging there.
- The average energy consumption is 0,16 kwh/km at the moment [Hacker, Harthan, Matthes, and Zimmer, 2009] and [Dutch Enterprice Agency, 2015]. In comperisson an average household uses 0,38 kwh/h in the Netherlands [NIBUT, 2015]. The energy consumption of EVs is expected to decrease in the future, due to technological progress. Before 2020 however no breakthroughs in the battery technology are expected as explained in chapter 5. After 2020 it is difficult to identify changes. According to [Abrams, 2013] new, improved battery types will be introduced in 2023 at the earliest. The influence of this on the average energy consumption is not clear yet. A range for the energy consumption in 2025 is therefore used of 0,12-0,16 kwh/km, because a 25% efficiency improvement is expected when new battery technologies are implemented [Abrams, 2013].

- The value for the utility rate differs according to the parking pressure in a neighbourhood. For neighbourhoods with low parking pressure a value of 8% is assumed but for neighbourhoods with high parking pressure the value is increased to 12%. However, it is not possible to determine an average value for parking pressure in neighbourhoods. In the calculation for individual neighbourhoods it is possible to take this into account. An example calculation for a high parking pressure case will be include in section 9-3 and 9-4.

- The average daily driven distance is expected to be more or less the same between now and 2020 because the change in the average daily driven distance has been minimal in the previous five years as well [CBS, 2015]. In 2025 it is more difficult to predict the average distance. Therefore a range for both low income neighbourhood type and other neighbourhood types is defined. For the low income neighbourhood type the range is between 30 and 40 km a day and for other neighbourhood types between 40 and 50 km a day.

- The amount of EVs per neighbourhood is calculated by the method explained in section 9-1. The average value of the neighbourhoods in the sample of chapter 8 is used. The average amount of EVs per squared km is higher in low income neighbourhoods because the amount of addresses per squared km is higher in low income neighbourhoods. Corrected for this the amount in high income neighbourhoods is higher.

Table 9-1: Value of variables in different types of neighbourhoods for baseline scenario.

	2020				2025			
	Residential high	**Residential low**	**Commercial**	**Working**	**Residential high**	**Residential low**	**Commercial**	**Working**
$P[kwh]$	7,5	7,5	8	7,5	7,5-8,5	7,5-8,5	8,0-9,0	7,5-8,5
$e[kwh/km]$	0,16	0,16	0,16	0,16	0,12-0,16	0,12-0,16	0,12-0,16	0,12-0,16
$d[km]$	48,6	35,7	48,6	48,6	40-50	30-40	40-50	40-50
$U_N[\%]$	8-12	8-12	8-12	8-12	8-12	8-12	8-12	8-12
$R_N[\%]$	25	18	36	54	25	18	36	54
EV_N $[amount/km^2]$	73	84	125	56	367	421	627	279

Changing policy scenario

For the changing policy scenario the change in variables is summarized in table 9-2. The values that change compared to the baseline scenario are marked in this table. The assumptions made are:

- The changing policy scenario has the same developments as the baseline scenario in power transmission and energy consumption for 2020 and 2025.

- For the changing policy scenario the type of driver of EVs is expected to change. This will influence the division of the amount of EVs between especially the residential neighbourhoods. This will be included in the calculation of individual neighbourhoods but will not affect the average of all the neighbourhoods. The factor which does effect the average value is the value for R_N. In the changing policy scenario the differences between high income neighbourhoods and low income neighbourhoods are expected to vanish and therefore the value for R_N is expected to become the same (average of the current values).

- The average daily distance driven is likely to change in this scenario because the type drivers of EVs will change from business drivers to all types of drivers. The average daily driven distance is therefore assumed to be the average daily distance driven by all car users: 35,7 km [CBS, 2015]. For 2025 the amount is expected to be between 30 and 40 km a day as explained in the baseline scenario.

Table 9-2: Value of variables in different types of neighbourhoods for changing policy scenario.

	2020				2025			
	Residen-tial high	**Residen-tial low**	**Commer-cial**	**Working**	**Residen-tial high**	**Residen-tial low**	**Commer-cial**	**Working**
$P[kw]$	7,5	7,5	8	7,5	7,5-8,5	7,5-8,5	8,0-9,0	7,5-8,5
$e[kwh/km]$	0,16	0,16	0,16	0,16	0,12-0,16	0,12-0,16	0,12-0,16	0,12-0,16
$d[km]$	48,6	35,7	35,7	35,7	40-50	30-40	30-40	30-40
$U_N[\%]$	8-12	8-12	8-12	8-12	8-12	8-12	8-12	8-12
$R_N[\%]$	22	22	36	54	22	22	36	54
EV_N $[amount/km^2]$	73	84	125	56	367	421	627	279

Export scenario

Table 9-3 gives a summary of the changes in variables in the export scenario. The values that change compared to the baseline scenario are marked. In the export scenario the older, second hand EVs are exported to other countries. As explained in chapter 8 this means that the dominant user group remains the high income group and the total amount of EVs will be less than in the baseline scenario. The assumptions which are based on this are:

- The developments in the variables other than the amount of EVs are expected to be the same as in the baseline scenario.

- Therefore the amount of EVs per neighbourhood in 2020 and 2025 will decrease in this scenario.

Table 9-3: Value of variables in different types of neighbourhoods for export scenario.

	2020				2025			
	Residential high	**Residential low**	**Commercial**	**Working**	**Residential high**	**Residential low**	**Commercial**	**Working**
$P[kw]$	7,5	7,5	8	7,5	7,5-8,5	7,5-8,5	8,0-9,0	7,5-8,5
$e[kwh/km]$	0,16	0,16	0,16	0,16	0,12-0,16	0,12-0,16	0,12-0,16	0,12-0,16
$d[km]$	48,6	35,7	48,6	48,6	40-50	30-40	40-50	40-50
$U_N[\%]$	8-12	8-12	8-12	8-12	8-12	8-12	8-12	8-12
$R_N[\%]$	25	18	36	54	25	18	36	54
EV_N $[amount/km^2]$	65	74	111	49	315	360	538	239

Regression scenario

A summary of the change in variables in this scenario is given in table 9-4. Again the changes compared to the baseline scenario are marked. The assumptions in this scenario are:

- The amount of EVs is expected to increase according to the S-curve model of technological adoption. Therefore the amount of EVs per neighbourhood is expected to change compared to the baseline scenario, according to the amount calculated in chapter 8.
- The user group is expected to be the same and therefore the other variables are changing in a similar way as in the baseline scenario.

Table 9-4: Value of variables in different types of neighbourhoods for regression scenario.

	2020				2025			
	Residential high	**Residential low**	**Commercial**	**Working**	**Residential high**	**Residential low**	**Commercial**	**Working**
$P[kw]$	7,5	7,5	8	7,5	7,5-8,5	7,5-8,5	8,0-9,0	7,5-8,5
$e[kwh/km]$	0,16	0,16	0,16	0,16	0,12-0,16	0,12-0,16	0,12-0,16	0,12-0,16
$d[km]$	48,6	35,7	48,6	48,6	40-50	30-40	40-50	40-50
$U_N[\%]$	8-12	8-12	8-12	8-12	8-12	8-12	8-12	8-12
$R_N[\%]$	25	18	36	54	25	18	36	54
EV_N $[amount/km^2]$	120	137	204	91	335	274	729	299

Discontinuous policy scenario

This scenario is based on the assumption that a switch in dominant technology is made towards hydrogen vehicles. The assumptions for this scenario are:

- The amount of EVs stays the same as in the baseline scenario until 2020.
- The other variables stay the same as in the baseline scenario in table 9-1, only the amount of EVs for 2025 will change.

9-3 Expected demand for charging places 2020

The change in variable explained in the previous section is used to calculate the expected demand for charging places in 2020 for the different types of neighbourhoods and the different types of districts.

Formula (2-1) is used to calculate the amount of charging places per squared km for the different types of neighbourhood. Table 9-5 gives an overview of the range of the amount of charging places per km squared in the different scenarios and for the different neighbourhood types in 2020. For each scenario the value of variables of the tables 9-1 to 9-4 are used. The discontinuous policy scenario is not included here because the values are the same as the baseline scenario until 2020.

Table 9-5: Calculation of amount of demand for charging places per km^2 in 2020 for different types of neighbourhoods and scenarios.

	Baseline		**Changing policy**		**Export**		**Regression**	
Parking pressure	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Residential high income	10	7	9	6	9	6	16	11
Residential low income	6	4	7	5	5	4	10	7
Commercial	23	15	17	11	20	13	37	25
Working	16	11	12	8	14	9	26	18

If the results are analysed it is most likely that the amount of charging places per km^2 in 2020 will be between 8 and 10 in residential neighbourhoods with high income. For residential neighbourhoods with low income it will be between the 3 and 5. In commercial neighbourhoods the amount is a lot higher, between 20 and 30 charging places per km^2. In working neighbourhoods the amount is between the 12 and 20. In neighbourhoods with a high parking pressure it is calculate that about 30% less charging places could be constructed.

9-4 Expected demand for charging places 2025

For 2025 the amount of charging places per squared km is calculated in the same way as for 2020. However, the uncertainty about the future value of the variables is larger in 2025.

Therefore a range is defined for each variable as defined in section 9-2. The results of the prediction for 2025 are shown in table 9-6. The regression scenario is not included in 2025 because the value of the variables of table 9-4 are almost the same as for the baseline scenario in 2025.

Table 9-6: Calculation of amount of demand for charging places per km^2 in 2025 for different types of neighbourhoods and scenarios.

	Baseline		Changing policy		Export		Discontinuous	
Range	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
Residential high income	52	25	45	22	44	22	9	5
Residential low income	34	17	41	20	30	14	6	3
Commercial	118	58	94	45	101	50	21	10
Working	84	41	67	32	72	35	15	7

When the results are analysed the conclusion can be drawn that for 2025 the influence of the value of the amount of EVs in the different scenario is less influential compared to the extreme values in the ranges. This is an important finding because it means that it is much more important for the prediction of the future amount of charging places to monitor the technological progress and the developments in charging behaviour than to monitor the development along the different scenarios. The only scenario which differs substantially is the discontinuous policy scenario. The amount of charging places stay approximately the same in this scenario compared to 2020. So it is important for municipalities to monitor the availability of hydrogen vehicles and follow changes in the government policy about this.

9-5 Sensitivity analysis for expected demand for charging places

To be able to give an indication of the robustness of the calculations a sensitivity analysis is used. This sensitivity analysis indicates the effect of changes in the values of the predicted variables. This is done because the predictions about the future developments deal with uncertainty. Part of this uncertainty is covered by the definition of the ranges of possible values in 2020 and 2025. More extreme changes in the variables because of uncertainty are covered in this sensitivity analysis. For the sensitivity analysis the baseline scenario is used because the influence of changes in variables in the other scenarios will be about the same.

In the sensitivity analysis the values of the variables in formula 2-1 are changed. The results of the sensitivity analysis are shown in appendix F. Only for a substantial change in the efficiency of EVs or the correction factor R_N substantial changes in the amount of charging places are observed. This is similar to the results found in section 9-4: uncertainties in technological developments are the most important influential factor for the expected amount of charging places.

9-6 Summary research flow expected demand for infrastructure electric vehicles in types of neighbourhoods

An indication about the size of the charging infrastructure to be implemented is an important characteristic for the strategy which should be followed. In chapter 8 it is argued that there are differences in the size of the demanded charging infrastructure between different types of neighbourhoods. Using a statistical analysis of 400 neighbourhoods in the Netherlands different types of neighbourhoods have been identified:

- Commercial neighbourhood: area with shops and companies in the hospitality industry have a relative high demand because of visitors.
- Working neighbourhoods: area with a lot of companies where workers park their cars during office hours.
- High income residential neighbourhoods: area where people live with an above average income.
- Low income residential neighbourhoods: area where people live with a below average income.

A model, based on energy balance, is used to determine the expected amount of charging places in these different types of neighbourhoods. In this model different scenarios for the adaptation of the EV at the Dutch market are used, based on governmental targets, other studies and experiences with previous technological adaptation patterns. Another factor which influences the amount of available parking places in a neighbourhood is the parking pressure. A high and a low level for parking pressure are included. This results in expected amounts in the different types of neighbourhoods for 2020 and 2025. An indication of the range using the different scenarios is given in table 9-7. The results of the predictions are

Table 9-7: Indication of amount of charging places per km^2 in different types of neighbourhoods using different scenarios for low parking pressure.

Neighbourhood type	2020	2025
Residential high income	9-14	25-40
Residential low income	6-10	18-35
Commercial	20-30	50-90
Working	10-20	40-70

used to formulate specific strategy advice for municipalities on the level of neighbourhoods in section 11-2-2. A conclusion which is found in both the calculations for the expected demand in 2025 and the sensitivity analysis for the calculations in expected demand is that technological change influences the demand for charging places substantially. Therefore it is important to monitor this technological change.

Chapter 10

Multi-criteria analysis of municipality strategy alternatives

In this chapter a multi-criteria analysis is used to evaluate different strategy alternatives for municipalities to facilitate or stimulate a charging infrastructure for Electric Vehicle (EV)s. The outcomes of this chapter are preferred methods based on the opinion of municipalities. The method used for this multi-criteria analysis is the Weighted Product Model (WPM), which is explained in section 2-4-2. The predicted developments in the demand for a charging infrastructure (chapter 9) and in the technology (chapter 5), will be used together with the outcomes of this multi-criteria analysis to develop an advice for municipalities. The different strategy alternatives and their scores are introduced and augmented in chapter 6, as can be seen in figure 10-1.

The criteria on which the alternatives are evaluated are gathered and weighted using a survey at different types of municipalities. Section 10-1 will present the weights, which follow from the results of this survey. The WPM is performed in section 10-2.

10-1 Weights of criteria

In this section first the survey, which is sent to municipalities, will be discussed. Second the results of the survey will be calculated and trends, which are found, will be explained.

10-1-1 Results survey municipalities

As explained in section 2-4-2 30 municipalities completed the survey. The results of the survey are used to determine the average scores for the weights that municipalities give to different criteria. In the survey the first question is formulated to ask municipalities if they have a policy for the infrastructure for EVs. The definition of a policy used in this question is: regulation and guidelines about the application for charging places, the construction of charging places and the responsibility for the charging places. Municipalities answered this question with a statement about whether or not they have a policy regarding a charging infrastructure and an explanation of this policy. In the second question the respondent is asked to give a score between 1 and 10 for different criteria, in which 1 is not important at all and 10 is very important. The criteria, which are asked to score, are the same as the criteria, which are identified in chapter 6. Besides these eight criteria, respondents have the possibility to add additional criteria and give them a score. An example of a completed question in which scores are given is shown in table 10-1.

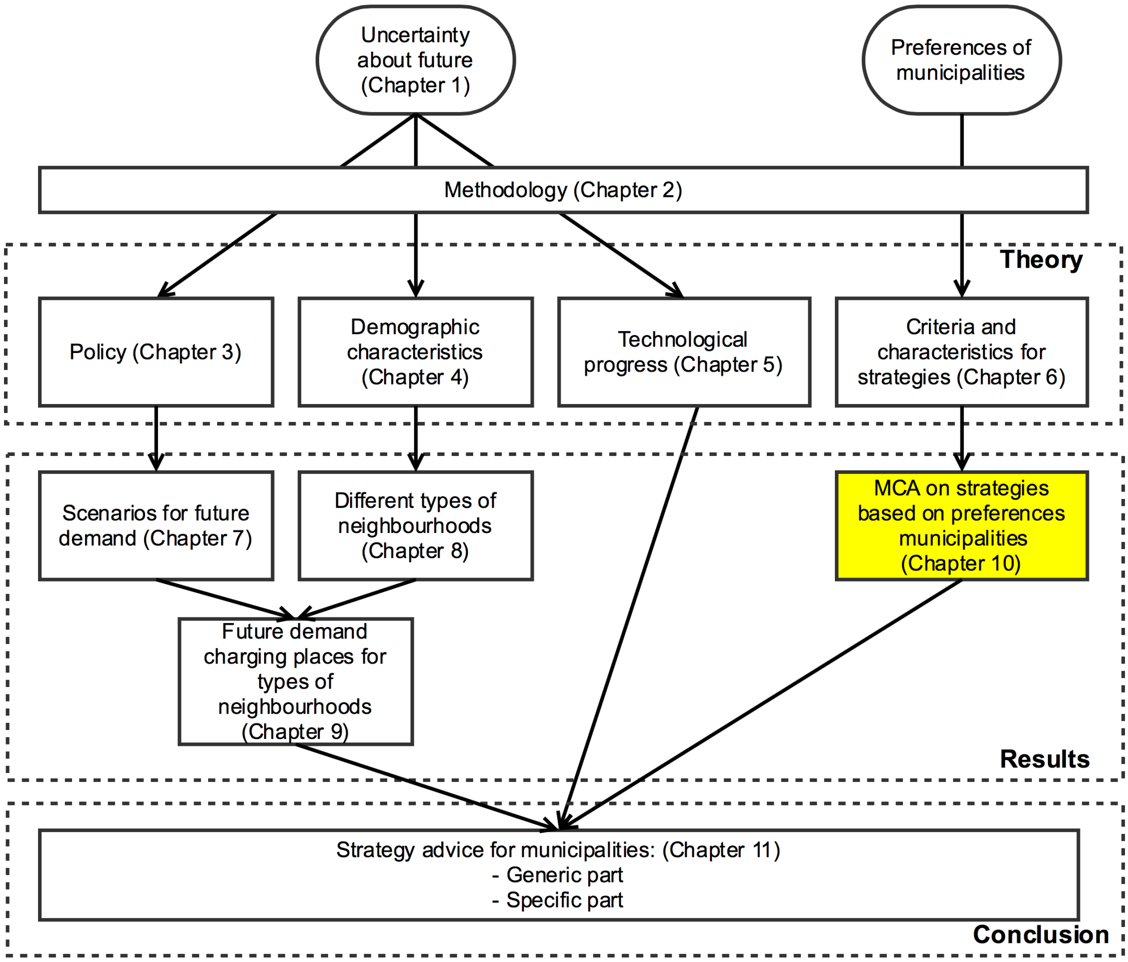

Figure 10-1: Sequence of steps in research, currently at chapter ten in which the different strategy alternatives for municipalities are compared.

The final question of the survey asked if the respondent has any comments on the survey or on the infrastructure of electrical transportation in general. A lot of respondents answered this question by explaining their expectation about the future of electrical transportation. An overview of all the scores in completed surveys is given in appendix H.

Besides the scores for the criteria listed in the question additional criteria are added by the municipalities. An overview of the criteria which are mentioned by the 30 respondents together with the way in which these added criteria are processed, is given below:

- Expected usage/uncertainty about usage: This criteria is mentioned twice. It is similar to the uncertainty in future demand for charging places. The difference is that there could be a demand for charging places but an individual constructed charging place is barely used. So this criteria focusses more on individual constructed charging places.

Table 10-1: Example of the results of the scores given in a completed survey.

Criteria	Amount of points from 1 to 10
Low cost for municipality	9
Safety of charging place	9
Simplicity of procedure for citizens	8
Simplicity of policy for municipalities	5
Environmental friendly image municipalities	7
Uniformity in charging places in municipalities	4
Reaching targets in air quality	7
Uncertainty about future demand for charging places	4
ADDITIONAL: expected usage	8

This criteria will be combined in the multi-criteria analysis with the uncertainty in future demand.

- Influence on public area: in one case the influence of the implementation of a charging place on the public space is mentioned. This is mainly of influence in combination with parking pressure in the public area. The importance of this characteristic is mentioned by Welleweerd [2015]. However, it is a characteristic of individual neighbourhoods or even streets and therefore difficult to include in a general analysis. It will be included as part of the advice to take into consideration but not as a criteria in the multi-criteria analysis.

A couple of the criteria, which are mentioned, are criteria that are used to choose between different suppliers of charging places. These are other types of criteria and do not influence the multi-criteria analysis for strategy options. They do influence the execution of the implemented strategy.

- Transparency in costs electricity of charging place
- Easy to pay at charging place
- Cost energy at charging place
- Low carbon emission of a place
- Innovative technology used
- Quick service possible
- Clear policy

And there are a couple of additional criteria mentioned which are actually suggestions. These suggestions are included as qualitative notes in the formulation of a strategy advice. Especially the suggestions to cooperate stand out. The suggestions are:

- Develop national policy
- Shared policy: mentioned by two municipalities
- No task for municipality/responsibility for municipality?
- Demand driven implementation

10-1-2 Trends identified in survey municipalities

The average scores that municipalities have given in the second question of the survey, is calculated for the different categories of municipalities (large/ middle-large/ small). Table 10-2 gives an overview of these average scores which are used as the weights in the multi-criteria analysis. There are a couple of trends, which can be seen in the results. However, it

Table 10-2: Average weights of categories of municipalities resulting from the survey.

	Large municipalities	**Middle-large municipalities**	**Small municipalities**	**All respondents**
Low cost municipality	8,5	9,2	8,75	8,8
Safety of charging place	8,1	8,4	9,1	8,5
Simplicity of procedure for citizens	8,5	7,25	6,1	7,4
Simplicity of policy for municipalities	7,9	6,9	6,5	7,1
Environmental friendly image municipalities	6,6	8,4	6	7,2
Uniformity in charging places in municipalities	6,7	7,6	6,6	7
Reaching targets in air quality	6,7	5,6	5,9	6,1
Uncertainty about future demand	5,7	7,8	7,4	6,9

should be emphasised that the group of respondents in each category is small and outliers therefore have a relative large impact on the results. For this reason one of the completed results is not included because the scores differed a lot form the other scores, which are given. The trends are tested for significance using the non-parametric Kruskal Wallis test in SPSS, as explained in section 2-4-2. The results of these tests are mentioned below and shown in appendix H. The significances are tested for different categories in size to identify the size for which a identified trend is most significant. In table 10-3 the significance of each characteristic for each criteria is given for different limits in size. The limits which are tested are at 50.000 citizens, 100.000 citizens and 150.000 citizens. The yellow values in the table are showing the significant differences. Below the main trends with an explanation are given.

Table 10-3: Significance of differences between preferences of municipalities at different sizes.

Criteria	Limit at 50.000	Limit at 100.000	Limit at 150.000
Low cost municipality	0,371	0,329	0,352
Safety of charging place	0,864	0,649	0,225
Simplicity of procedure for citizens	0,017	0,008	0,153
Simplicity of policy for municipalities	0,371	0,129	0,684
Environmental friendly image municipalities	0,017	0,313	0,796
Uniformity in charging places in municipalities	0,187	0,388	0,061
Reaching targets in air quality	0,555	0,108	0,094
Uncertainty about future demand	0,202	0,092	0,166

- Cost for the municipality and safety are seen as the most important criteria by all three categories of municipalities. A respondent mentions:

  "the safety of the charging point is regulated by law and all the providers of charging points have to comply with this".

  However, the importance of safety also gives an indication about the willingness of municipalities to allow wires across streets to charge EVs because this would reduce the safety and increase the risk of accidents. The availability of safe charging places is therefore important for municipalities, but for the lowest costs possible for the municipality. The low budget that municipalities have available to support a charging infrastructure is also mentioned in chapter 6 by Wiederer and Philip [2010] in there analysis, and is confirmed by the results of the survey by the importance given to the cost for the municipality.

- Simplicity of the procedure and policies is, in general, more important in large municipalities. The maximum significance is found when municipalities are divided in two groups, with the boundary at 100.000 citizens. The significance in the Kruskal Wallis test is: 0,992. The scale at which large municipalities should execute the procedures can explain this. In large municipalities the amount of citizens is higher so more time is saved when the procedure is less complicated compared to small municipalities with a lower amount of citizens.

- Reaching targets in air quality is in general more important in large municipalities than in small municipalities. However, the boundary of the amount of citizens of municipalities at which the significance is maximized is higher for this relation than for the previous one. If the municipalities with more than 150.000 citizens are grouped the significance of the Kruskal Wallis test is highest: 0,906. An explanation for this is that large municipalities are more likely to have problems with the air quality because the number of citizens is larger and therefore the number of cars and probably visiting cars is larger as well. This has a negative impact on the air quality, which increases the probability that a municipality will not comply with the European regulations for air quality, resulting in a fine. This risk increases the awareness and the urgency for large municipalities to take measure to comply to the regulations for air quality. One of these measures could be the stimulation of electrical transportation through the facilitation of a infrastructure for EVs.

- Large municipalities give a lower score to the criteria uncertainty about future demand. The significance of this trend is largest when the municipalities with more than 100.000 citizens are grouped. The significance of the Kruskal Wallis test is 0,908 in this case. This can be explained using the reasoning that small municipalities are more concerned about the uncertainty about the future demand for a charging infrastructure. This can be explained by the size of the population of a municipality. Small municipalities have a lower amount of citizens. Therefore a small fluctuation in the demand by individuals will have a relative large impact on the total demand. In large municipalities the population is larger and the rest of the population will probably average out a small fluctuation in an individual case. This means that the influence and therefore the importance of the uncertainty in future demand is larger in small municipalities.

- Small municipalities give a lower score to an environmental friendly image than larger municipalities. This difference is significant when municipalities with more than 50.000 citizens are grouped and municipalities with less than 50.000 citizens are grouped. The significance is 0,940 in this case. A possible explanation for this is the composition of small municipalities. They are in general located in an area with more nature than large municipalities and therefore the image of the municipality is already more environmentally friendly compared to large municipalities. So large municipalities have to work harder to reach the same "green" image.

The average scores for the criteria mentioned in table 10-2 are used in the following paragraph to execute the multi-criteria analysis between the different strategy alternatives.

10-2 Weighted product model for different strategy levels

In chapter 6 different levels of strategies are identified which answer two questions:

- How could municipalities facilitate the infrastructure for EVs?

- How could municipalities stimulate the infrastructure for EVs?

In chapter 6 alternative strategies to deal with both questions are identified. The alternatives will be evaluated using a multi-criteria analysis: the weighted product model, which is introduced in the methodology chapter in section 2-4-2. The outcomes of the multi-criteria analysis give the preferences of the municipalities combined with the theoretical effects on the society of different strategies. As explained in chapter 6, it is assumed that the effects of the strategies are according to the theoretical effects identified in chapter 6 and appendix G. It is possible that unforeseen practical implications or side effects occur. The assumption is made to neglect these in this multi-criteria analysis because it would be impossible to know or estimate them. The effects of this assumption and uncertainty are estimated by the sensitivity analysis of the weighted product model, which is enclosed in appendix I.

The preferences of the municipalities about the different strategies will be combined with the expected future demand and the expected technological developments to provide a strategic advice. The weighted product model is conducted on the two different questions mentioned above. The average of the weights resulting from all the surveys is taken, shown in the bottom row of table 10-2. The amount of respondents is too low to conduct a weighted product model on the different categories of municipalities (large, middle-large and small).

10-2-1 Strategy level 1 and 2: facilitation

The results for strategy level one are shown in table 10-4. The weights are gathered in the surveys at municipalities. The scores for the different alternatives at the different criteria are the theoretical effects identified in chapter 6 and appendix G. Theoretically the lowest score of this weighted product model is 8 (every criteria scores 1) and the highest score is 9,79 (every criteria scores 5). A regional cooperation scores highest (9,20) in the weighted product model for the model to facilitate an infrastructure for EVs. This is supported by two arguments:

- In the survey different municipalities stated that a shared policy would be desirable.
- The high importance of municipalities for the criteria cost, but at the same time, the desirability to support the infrastructure for EVs. Cooperating can be the solution.

A regional cooperation is a model to organise a policy but not the model to construct the charging places themselves. Therefore this regional cooperation could be combined with such a model. A concession model scores highest of these alternatives, closely followed by a commission. However, on the long-term a concession could potentially generate income for municipalities when the business model becomes profitable. This would be impossible with a commissions. Therefore a concession, like the concession for bus lines in the Netherlands is selected to be the most applicable alternative.

10-2-2 Strategy level 3: stimulation

In strategy level two a comparison is made between different strategies municipalities could implement to stimulate an infrastructure for EVs. The different strategies and their theoretical effects on the different criteria are described in chapter 6 and appendix G. The results

Table 10-4: Weighted product model for facilitation strategies.

Criteria	Weight	License	Concession	Commission	Ownership	Regional cooperation	No model
Low cost for municipality	0,88	4	2	2	1	3	5
Safety of charging place	0,85	3	4	4	5	2	1
Simplicity of procedure for citizens	0,74	2	4	3	5	3	1
Simplicity of policy for municipalities	0,71	4	2	3	5	3	1
Environmental friendly image municipalities	0,71	2	3	3	5	4	1
Uniformity in charging places in municipalities	0,7	2	4	3	5	3	1
Reaching targets in air quality	0,61	2	4	4	4	4	1
Uncertainty about future demand for charging places	0,69	3	2	2	1	5	4
WPM		9,06	9,17	9,14	9,06	9,20	8,66

of the weighted product model for strategy level two is shown in table 10-5. Two criteria are not included in this analysis because they are not related to the effects of stimulation policies. The safety of the charging places and the uniformity of the charging places in the municipality. Therefore the amount of criteria is 6. The lowest score a strategy could get is therefore 6 and the highest is 7,31.

The highest score in the weighted product model for a stimulation strategy is for informing citizens about the policy for a charging infrastructure. Together with providing the possibility to reserve charging places a higher score than doing nothing is obtained. Reserving parking places involves a risk as is mentioned in an interview with the municipality of Oegstgeest[1]. Reserving parking places in large cities with high parking pressure involves

[1] An interview with the municipality ir. Alma de Jong of the municipality of Oegstgeest is done to validate the findings in the research

the risk that citizens would reserve a charging place in order to be sure that their car could be parked close to their destination instead of reserving a charging place to charge the EV. This risk mainly occurs in large municipalities which have to deal with high parking pressure. The profitability in these areas is already higher because of the higher occupation rate [Jong de, 2015]. So charging place operators would not need the possibility to reserve charging places in order to make their business case profitable. In areas with low parking pressure the problem of a business case, which is not profitable, is larger. Therefore allowing to reserve parking places in areas with low parking pressure could be a solution to generate more income as explained in appendix J. The most important reason for this is the low cost of these stimulation strategies. For the same reason a subsidy for the construction of charging places scores lowest. This means that municipalities prefer to implement no stimulation strategy to a subsidy for charging places. Of course this is a general conclusion for the municipalities on average and individual municipalities could have other preferences.

Table 10-5: Weighted product model for stimulation strategies.

Criteria	**Weight**	**Subsidy charging place business**	**Subsidy charging place private**	**Parking advantages**	**Reserving place possible**	**Information for citizens**	**Nothing**
Low cost for municipality	0,88	1	1	3	5	4	5
Simplicity of procedure for citizens	0,74	2	2	3	2	5	4
Simplicity of policy for municipalities	0,71	2	2	1	3	4	5
Environmental friendly image municipalities	0,71	3	3	5	2	4	1
Reaching targets in air quality	0,61	3	3	4	3	2	1
Uncertainty about future demand for charging places	0,69	1	1	3	4	2	5
WPM		6,44	6,44	6,83	6,89	6,98	6,88

10-2-3 Sensitivity analysis of multi-criteria analysis

In order to deal with the uncertainty about the scores of the different strategies on the criteria, which is caused by the assumption to neglect the influence of unknown practical implications and side effects, a sensitivity analysis is conducted. This sensitivity analysis is an indication of the robustness of the WPM as well. In this sensitivity analysis the scores of the strategies on different criteria are reversed in order to get an indication of the effects of the assumption. In appendix I the sensitivity analysis of both weighted product models is shown. On the facilitation strategy level regional cooperation scores highest in the sensitivity analysis. Followed by the different facilitation models. Ownership and no model score the worst. At the stimulation strategy level it is more difficult because the results are more diverted. Providing subsidies for the construction of charging places scores worst but the other four strategies are similar to each other.

10-3 Summery research flow preferences of municipalities regarding different strategy alternatives

The third research flow identified the preferences of municipalities regarding different criteria concerning the implementation of a strategy. These preferences of municipalities are included in the advice on both general and specific level. The strategies are evaluated and compared on different strategy levels, which focus on two questions:

- What facilitation strategies could municipalities use for the infrastructure of EVs?
- What stimulation strategies could municipalities use for the infrastructure of EVs?

The preferences of municipalities on different criteria concerning the charging infrastructure are used to evaluate different facilitation and stimulation alternatives. The preferences of municipalities are identified by the opinion of 30 municipalities in three different categories based on size. A multi-criteria analysis is used to compare the alternatives. This results in conclusions about the preferences of municipalities towards different strategy alternatives:

- Facilitation level:
  - Regional cooperation of municipalities for the development of a charging infrastructure scores best when the criteria's are evaluated. The main reason for this is the increased scale, which reduces cost for municipalities.
  - A concession model can be used by these regional cooperations in order to maximize the potential market share.
- Stimulation level:
  - Subsidizing charging places is not preferred by municipalities because of the cost. Municipalities have a limited budget, which in many cases does not allow financial stimulations.

- To stimulate the profitability of charging places the municipality could use other stimulation strategies. A possibility is allowing charging place operators to reserve parking places. This could be considered in areas with low parking pressure to ensure that places won‘t be reserved for other purposes.
- Informing citizens about the procedure of the municipality could be a possibility to use for municipalities. This increases the visibility and the awareness of citizens for limited costs.

Part IV

Conclusion and Recommendations

Chapter 11

Conclusion and recommendations

In this chapter the conclusions and recommendations will be formulated based on the three research flows as seen in figure 11-1. The conclusions will have the form of a strategy advice for municipalities. The research question of this thesis was:

What strategies could be advised to municipalities to facilitate or stimulate the infrastructure for electric vehicles in neighbourhoods, given future expectations and uncertainties of the demand for - and technology of - the charging infrastructure?

The general answer to this research question is:

Municipalities is advised to cooperate on a regional level in facilitating the infrastructure for electric vehicles. This reduces the risk of the uncertainties accompanying the future demand for charging infrastructure and the technological progress in charging technologies. Specific advice about facilitation models and stimulation measures differ based on specific local characteristics and different types of neighbourhoods.

The first part of this conclusion is considered to be the general advice. The second part focusus on the specific advice. A more detailed description of both the general and the specific part of this conclusion will be given in the second section of this chapter. In the first second an advice to deal with the uncertainty is formulated.

11-1 Dealing with uncertainty in advice

The theory explained by Marchau et al. [2010] on the usage of a dynamic adaptive approach to policy making to handle long-term uncertainty when it comes to infrastructures is introduced in chapter 1. The model which Marchau et al. [2010] uses is based on a basic policy with a framework for future actions that allow for adaptations over time when knowledge is gathered. In the initial stage the goal is set. Influences along the way contribute in adjustments of the policy to remain at the same direction (goal). Marchau et al. [2010] identify steps to develop such a dynamic policy framework:

- Specify vulnerabilities of basic policy.
- Define actions to take immediately to respond to these vulnerabilities if they occur in future (mitigating – reduce certain adverse effect of policy, hedging – to reduce risk of uncertain adverse effect, Shaping – to control the future as much as possible).

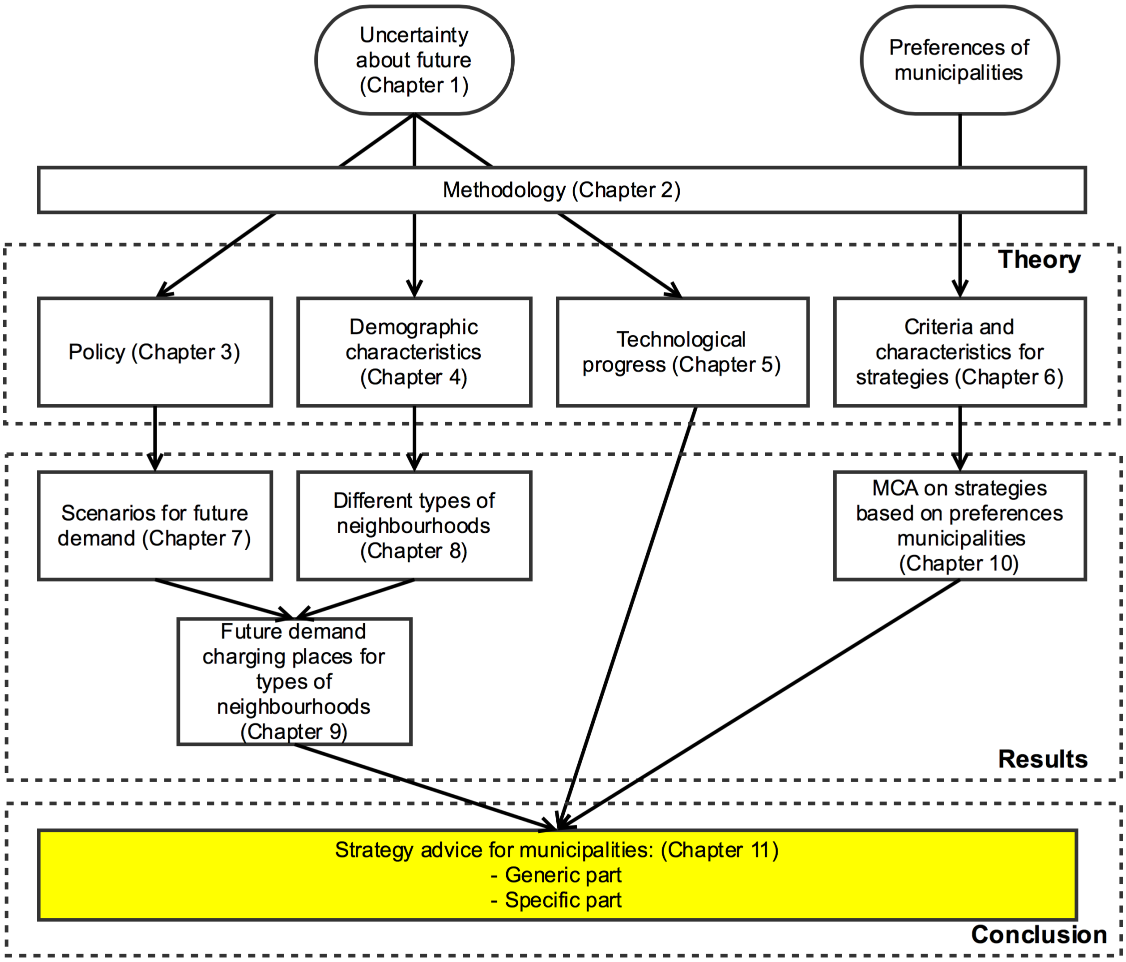

Figure 11-1: Sequence of steps in research, currently at the final chapter in which an advice for municipalities is formulated and the conclusions are provided.

- Define signposts that should be monitored.

The strategy advice which is formulated will use this steps to develop a framework to specify adjustments and possible changes which can occur in the future. This will result in a framework which can be used to monitor the uncertainties when a strategy is implemented.

11-2 Strategy advice

This section will use the results of the three research flows, which are:

- Analysis of the expected amount of charging places in different types of neighbourhoods
- Identification of expected developments in technological progress

- Analysis of preferences of municipalities about different strategies

to formulate a strategy advice. In this strategy advice a framework to deal with the uncertainty according to the theory of Marchau et al. [2010] is included. First a general advice for municipalities is provided. Second the different types of neighbourhoods are used to formulate specific advice for different neighbourhood types.

11-2-1 General advice for municipalities

Municipalities are advised to cooperate on a regional level. Most effective in this cooperation would be a concession model. This would look like the model that is used to give concessions for bus lines in which certain routes are obligated. The same model is used for petrol stations along Dutch highways, to ensure a minimum but also a maximum coverage. For the regional cooperation of municipalities it is possible to provide concessions in which a minimum coverage is demanded. In the future it might be necessary to include a maximum coverage as well to be able to regulate the amount of public assessable places available for conventional gasoline cars. In the future these regional cooperation's are able to sell these concessions to private exploiters of charging places. However, at the moment this is not possible because of the current lack in profitability of the business model of a charging place. Municipalities should therefore use this regional cooperation's to take creative measures to effectuate the implementation of a charging infrastructure. These measures could be:

- Coupling of locations with a high potential to places with a lower potential to average potential revenues and ensure complete coverage.
- Discounts on building rights charged on the area where a charging place is constructed, as include in the business case in appendix J. These buiding rights are charges for the usage of the ground which is owned by the municipality.
- Consideration of the possibility to allow operators to reserve a charging place to give them an additional possibility to earn income from a charging place and increase the profitability of a charging place as explained in section 6-2. The business case of charging places is introduced in appendix J.

There are two possibilities for municipalities to formulate the locations of the charging places:

- Concession holders can be obligated in advance to create an amount of charging places in a certain neighbourhood and timeframe. When the municipality or region is willing to subsidize charging places it is advised to use this strategy and require a minimum amount of investment of the operator, holding the concession. In this case a "green deal" signed by the national government can be used to obtain an additional subsidy. In 2015 this subsidy is €900, in 2017 €600 and 2018 €300 [Vereniging Nederlandse Gemeenten, 2015]. Therefore it is advised to create the charging places which are expected to be needed between now and 2018 (can be assumed with required level of certainty) to be able to obtain the highest subsidy from the national government. Only in areas with high parking pressure this method is not recommended.

- Or municipalities/regional cooperation‘s could provide a concession for a certain area (couple of neighbourhoods, possibly selection of different neighbourhoods in different municipalities) and wait until requests from citizens for charging places are received. At the moment the request is received the operator in the concession can be ordered to implement a charging place at a certain location, which is within the concession area. In the concession a maximum amount of places in a neighbourhood in the concession is mentioned and the concession is specified for a certain amount of time. As part of this strategy it is important for municipalities to inform their citizens about the procedure to request a charging place. Besides, a maximum amount of time between a request and the implementation of a charging place should be specified in the concession.

It is important that the type of connection is mentioned explicitly in the concession in order to minimize the chance of different connections in a region. It is advised to follow the guideline of the National knowledge center charging infrastructure (NKL) and Netherlands Enterprise Agency (RVO) in this. It is advised to minimize the time frame of the concession to maximum 3 years because of the uncertainty in the development. The current strategy can be reviewed using the framework mentioned in table 11-1 in order to see if adjustments need to be made in the type of technology which is used, in the amount of charging places to be implemented or in the financial construction of the concession.

The long-term goal of the strategy should be that the barrier to drive an Electric Vehicle (EV) should be minimized. The framework is developed using the steps Marchau et al. [2010] identified. The first step is to develop a framework to monitor the development in the market should identify vulnerabilities in the assumptions about the future developments. These vulnerabilities are:

- Implementation of inductive charging, because of the change in the type charging places demanded.

- Policy of national government on stimulation of EVs, because of the influence on the adaptation of EVs in the market.

- Role of hydrogen vehicles on the market, because of the possible switch towards another dominant technology.

- Charging behaviour can change. Currently assumed that citizens want to charge their car at home but other preferences would be possible.

- Monitoring of amount of EVs in municipality, if possibly on a neighbourhood level, because of the range of the expected amount of EVs on the market.

Based on these vulnerabilities signposts are developed which indicate possible developments in a vulnerability. For each possible development the consequences are identified and used to formulate the action, which should be taken. In table 11-1 the framework to deal with this uncertainty is shown. It is advised to complete the framework once a year and more often if required by circumstances.

Table 11-1: Framework to deal with uncertainty in strategy for charging infrastructure.

Vulnerability	**Select option**	**Development / Signpost**	**Consequence / action**
1. Inductive charging		Large scale implemented	Switch to support for inductive charging place, stop conventional points
		First types on the market	Continue charging points but provide option for inductive places
		Not implemented	Only conventional charging points
2. Change (inter)national policy		Stop support targets 2020 and 2025	Delay in adoption expected, monitor amount of EVs in neighbourhoods (step 5) more frequent
		Stimulation small EV	Switch to demand in neighbourhoods with lower income expected, monitor step 5 more frequent
		Continuous	Continue same strategy
3. Adoption of hydrogen cars		More hydrogen than EVs on the market	Stop with facilitation and stimulation of charging infrastructure
		Start implementation hydrogen cars	Continue with facilitation but stop stimulation of charging infrastructure
		No implementation of hydrogen	Continue same strategy
4.Change in charging behaviour		Fast charging used by most EV drivers (at highways and shopping malls)	Stop facilitation and stimulation of infrastructure in residential neighbourhoods
		Charging at home and at work used most	Continue same strategy
		Other development in charging behaviour	Monitor influence in step 5 more frequent
5. Amount of EVs in municipality and neighbourhoods		Higher than prediction	Continue same strategy
		Equal to prediction	Continue same strategy
		Lower than prediction	Stop stimulation and increase requirements for facilitation

11-2-2 Specific advice for types of neighbourhoods

The previous part described the general strategy advice for municipalities concerning the facilitation and stimulation of the infrastructure of EVs. In the specific advice, the results of the research flow identifying the expected amount of charging places in different types of neighbourhoods are used. Each type has its own characteristics in charging behaviour, requiring different sets of strategies. The strategies are based on the amount of expected charging places in table 9-7 and the characteristics in charging behaviour in the different types of neighbourhoods. Each type is discussed below:

- High income residential neighbourhood: the charging behaviour in this type of neighbourhood is in general over night when citizens park their car near their homes. For 2020 the amount of charging places is expected to be between 9 and 14 per square km. There are two options for municipalities in facilitating these charging points on local level:
  - Municipalities can decide to select locations for these charging places based on relative distance to each other, in order to reach an equal distribution across the neighbourhood. This could be done by a step by step expansion of the current charging infrastructure until 2020. Regular monitoring of the framework in table 11-1 and cooperation with charging place operators is recommended for this. The amount of charging places and the rate of expansion can be regulated in a concession.
  - Alternatively municipalities could develop an online tool which citizens could use to request charging places. The locations of these request can be used to decide about the location of additional charging points. It is recommended to develop a online tool for this because other procedures would be more labour-intensive. Especially in the development of such a tool cooperation could be beneficial.
- Low income residential neighbourhood: the charging behaviour in these neighbourhoods is in general the same as in high income residential neighbourhoods. The amount of charging places in low income residential neighbourhoods is 6 to 10 per square km. This is almost the same as high income residential neighbourhoods. A reason for this is that the area of addresses is higher in low income neighbourhoods than in high income neighbourhoods. In high income neighbourhoods the houses are larger and the space between houses is larger than in low income areas. So there are more houses per square km in low income residential neighbourhoods. The amount of charging places is therefore relatively lower than in high income neighbourhoods. To deal with this lower and therefore more specific demand in charging places, it is recommended to select locations based on the demand, gathered with an online application as described above.
- Commercial neighbourhoods: the charging behaviour in commercial neighbourhoods is different than in residential neighbourhoods. In commercial neighbourhoods visitors want to charge their EV in a relative short amount of time, while they are shopping or eating. The demand at these neighbourhoods is therefore fast charging points. Additionally citizens in these neighbourhoods are still demanding overnight normal charge places. It is recommended to leave the implementation of fast charging point to the market. The price at fast charging points is not fixed and the implementation of fast charging points along the highway by Fastned show that the market is perfectly able to develop these point by themselves [Fastnet, 2015]. An opportunity could be to include fast charging points in the regional concession to increase the profitability of the concession. It is recommended to provide licenses to charging point operators to

develop fast charging points in commercial neighbourhoods as long as the expansion rate fits within the expected demand of table 9-7.

- Working neighbourhoods: the charging behaviour in working neighbourhoods is for normal charge places during the day. The demand for charging places in these neighbourhoods is between 10 and 20 in 2020. This range is large than in other types of neighbourhoods because of differences between working neighbourhoods. If there are only companies with their own parking facilities in a neighbourhood no public charging places are needed and the municipality is not involved. Contradictory if the employees of companies are dependent on public parking places, the demand in a working neighbourhood is relatively high. Working neighbourhoods should therefore be analysed case wise. It is recommended that municipalities provided licenses for charging places in working neighbourhoods and do not include them in concessions because charging places around companies are benefitial for the company as well (environmental friendly image company and care for employees). Therefore companies should invest in these points, instead of the municipality.

A summary of the specific strategy advice in different types of neighbourhoods can be seen in table 11-2.

Table 11-2: Advice for municipalities in different types of neighbourhoods.

Neighbourhood type	Charging behaviour	Type charging place	Role municipality	Facilitation model
High income residential	Over night (long)	Normal	Active or reactive	Regional concession
Low income residential	Over night (long)	Normal	Reactive	Regional concession
Commercial	During shopping (short)	Fast	Leave to market	Licencing or part of concession
Working	During office hours (long)	Normal	Leave to companies	Licencing

Chapter 12

Reflection and discussion

A reflection on the research and suggestions for future research are done in this chapter. First future research suggestions will be done. Second a reflection will be included, with a reflection on my personal development during the research and with a reflection on the process itself.

12-1 Future research

As in every research, improvements and additional research could be done when this research is finished. Especially concerning the model, which is used to calculate the expected amount of charging places in 2020 and 2025. Additional research could be done to validate the model, optimize its calculations and extends it applicability. Research suggestions concerning this model are:

- Electric Vehicle (EV) per neighbourhood: the expected amount of EVs in neighbourhoods is based on the current division of EVs over municipalities. Data about the amount of EVs in neighbourhoods is not available at the moment. It would be interesting to collect data about the amount of EVs in individual neighbourhoods at municipalities or Dutch vehicle information and registration office (VWE) and use this to determine the division of EVs in scenarios about the predicted amount of EVs.
- Possible changes in the division of EVs of neighbourhoods in the future are not included. It would be interesting to see if changes are expected.
- Amount of households with drive lane at different types of neighbourhoods: in the research the percentage of energy charged at public charging points is included in the correction factor. If data about the percentage of driving lanes in a particular neighbourhood would be known it would be possible to increase the accuracy of the estimated amounts.
- Individual neighbourhoods in case of one or several municipalities: It would be interesting to use the model in case studies in several municipalities. This can be used as validation and optimization, especially when it is combined with one or more of the suggestions mentioned above.
- Composition of correction factor: the correction factor in the model includes multiple influencing factors. It could increase the applicability and accuracy if the influence of each factor could be determined separately.

Other parts on which future research is recommended are:

- Role parking pressure: the effects of parking pressure on the utility rate of charging places is based on an assumption. It would be interesting to investigate the relation between parking pressure and the utility rate of charging places.
- Possible demand for reserving parking places: part of the advice is based on the possibility to reserve charging places. This would increase the profitability of the business case for charging places. It would be interesting to see if drivers of EVs are willing to pay for these reservations, to estimate its potential.
- Preferences of municipalities towards individual stimulation strategies: the evaluation of the facilitation and stimulation alternatives are based on the preferences of municipalities towards criteria. A research of the preference of municipalities to the different facilitation and stimulation alternatives could be interesting. It is recommended to use a qualitative study for this because of the complexity of the alternatives. In this study a survey is used to increase the likelihood that municipalities would understand the criteria. In a survey to rank alternatives the risk of misunderstandings is higher.
- Scores of different facilitation and stimulation strategies on criteria: the scores in the evaluation of strategy alternatives are based on theoretical effects. Practical implications and side effects are neglected in this. A research could be done to the effects of these practical implications and side effects by using testing cases.

12-2 Reflection

This reflection includes two parts:

- Process reflection on what went well and wrong in the execution of the research.
- Personal reflection on what I have learned during this research.

12-2-1 Process reflection

In the execution of this research a couple of obstacles have been taken.

- At the start of the research I focussed mainly on predicting the future demand for a charging infrastructure. It took me some time to broaden my perspective and focus on a strategic advice for municipalities using this expected demand and other uncertainties. This was the first adjustment needed.
- I started by working out the expected demand for a charging infrastructure. And I started to think about a method to include the preferences of municipalities afterwards. This had two consequences:
  - I developed strategy alternatives is a later stage. If I had done this before working out the other research flows I could have took them in mind.

  - It put time pressure on the gathering of the results of the survey. If I would have done it in a earlier stage potentially more municipalities could have been reached for the survey.

- The data about the current amount of charging places was not normally distributed. Therefore a regression analysis with demographic characteristics, as originally planed, was not possible. I had to switch to another model based on a energy balance which changed the role of demographic characteristics in neighbourhoods in the research. Although, it still enabled me to identify different types of neighbourhoods based on demographic characteristics.

- The scores for the different strategy alternatives are based on estimations of their relative theoretical impact on the criteria. The robustness could have been increased when a more detailed study of the effects of different alternatives on the different criteria had been included. Interviews with stakeholders and experts could have been used for this. Lack of time forced me to use the chosen method. To increase the robustness I have included a sensitivity analysis on the outcomes of the multi-criteria analysis.

12-2-2 Personal reflection

In the development of this thesis the original plan was to explain the future demand for charging places by a regression analysis of demographic factors. However, data about the current charging places in neighbourhoods is not normally distributed. Therefore an alternative plan had to be developed. This process to develop and adjust to a new execution plan taught me a lot in being open minded besides the direction I have in mind.

Being forced to change my planning and deviate from the developed path helped me to realize that I had to execute my research step by step. At a certain moment I wanted to gather results too fast without considering the alternatives and searching for the most optimal method. This taught me to update my planning along the execution instead of retaining to the original deadlines.

I have learned a lot in structuring my writing and thesis. The subject is complex with a lot of influential factors. Therefore structuring the project and especially guiding the reader through the thesis needed a lot of thinking and rewriting. Including the graphical representation of the research framework helped me with that. Next time, I would start thinking about the thesis structure in an earlier stage.

Part V

Appendices

Appendix A

Meta-analysis

The aim of this literature review is to identify concepts, which can be used to develop the conceptual model. The process to do this is derived from a specific type of literature study, called meta-analysis [van de Wijngaert, Bouwman, and Contractor, 2012]. First existing literature is selected from different sources. Second, specific data about the concepts investigated and hypothesis tested in the literature selected is gathered and the data is aggregated to make it consistent. Third, a network will be constructed using the aggregated data. This network will be analysed, identifying gaps in the existing literature in which this thesis should fit. Finally there are a couple of pilot areas and interesting organisations involved in electrical driving. To be fully informed this will be included as well.

A-1 Selection of literature

In the selection of literature, research has been done about the different concepts that are defined in chapter 1. A couple of interesting researches have been found which include subjects like characteristics of drivers of electric vehicles, the spatial planning of charge facilities around Stuttgart [Wirges, Linder, and Kessler, 2012], the development of parking places for electric vehicles in Brussel [van der Bossche, van Mierlo, and Maggetto, 2011], the forecast of sales in electric vehicles [Orbach and Fruchter, 2011], the market demand for PHEVs and BEVs in California [Tal and Nicholas, 2013] and the spatial demand for parking places for electric vehicles in North-East England [Namdeo, Tiwary, and Dziurla, 2014]. To be able to use these articles to develop an advanced model they will be analysed here. There are multiple subjects which are mentioned in the existing literature, these will be introduced here.

Demographic characteristics
A lot of research has been done to this subject and different groups of users have been identified. The characteristics of these groups focusses mainly on gender, age, income, number of cars per household and type of traffic [Orbach and Fruchter, 2011] and [Tal and Nicholas, 2013]. The type of traffic is used to differentiate commuter traffic from leisure traffic and freight transport. Other characteristics are estimated to have an impact on the demand for electric vehicles: in general males between 25 and 40 years old with an above average income are drivers of electric cars [Orbach and Fruchter, 2011, Wirges, Linder, and Kessler, 2012]. However, in general more cars are bought by man and used by every member of the family so it is the question if males are actually the driver of the electric car or only the buyer in a family setting.

Willingness to pay is another way to estimate the likelihood that people will buy electric cars [Hidrue, Parsons, Kempton, and Gardner, 2011]. From the perspective of willingness to pay Hidrue et al. [2011] have found that young and educated people are the most promising group to target but that income is probably less important than expected. If the price of an electric car is competitive to a combustion engine car the demand will rise from all income groups according to their research [Hidrue, Parsons, Kempton, and Gardner, 2011].

Using demographic characteristics, different groups of drivers of electric vehicles can be defined as several researches showed. Namdeo et al. [2014] define the following groups [Namdeo, Tiwary, and Dziurla, 2014]:

- New Urban Colonists: Small households living in inner city, dependant on public charging facility.
- City Adventurers: young professionals living in inner city, dependant on public charging places.
- Corporate Chieftains: senior management professionals, residing in peri-urban locations, with multi-car ownership with own charging facility

Wirges et al. describe the categories of electric vehicle owners more precise [Wirges, Linder, and Kessler, 2012]:

- The urban trend-setter: younger persons in single or couple household with high level of education and high income.
- The multiple-car family: family households owning at least two cars and living in detached or semi-detached houses with own garage. Relative high income and mostly second car is replaced by electric one.
- The dynamic senior citizen: people between 60 and 75, owning high-capital. This group will increasingly become more mobile.
- The innovative fleet manager: enterprises adopting electric cars because of the environmentally friendly image.

The identification of different demographic characteristics will also be part of the first subquestion in the research.

Types of neighbourhoods
The article by Wirges et al. [2012] distinguishes different types of neighbourhoods and the associated demand for parking places for electric vehicles. A distinction is made between commercial, working and residential neighbourhoods.

Future demand for electric vehicles
The concept of the future demand for electric vehicles is subject of the second research question and will only be briefly introduced here. There are different scenarios for the development for the demand of electric vehicles. The baseline scenario is the targeted amount of electric vehicles of the Dutch government in 2020 [Environmental Agency, 2009]. Other

scenarios can be constructed by predicting the demand along the S-curve for technological innovation [van Deventer, van der Steen, van Schelven, and Rubin, 2014]. Another alternative can be to use the production plans of large automotive companies to identify the growth scenario [Welleweerd, 2015].

Charging infrastructure for electric vehicles

The literature about the spatial planning of electric vehicles is limited. In a section of a paper about the infrastructure for electric vehicles in Brussel a couple of locations are advised to develop parking places for electric vehicles. These locations are activity hubs, in which a high amount of electrical traffic may be expected [van der Bossche, van Mierlo, and Maggetto, 2011]. A more detailed analysis is made in the North-Eastern region of England. An area around Newcastle is analysed, identifying different types of potential groups of users, which correspond to the groups identified in the buyers of electric cars above. Using the characteristics of these groups‘ maps are created identifying the expected activity of electrical drivers [Namdeo, Tiwary, and Dziurla, 2014].

In the region around Stuttgart, Germany, a detailed analysis of the demand for public infrastructure for electric vehicles is made. Resulting in models indicating the amount of parking places for electric vehicles needed [Wirges, Linder, and Kessler, 2012]. The article identifies the importance of dividing types of parking places for electric vehicles. Private places are not included and estimate to cover all the demand for parking places at home in Germany. This is not the case for the Netherlands where most of the residential parking places in cities and villages are along the street in the public areas.

Typically is the low amount of driveways per home in the Netherlands compared to many other countries which implicates an increased demand for public parking places for electric vehicles. As explained in chapter one the guideline for the stimulation of electrical driving at Dutch municipalities gives a clear overview of the different types of charging facilities [Netherlands Enterprise Agency: Environment, 2012]. These possible charging types are also mentioned in an article about the future of battery technologies for electric vehicles. The possibilities mentioned there are [Catenacci, Verdolini, Bosetti, and Fiorese, 2013]:

- Normal charging: on normal 230 power grid at home or in public.
- Fast charging: on higher voltage with public or private fast chargers.
- Inductive: charging without wires.
- Switching batteries: on public places a switch between batteries to deliver an empty one and insert a full one.
- Battery capacity progress: the more R&D expenditure the better the capabilities of the batteries will become.

A-2 Data gathering and aggregation

Using the information identified in the articles introduced above a database is developed identifying the relations tested in the articles. From the studies selected a database is constructed identifying the following information about the papers:

- Bibliographic information about study (title, author, year)
- Method of investigation
- Independent variable/concept
- Dependent variable/concept
- Result (relation between dependant and independent variable)
- Remarks

The database is shown in figure D-1.

Aggregation

Bibliographic information			Study specific information			Conclusion	
Author	Title	Year	Method of investigation	Independant concept	Dependant concept	Results (relation/not)	Remarks
Wirges, J.; L	Modelling the	2012	Case study	Utility	Number of public places per charging type	Yes	Single formula
Wirges, J.; L	Modelling the	2012	Case study	Power per charging type	Number of public places per charging type	Yes	Single formula
Wirges, J.; L	Modelling the	2012	Case study	Number of electrical vehicles	Number of public places per charging type	Yes	Single formula
Wirges, J.; L	Modelling the	2012	Case study	Daily driven distance of EV	Number of public places per charging type	Yes	Single formula
Wirges, J.; L	Modelling the	2012	Case study	Percentage consumed energy recha	Number of public places per charging type	Yes	Single formula
Wirges, J.; L	Modelling the	2012	Case study	Amount of traffic	Number of public places per charging type	Yes	Single formula
Wirges, J.; L	Modelling the	2012	Case study	Energy consumption of an EV	Number of public places per charging type	Yes	Single formula
Namdeo, A.	Spatial plannin	2013	Case study	Car ownership	Location	Yes	
Namdeo, A.	Spatial plannin	2013	Case study	Car cummuter traffic	Location	Yes	
Namdeo, A.	Spatial plannin	2013	Case study	Amount of new Urban Colonists	Location	Yes	
Namdeo, A.	Spatial plannin	2013	Case study	Amount of city adventurers	Location	Yes	
Namdeo, A.	Spatial plannin	2013	Case study	Amount of corporate chieftrains	Location	Yes	
Namdeo, A.	Spatial plannin	2013	Case study	Private charging places	Location	Yes	
Namdeo, A.	Spatial plannin	2013	Case study	Public charging places	Location	Yes	
Orbach, Y.;	Forecasting sal	2011	Theoretical study	Purchase consideration rate	Demand for electrical vehicles	Yes	
Orbach, Y.;	Forecasting sal	2011	Theoretical study	Potential market share	Demand for electrical vehicles	Yes	
Orbach, Y.;	Forecasting sal	2011	Theoretical study	Market size	Demand for electrical vehicles	Yes	
Orbach, Y.;	Forecasting sal	2011	Theoretical study	Technological progress	Demand for electrical vehicles	Yes	
Tal, G.; Nich	Studying the P	2013	Case study	House type	Electric vehicle	Yes	Detached or at
Tal, G.; Nich	Studying the P	2013	Case study	Average daily miles	Model of electric vehicle	No	
Tal, G.; Nich	Studying the P	2013	Case study	Buy/Lease	Model of electric vehicle	Yes	
Chung, S.H.	Multi-period p	2014	Case study	Amount of traffic	Demand for electrical charging places	Yes	Expressway
Chung, S.H.	Multi-period p	2014	Case study	Driving range	Demand for electrical charging places	Yes	Expressway
Van der Bos	The Brussel ca	2001	Case study	Kind of neighbourhood	Demand for electrical charging places	Yes	General
Hidrue, M.K	Willingness to	2011	Theoretical study	Income	Willingness to pay for electric vehicle	Yes	Less than expe

Figure A-1: Database meta-analysis.

The concepts identified in the database needs to be adjusted to be as consistent as possible. This is necessary to be able to construct a network and analyse it. The aggregated database is presented in figure A-2. A couple of adjustments have been made:

- All the parking places for electric vehicles mentioned as dependent concept are public parking places and so the concepts are all changed to demand for public charging places. This adjustment is shown with a (1) behind the concept.
- The electric vehicle in the study of Tal and Nicholas is actually the demand for electric vehicles and therefore it is changed. It is marked with a (2) in the aggregation table.

- The power per charging type can be changed to the charging type because the power is a characteristic of this charging type. This is shown with a (3).
- Finally a couple of independent variables are examples of demographic characteristics and this is added. In the aggregation table this adjustment is identified with an (4).

Bibliographic information			Study specific information			Conclusion	
Author	Title	Year	Method of investigation	Independant concept	Dependant concept	Results (rela	Remarks
Wirges, J.; Lin	Modelling th	2012	Case study	Utility	Demand for public electric charging places (1)	Yes	Single formula
Wirges, J.; Lin	Modelling th	2012	Case study	Charging type (3)	Demand for public electric charging places (1)	Yes	Single formula
Wirges, J.; Lin	Modelling th	2012	Case study	Number of electrical vehicles	Demand for public electric charging places (1)	Yes	Single formula
Wirges, J.; Lin	Modelling th	2012	Case study	Daily driven distance of EV	Demand for public electric charging places (1)	Yes	Single formula
Wirges, J.; Lin	Modelling th	2012	Case study	Percentage consumed energy recharged	Demand for public electric charging places (1)	Yes	Single formula
Wirges, J.; Lin	Modelling th	2012	Case study	Amount of traffic	Demand for public electric charging places (1)	Yes	Single formula
Wirges, J.; Lin	Modelling th	2012	Case study	Energy consumption of an EV	Demand for public electric charging places (1)	Yes	Single formula
Namdeo, A.; T	Spatial plan	2013	Case study	Car ownership (demographic characteris	Location	Yes	
Namdeo, A.; T	Spatial plan	2013	Case study	Car cummuter traffic	Location	Yes	
Namdeo, A.; T	Spatial plan	2013	Case study	Amount of new Urban Colonists (demog	Location	Yes	
Namdeo, A.; T	Spatial plan	2013	Case study	Amount of city adventurers (demograph	Location	Yes	
Namdeo, A.; T	Spatial plan	2013	Case study	Amount of corporate chieftrains (demog	Location	Yes	
Namdeo, A.; T	Spatial plan	2013	Case study	Amount of private charging places	Location	Yes	
Namdeo, A.; T	Spatial plan	2013	Case study	Amount of public charging places	Location	Yes	
Orbach, Y.; Fr	Forecasting	2011	Theoretical study	Purchase consideration rate	Demand for electrical vehicles	Yes	
Orbach, Y.; Fr	Forecasting	2011	Theoretical study	Potential market share	Demand for electrical vehicles	Yes	
Orbach, Y.; Fr	Forecasting	2011	Theoretical study	Market size	Demand for electrical vehicles	Yes	
Orbach, Y.; Fr	Forecasting	2011	Theoretical study	Technological progress	Demand for electrical vehicles	Yes	
Tal, G.; Nicho	Studying the	2013	Case study	House type (demographic characteristic)	Demand for electrical vehicles (2)	Yes	Detached or atta
Tal, G.; Nicho	Studying the	2013	Case study	Average daily miles	Model of electric vehicle	No	
Tal, G.; Nicho	Studying the	2013	Case study	Buy/Lease	Model of electric vehicle	Yes	
Chung, S.H.; K	Multi-perioc	2014	Case study	Amount of traffic	Demand for public electric charging places (1)	Yes	Expressway
Chung, S.H.; K	Multi-perioc	2014	Case study	Driving range	Demand for public electric charging places (1)	Yes	Expressway
Van der Boss	The Brussel	2001	Case study	Kind of neighbourhood	Demand for public electric charging places (1)	Yes	General
Hidrue, M.K.;	Willingness	2011	Theoretical study	Income (demographic characteristic) (4)	Willingness to pay for electric vehicle	Yes	Less than expect

Figure A-2: Aggregated database meta-analysis.

A-3 Network analysis

With the data adjusted in the aggregation above a network is constructed. This network is used to identify gaps in the current literature and to position this thesis in the existing literature. In the network different colours are used for different kinds of relations. The blue lines indicate a specification of a core concept. The green lines indicate a conceptual relation tested in one of the papers analysed. The red lines indicate the relation between the core concepts. In figure A-3 the network is shown.

When the network is analysed it becomes clear that especially a lot of research is done around the demand for electric vehicles and the characteristics of these people. As shown by the red triangle, the relation suggested in this study is not investigated directly yet. In chapter 3 the concepts will be further specified in a conceptual model.

A-4 Existing projects

There are a couple of research institutes which are, among other subjects, focussing on electrical driving. Partly these institutes refer to existing (pilot) projects of electric vehicles. To be fully informed about the current available knowledge these projects and institutes are

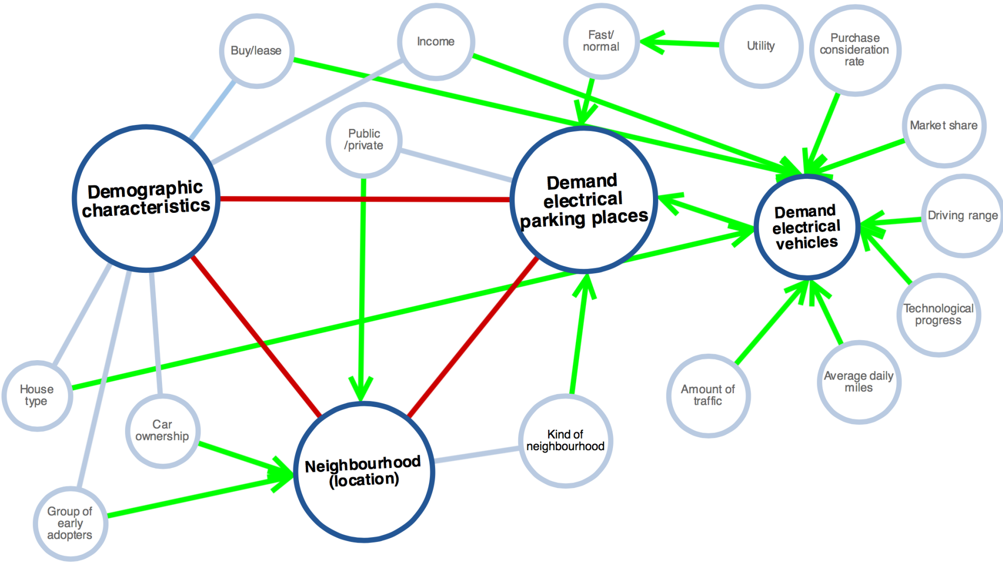

Figure A-3: Network of concepts.

described here.

Mendriso

In Mendriso, Switzerland, a pilot has been done to stimulate the usage electric vehicles. First the project VEL1 took place from 1995 to 2001, followed by VEL2 from 2001 to 2007. The target was to show that electric vehicles were a realistic alternative. The amount of cars sold in VEL1 was 400 and the most important statistic generated was the division between charging time, parking time and usage time as being 9%, 89% and 2% respectively [Ajanovic, 2014]. The second project targeted on the entire region of Tessin (province in Switzerland), but it failed because of a down-swing in electric vehicle appreciation [Ajanovic, 2014].

California

The state of California is a beachhead in the United States as it comes to electric vehicles. Joeri Wesseling compared the European case with the Californian one and discovered a fundamental difference in the governmental policy. In California the governmental policy is focussed on technological breakthroughs and progress where the European policy focusses on incremental change [Wesseling, 2015]. This makes the prices of electric cars in California higher than in Europe and therefore the focus on willingness to pay for electric cars more important as is shown by several papers [Hidrue, Parsons, Kempton, and Gardner, 2011, Tal and Nicholas, 2013]. However in the long-term the Californian policy is expected to be more effective to radical change the embedded conventional driving system [Wesseling, 2015].

RVO

The Dutch Enterprise Agency (Netherlands Enterprise Agency (RVO)) is part of the ministry of economic affairs and is responsible for the governmental affairs concerning electric vehicles. It offers subsidies for the development of electric parking places and provides other grants for start-ups and researches [Netherlands Enterprise Agency, 2015a].

Automotive Centre of Expertise

There is an educational institute in Helmond which focusses on the automotive sector. At the automotive centre research is conducted concerning automotive technology, including electric vehicles. However, the focus is mostly on the vehicle itself and not on the infrastructure needed for electric vehicles [ACE: Automotive Centre of Expertise, 2015].

Amsterdam Elektrisch

The municipality of Amsterdam has set targets for the implementation of electric transportation and especially an infrastructure for electric transportation. Recently Amsterdam welcomed the 2000th electrical parking place. These places generate a lot of data about charging habitats of electric vehicle owners. Currently Amsterdam and the HvA (University applied sciences of Amsterdam) signed an agreement about the usage of these data for educational purposes. The data is promising and will probably become of use in this thesis however it focusses only on Amsterdam and the development of an electric infrastructure in Amsterdam and this thesis aims to provide a tool for all municipalities in the Netherlands [Mun, 2015].

Appendix B

Conceptual model

The conceptual model that will be used for this thesis is introduced and explained in this section, based on the theory identified in the previous sections and chapters. In general six concepts are included in the conceptual model. These concepts are related, introduced and explained in the theory chapters 4, 3 and 5. The concepts are selected because of their influence on the research objective. The network analysis in appendix A shows that the proposed model is not been tested before and therefore is an addition to the existing literature. The relation as found in the theory is shown in figure B-1.

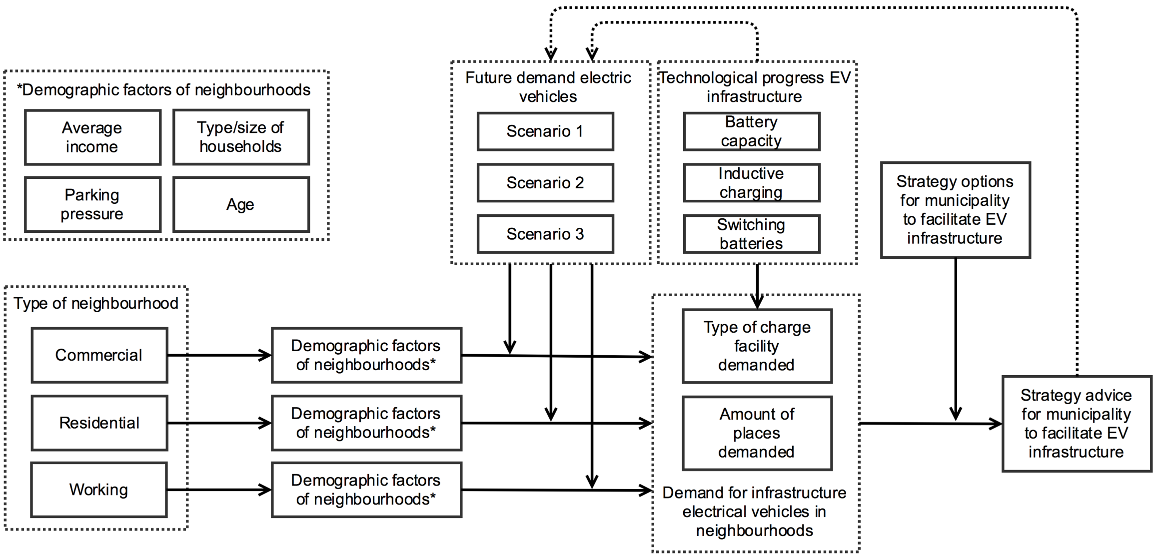

Figure B-1: Conceptual model

The conceptual model can be simplified to show the direct relation between the concepts. The simplified conceptual model is shown in figure B-2. The concepts are numbered and correspond to the explanation below.

1. Type of neighbourhood

An important measure to include according to the model from the article of Wirges et al. [2012] is the amount of driveways at homes [Wirges, Linder, and Kessler, 2012]. No information of this is available in the Netherlands. Because this research focuses on public electric parking places a distinctions is made between neighbourhoods which probably have

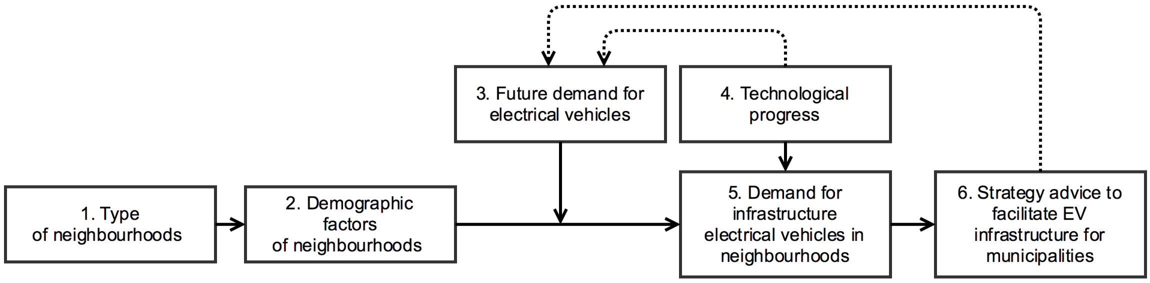

Figure B-2: Simplified conceptual model

driving lanes and neighbourhoods which have not. It is assumed that neighbourhoods with a density of more than 2000 people per square kilometre are neighbourhoods where the houses have no driving lanes. From Statistics Netherlands (CBS) data the amount of these kind of neighbourhoods is calculates as being: 4876 neighbourhoods. More details of this will be given in section 2-1.

The remaining neighbourhoods are divided between different types/variables as defined in section 4-1-1: Commercial neighbourhoods, with a lot of visitors for leisure, Working neighbourhoods, with a lot of companies with parking needs for commuter traffic and residential neighbourhoods, where people live [Wirges, Linder, and Kessler, 2012]. The different types of neighbourhoods are included in the research to investigate the differences in demand between different types.

2. Demographic factors of neighbourhoods

As described by the literature presented in chapter 4 the demand for electric cars can be explained using different demographic factors. In the literature these factors are used to form different groups of users. In this research the demographic factors will be used to explain the demand for electric vehicles at one side and to characterise differences between neighbourhoods on the other. The factors which will be used are:

- Age [average age in years]
- Income [average income per worker in €]
- Household size/type [average amount of citizens per household and three categories for house type: single person, families without children and families with children]
- Cars per household [average amount of cars per household]
- Parking pressure [combination of amount of cars per area land and density of houses]
- Density of houses [Area per Address: is the amount of addresses in a circle with a diameter of 1 kilometre. (OAD)]

3. Future demand for electric vehicles

As can be seen in figure B-1 the future demand for Electric Vehicle (EV)s is influencing the relation between the demographic factors of the different neighbourhoods and the actual demand for the infrastructure in neighbourhoods. The future demand can be summarized in different scenarios which indicate the estimated development in the electric vehicle demand in 2020. The scenarios which will be used are defined in chapter 7 and consist of a baseline scenario, a changing policy scenario, an export scenario, a discontinuous policy scenario and a regression scenario. Changes in the characteristics of neighbourhoods over time will be excluded, because the research focuses on the general demand for EV infrastructure in neighbourhoods in 2020. The changes will be minimal in this timeframe but they should be taken into account in the formulation of a policy strategy advice in specific neighbourhoods.

4. Technological progress
The influence of technological progress on the demand for EV infrastructure is mainly on the type of charging method. As is indicated in chapter 5 the new technology which should be taken into account is inductive charging because a lot of research has been done and it is likely to be implemented in the near future. Improvements in the battery capacity are expected as well but slowly. As indicated in chapter 5 the price of batteries and therefore of EVs is not likely to decrease a lot in the next years and real radical improvements are not expected within the next five to ten years. According to the literature study the technology of switching batteries is not expected to be implemented soon.

5. Demand for infrastructure for electric vehicles in a neighbourhood
This concept will be the actual output of the model that will be constructed. Using the demographic factors (income, number of citizens, type of households and age) of the different types of neighbourhoods (commercial, working and residential) the demand for the infrastructure in these different types of neighbourhoods will be calculated. The infrastructure for electric vehicles can be divided in two different variables as shown in figure B-1

- Amount of places: this is the amount of parking places for electric vehicles needed in a neighbourhood.
- Type of charge facility: this can be fast charge or normal charge at this moment. It is expected that especially in commercial neighbourhoods the demand is for fast charge facilities and in working and residential neighbourhoods for normal charge. For the future other possibilities like inductive charging and switching batteries are also taken into account. The development in the capacity of batteries will also be taken into account. This can be seen in the influence of the technological progress in the conceptual model in figure B-1.

6. Strategy for municipalities to facilitate infrastructure
This will be the advice to municipalities about the best way to organize the facilitation of an infrastructure for electric vehicles in their neighbourhoods. This advice will be formulated using a multi-criteria analysis between alternative policy strategies. Chapter 2 will explain the method used for this multi-criteria analysis. In section 6-2 an empirical study has identified possible policies to facilitate EV infrastructure in neighbourhoods.

Output
The final output of the master thesis will be a policy advice for municipalities to facilitate the infrastructure for EV. Additional outputs needed for this, are models for the different types of neighbourhoods explaining the amount of places needed in a neighbourhood and the type of charging facility demanded using demographic characteristics and current data on the amount and type of charging places for EVs. These models will be constructed in different scenarios depending on other influential factors, like government policies and future technological possibilities.

Appendix C

Calculation future demand for Electric Vehicles

This appendix presents the calculations for the scenarios defined in chapter 7. Calculations are made for the regression scenario and for the discontinuous policy scenario.

C-1 Calculation regression scenario

In chapter 7 a calculation of the future demand for Electric Vehicle (EV)s based on the amount of EVs sold in the previous years was presented. The calculation for this is presented here. In tabel C-1 the market share of EVs on different moments in time is shown based on data of [BOVAG, 2013, Netherlands Enterprice Agency, 2015, Autoweek, 2013, RAI Agency, 2015]. The market share is calculated by dividing the amount of EVs sold in a period by the total amount of vehicles sold in the same period.

Table C-1: Marketshare development EVs.

Year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Market share EV	0,02%	0,03%	0,15%	0,48%	1,30%	3,44%	4,97%

The development of the market share in sold cars is plotted in the graph shown in figure C-1.

This graph is used to extrapolate the development in the marketshare. A function of the second order is used for this. This gives a function with a R^2 of 0,9867, which is a measure for the correspondens of the trend line to the original data points. 1 is a perfect fit and zero the opposite, so in this case the trend line nearly fits. means that it nearly fits, figure C-2 shows this. The function found is:

$$y = 0,0022x^2 - 8,9127x + 8958 \tag{C-1}$$

In which y is the market share of EVs in year x. This function is used to calculate the market share of EVs in the coming years. The trendline and the data can be seen in figure C-2.

In table C-2 the market share and amount of EVs sold between now and 2020 is shown using this formula. For the calculation the amount of car sales of 2014 is taken [Netherlands Enterprice Agency, 2015].

This gives a total amount of 342.815 EVs sold by the end of 2020. To make things easier the rounded number of 340.000 EVs will be used in the scenario.

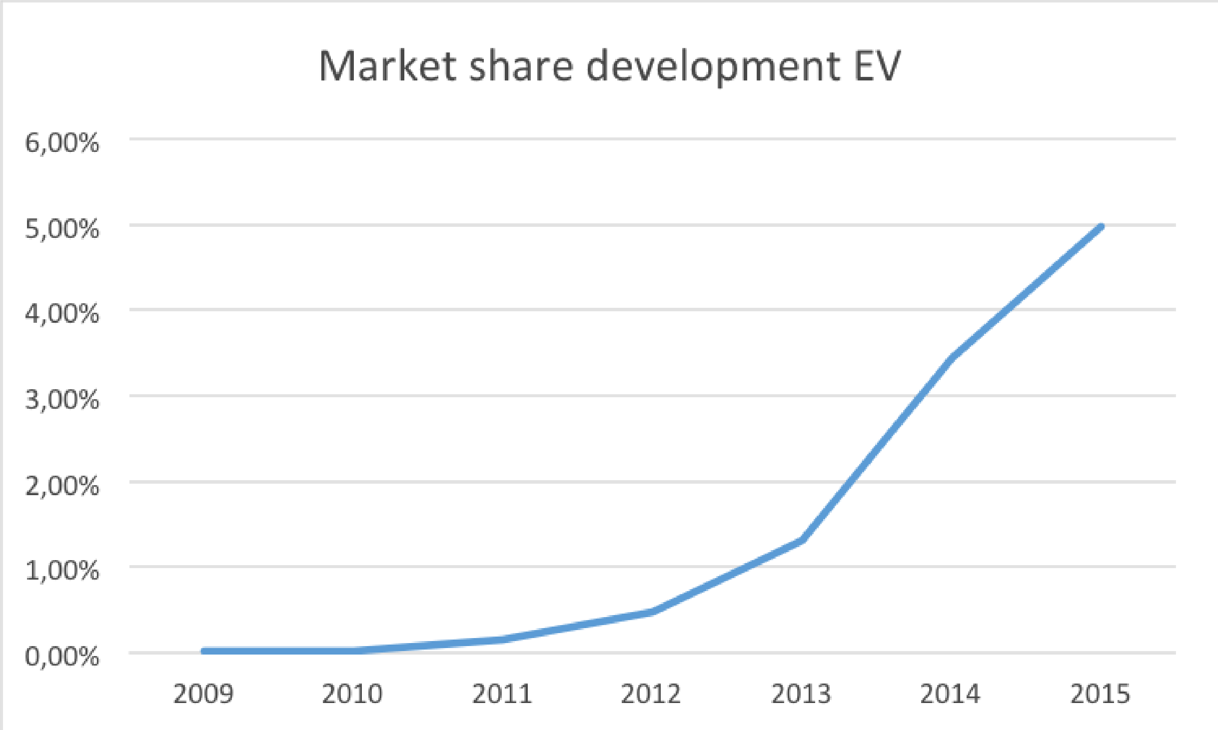

Figure C-1: Development of marketshare of amount of EVs sold as percentages of total amount of cars sold.

C-2 Discontinuous policy scenario

The calculation for the discontinuous policy scenario is based on the assumption that no EVs will be sold after 2020 because of a switch to hydrogen vehicles as dominant technology. It is assumed that the amount of EVs will decrease after 2020 because of the export and demolishing of vehicles. The percentage of the amount of EVs which is retracted from the market is assumed to be equal to the current percentage of cars of this age which is retracted from the market. This assumption has some uncertainty because it can be argued that EV drivers will remain loyal to the technology and the amount of cars exported will be lower. At the same time a the switch to another technology can be a reason to sell an EV quicker. The average age of EVs is assumed to be between 0 and 6 years in 2020 because the EVs are just sold or will be sold in the years before 2020.

Data of the Statistics Netherlands (CBS) is used to calculate the percentage of cars which is being retracted from the market. Data of the amount of cars which are retracted from the market per age of the cars is collected [Statistical office in the Netherlands, 2015a] together with data about the amount of cars sold [Statistical office in the Netherlands, 2015b].

The amount of cars which is retracted from the market in the age of 0 to 6 years is 60.478 [Statistical office in the Netherlands, 2015a]. The amount of cars between 0 and 6

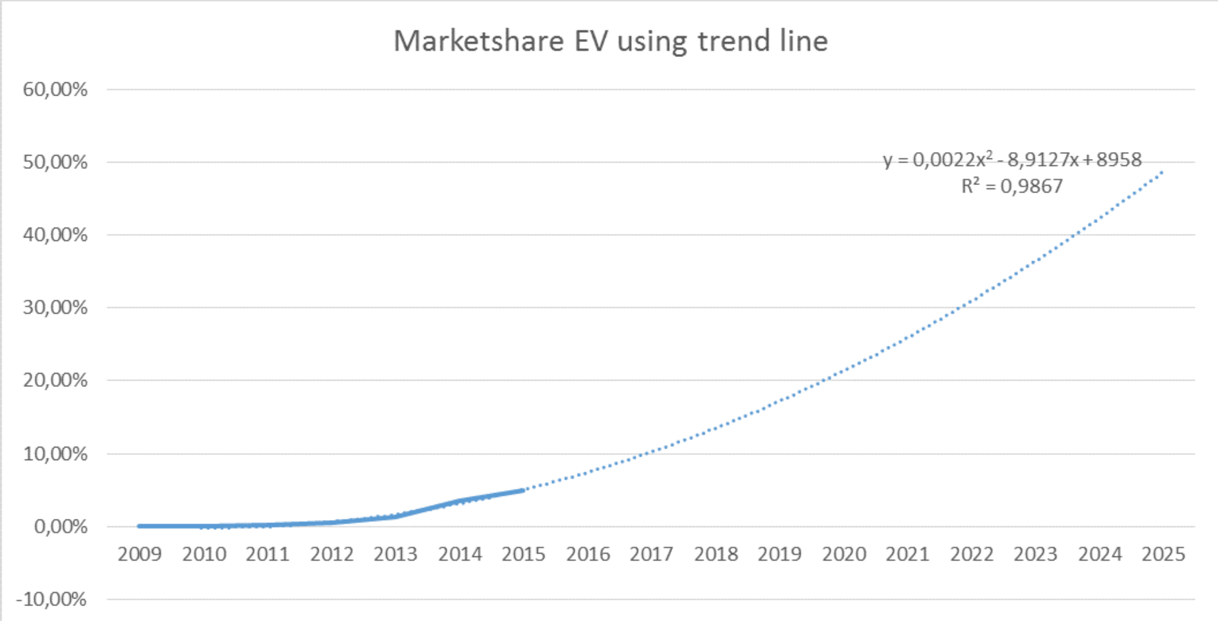

Figure C-2: Regression analysis of development in demand for EVs.

years old on the market is 2.687.774 [Statistical office in the Netherlands, 2015b]. When the percentages of the amount of retracted cars is calculated a percentage of 2,25% is found. The amount of EVs is assumed to reduce by this 2,25% every year after 2020 until 2025. When this is calculated an amount of 178.000 EVs on the market is found for 2025.

Table C-2: Calculation EVs sold using regression model.

Year	Marketshare	Amount of EVs sold
On the road 12/2014		46111
2015	5%	19520
2016	8%	31232
2017	10,5%	40992
2018	14%	54656
2019	17,5%	68320
2020	21%	81984
Totaal		342815

Appendix D

Data selection and gathering

D-1 Selection of neighbourhoods

The sampling method is introduced in the methodology 2-1 as randomized sampling. Therefore the neighbourhoods have to be selected from the database of all neighbourhoods with a population density of 2000 people per square km and more in a random way. To arrive at this database the total database with neighbourhoods was taken and records with no value and neighbourhoods with a density of less than 2000 people per square km where excluded. Next the randomized sampling is done using a programming code which gives an random number to each neighbourhood, in which each number is used once. The code can be seen below. The generated numbers are sorted from low to high and the first 375 items are selected. This number is the sampling size defined in 2-1. Additionally a group of 30 neighbourhoods with an density of less than 2000 is selected to be able to validate the assumption. Code to select sample randomly:

```
SubNieuwe_Cijfers()
ActiveSheet.Unprotect
SchreenUpdating = False
[A2 : A11897, DR2 : DR11897].ClearContents
SetCrange = Sheets("blad1").Range("DR2 : DR11897")
WithCrange
Randomize
Fori = 1To11896
Do
r = Int(Rnd * .Rows.Count) + 1
c = Int(Rnd * .Columns.Count) + 1
LoopUntilLen(.Cells(r, c).Formula) = 0
.Cells(r, c).Formula = i
Nexti
EndWith
[DR2 : DR11897].Copy[A2]'copyDR2 : DR11897andplaceinA2
Application.CutCopyMode = False
Range("A1").Select
SchreenUpdating = True
ActiveSheet.Protect
EndSub
```

D-2 Filling the database

The amount of charging stations neighbourhood is obtained by combining and analysing different sources. First a comparison is made between different applications/online platforms showing the locations of charging stations on a map. Oplaadpunten.nl, The New Motion and Laadpalen App are compared. Most reliable and complete is oplaadpunten.nl and therefore this one is used for the analysis [Oplaadpunten.nl, 2015].

Geodan is used together with buurtlink to identify the location of neighbourhoods on the map. Second, the same neighbourhood is loaded on the map of oplaadpunten.nl to identify the charging stations in a neighbourhood [Geodan, 2015] and [Buurtlink, 2015]. Besides the neighbourhoods, this process is also followed to gather the amount of charging locations for districts.

The other data is gathered and evaluated according to the steps explained in section D-3. The result is a database with the format of figure D-1.

	Code G	Name neighbourhood	W	Name municipality	Cn per km	Totaal neighbo urhoo	Region [N/W/ S/E]	Type [C/R/W/ Count	Type secor	Area land [km2]	Average age	Average income worker [x€1.00	Amount of cars per household	Amount commercial companie	Amount working compani
51	03620001	Randwijck	00	Amstelveen	1,25	1	W	R		0,8	39,23	45	0,9	165	375
60	02000808	De Vlijt	08	Apeldoorn	5,41	2	E	W		0,37	39,9	27,8	1,4	35	30
63	02000805	Kerschoten-West	08	Apeldoorn	3,85	1	E	R		0,26	48,57	27	0,8	25	35
64	02000301	Ugchelen	03	Apeldoorn	0,65	1	E	R		1,55	46,26	34,7	1,2	90	150
68	02000403	Staatsliedenkwartier	04	Apeldoorn	0	0	E	R		0,53	38,66	23,8	0,8	30	40
92	03730114	Beekhove	01	Bergen (NH.)	0	0	W	R		0,11	46,76	46,5	1,1	10	40
93	03730110	Tuin-en Oostdorp	01	Bergen (NH.)	12,9	4	W	R		0,31	44,7	30,6	1	30	70
95	03730104	Negen-Nessen	01	Bergen (NH.)	8,33	2	W	R		0,24	39,98	40,9	1,1	5	35
131	07580106	Geeren-Noord	01	Breda	0	0	S	R		0,45	39,3	22,2	0,7	15	50
134	07580203	Heusdenhout	02	Breda	3,97	6	S	R	W	1,51	44,83	29,3	1	75	180
137	07580600	Gageldonk	06	Breda	1,25	1	S	R		0,8	36,67	30,3	1,1	90	150
139	07580602	Kesteren	06	Breda	2,6	2	S	R		0,77	35,83	27,7	1	75	140
252	07721515	Winkelcentrum	15	Eindhoven	16,7	3	S	C		0,18	44,91	31,1	0,7	135	50
255	07721531	Woenselse Heide	15	Eindhoven	4,94	4	S	R		0,81	42,73	26,5	1,1	90	145
257	07721722	Blaarthem	17	Eindhoven	0	0	S	R		0,36	39,55	26	0,7	55	80
265	01530601	Stroinkslanden-Zuid	06	Enschede	0	0	E	R		0,84	36,25	22,2	0,9	40	75
266	01530003	De Bothoven	00	Enschede	1,54	1	E	R		0,65	44,06	24,5	0,5	115	140
267	01530603	Wesselerbrink Noord-Oost	06	Enschede	1,11	1	E	R	W	0,9	40,44	18,8	0,8	115	65
268	01530500	Schreurserve	05	Enschede	0	0	E	W		0,46	42,38	22,9	0,8	50	60
271	01530204	Stadsveld-Zuid	02	Enschede	0	0	E	R		0,29	40,13	22	0,8	35	35
272	01530006	Veldkamp-Getfert-West	00	Enschede	2,63	1	E	R	C	0,38	38,4	22	0,7	65	55
315	03920501	Transvaalbuurt	05	Haarlem	2,5	1	W	R		0,4	35,24	29,1	0,6	220	250
318	03920402	Den Hout	04	Haarlem	0,85	1	W	R		1,17	44,97	60,7	1,1	75	250
326	03920504	Frans Halsbuurt	05	Haarlem	8,33	1	W	R		0,12	35,92	32,2	0,5	60	110

Figure D-1: Database used for regression analysis

In this database the following columns can be identified from left to right:

1. The first column is a random number which is used to make a random selection.

2. The second column is the code of the neighbourhood which the Statistics Netherlands (CBS) uses. This is needed to be able to find the right data for the right neighbourhood.

3. The third column is the name of the neighbourhood.

4. The fourth column is the code of the district in which the neighbourhood is located. This is needed to analyse the amount of charging places in the districts.

5. The fifth column is the name of the municipality in which the neighbourhood is located.
6. The sixth column is the total amount of charging places (column seven) divided by the area land of a neighbourhood (column eleven).
7. The seventh column is the total amount of charging places in a neighbourhood, gathered by the process explained above.
8. The eighth column is the national area of the neighbourhood, depending on the province in which the municipality is located.
9. The ninth column is the type of the neighbourhood selected. This is defined by analysing the amount of companies and the map as explained in section D-3.
10. It is possible that a neighbourhood has more than one type of area inside its borders. In this case a neighbourhoods gets a second type in column ten.
11. The amount of area land in square km is shown in the eleventh column.
12. The average age in a neighbourhood is calculated in the twelfth column.
13. The average income per worker in a neighbourhood is shown in column thirteen. The displayed value should be multiplied by 1000 to get the average income per worker.
14. The amount of cars per household is shown in column fourteen.
15. In the fifteenth column the amount of commercial companies is calculated.
16. In the final column the amount of working companies is calculated.

D-3 Data gathering

The data which is used in the statistical tests for the analysis is identified here. The data is gathered from different sources and recoding and calculations steps are taken to ensure the cosistency of the data. The random selection of the neighbourhoods in the sampling process is an important issue. This, together with an overview of the data and the way in which they are gathered can be seen in appendix D. Below a list of all the needed data for the analysis with a description is given. The different factors which are included are introduced in chapter 4.

- Amount of charging places per area neighbourhood: the neighbourhoods are analysed using the method explained in appendix D. The total amount of charging places in a neighbourhood is divided by the area land of a neighbourhood in km^2. So the area covered by lakes or rivers is not included in the calculation for the area of a neighbourhood. The sources of the data are CBS [2015a] and Oplaadpunten.nl [2015]. The different types of charging places (normal and fast) are summed. At first a division was made between the type of charging place, normal or fast. However, fast charging locations are at the moment almost only located along highways in the Netherlands. Therefore the amount of fast charging locations in neighbourhoods with a density of more than 2000 people per square km is very low and a division between types of charging places is not possible.

- Type of neighbourhood: the type of neighbourhood is determined by three steps:
  - Calculation of the amount of companies per km^2 in a neighbourhood.
  - Indication of the neighbourhoods with an amount of companies per km^2 higher than 500 are marked.
  - The market but also the unmarked neighbourhoods are analysed on the map to identify the major function of the neighbourhood. In some cases neighbourhoods get a second type when a different areas are located within the neighbourhood.
- National region of neighbourhood: the division between different national regions is based on the province in which an neighbourhood is located. The following definition is used:
  - North: Groningen, Friesland and Drenthe.
  - West: Noord-Holland, Zuid-Holland, Utrecht and Flevoland.
  - East: Overijssel and Gelderland.
  - South: Zeeland, Noord-Brabant and Limburg.
- Amount of households in neighbourhood: the amount of households is based on CBS data.
- Population of neighbourhood: the population is based on CBS data.
- Density of addresses: the density of addresses is based on CBS data. The total density of addresses is divided by 1000.
- Average age in neighbourhood: the average age in a neighbourhood is based on CBS data. It is calculated by multiplying the percentage in the different groups with the average age in that group.
- Average income per worker in neighbourhood: The average income per worker divided by 1000 in a neighbourhood is directly measured by the CBS.
- Amount of commercial companies in neighbourhood: CBS measures the amount of companies in a neighbourhood in seven different sectors: agriculture, construction/energy, retail/hospitality, transportation/communication, finance/real-estate, business services and culture/leisure. The commercial companies are calculated by adding the amount of retail/hospitality companies and the amount of culture/leisure companies together because these are all types of companies which people visit.

- Amount of working companies in neighbourhood: for the working companies the amount of companies of the sectors construction/energy, transportation/communication, finance/real-estate and business services are added together.
- Average amount of people per household: is directly available from the CBS data.
- Average amount of cars per household: is directly available from the CBS data.

Appendix E

Data analysis charging places neighbourhoods

In this appendix a regression model is used to make a comparison between different categories as defined and explained in section 8-1. First the regression model is explained. Second, the gathered data is checked and compared on different characteristics. Finally the results of the comparison for the different groups are given.

E-1 Regression model

The regression analysis will be conducted using SPSS. The model will be based on a multivariate regression model based on current data on demographic characteristics and the amount of Electric Vehicle (EV)s. The estimated future amount of EVs in the different scenarios will be used to estimate the future demand for a charging infrastructure in the different types of neighbourhoods. Several steps are taken to maximize the validity of the research and the regression analysis. The general regression formula is formulated using the founded factors in chapter 4. These factors are the main input for the model to explain the differences in demand for charging infrastructure in different neighbourhoods. The identified scenarios of future demand in chapter 3 will be used to predict the future demand for the charging infrastructure devided between the neighbourhoods according to the model found in this regression analysis. Finally this demand, future changes in technology, identified in chapter 5, and other factors will be used to formulate a strategy advice for the municipalities in facilitating the charging infrastructure.

In the regression analysis differences are identified between the different types of neighbourhood. This means that three different regression analysis will be preformed for residential, commercial and working neighbourhoods. The regression formula for residential neighbourhoods which will be tested is:

$$Y_R = \alpha + \beta_{EV} * EV_{av} + \beta_{HH} * HH_{x1000} + \beta_A * A_{av} + \beta_I * I_{avx1000} + \beta_{HH_{size}} * HH_{size}$$

$$+\beta_{OAD} * D_{OAD} + \beta_{HHcar} * HH_{car} + \epsilon \quad \text{(E-1)}$$

Each β corresponds to the beta-term of each characteristic. α is the constant. The other symbols that are used stand for:

- $Y_R =$ Amount of charging places in residential neighbourhood.

- EV_{av} = Average amount of EVs in a neighbourhood based on amount of EVs in a municipality [Ministry of Infrastructure and the Environment, 2015]. The calculation is made using the method explained below.
- HH_{x1000} = Amount of households in neighbourhood times 1000.
- A_{av} = Average age in neighbourhood.
- $I_{avx1000}$ = Average income per worker in neighbourhood times 1000.
- HH_{size} = Average amount of people per household in neighbourhood.
- D_{OAD} = Density of addresses in neighbourhood times 1000.
- HH_{car} = Average amount of cars per household in neighbourhood.
- ϵ = Error term.

Calculation amount of EVs

The calculation for the amounts of EVs is based on data about the current amount of EVs in each municipality in the Netherlands of the ministry of Infrastructure and Environment [Ministry of Infrastructure and the Environment, 2015]. The amount of EVs in each neighbourhood is divided by the total amount of EVs in the Netherlands to find the percentage of EVs in a neighbourhood. The predicted amount of EVs in the scenario's are divided over the municipalities using this percentages. This implies the assumption that the division of the EVs over the neighbourhoods stays the same in the future. This seems valid because the same usergroups are assumed to use EVs in the future. Only in the changing policy scenario a change in the usergroups is expected and future research could be done to the consequences of this for the division of the EVs over the municipalities.

The amount of EVs which is found for each municipality is divided over the neighbourhoods using the following method. The amount of EVs in a neighbourhoods is divided by the amount of households in a municipality. This number is multiplied by the amount of households in a neighbourhood to find an approximate of the amount of EVs in a neighbourhood. Households are used for this because car ownership is more related to households than to the amount of people in a household. For example a household with 2 adults has most probably 1 or 2 cars and a household with 5 persons (2 adults and 3 children) has most probably 1 or 2 cars as well.

Statistical checks

For commercial and working neighbourhoods (Y_C and Y_W) the regression analysis will be based on the amount of shopping companies (C_{com}) and the amount of other companies (C_{work}) respectively. In the category of shopping companies, leisure companies are included as well. Agricultural companies are not included in the calculation because they are in general not characterised by a high demand for parking places by employees. The steps that are taken to maximize the validity are the following:

- Significance beta coefficients: each beta coefficient is tested for significance and only characteristics with a significant beta coefficient are included in the model. The significance level to include a beta coefficient is 95%.

- Test for collinearity: n each regression the collinearity of the independent variables will be checked. An example of variables with high collinearity are the amount of households and the amount of citizens in a neighbourhood. Because the amount of households is closer related to the amount of cars this one is used.

- Linear of other type of relation: besides the linear regression model described above it is possible that the relation is not linear. A test will be preformed to check if the relation is linear or not by identifying the nonlinear model and comparing the R^2 of both.

- R^2: the value of R^2 determines the strength of the found relationship and should be taken into account.

- Significance in differences between types of neighbourhoods: Before different models for residential, commercial and working neighbourhoods are made it is important to know if they significantly differ from each other. Therefore the means of the groups are compared and when they differ a significance level of 95% is used.

- Significance in differences between location in the Netherlands: In order to be able to adjust the advice to certain regions in the Netherlands the means of different regions are compared with the total mean to see if a specific region has more or less charging points on average. Again a significance level of 95% is used.

- Comparing with districts: to check if the data found in neighbourhoods is reliable the data is also gathered for districts in which the neighbourhoods are located. These districts are larger than neighbourhoods which reduces neighbourhood effects.

E-2 Types of neighbourhoods

The first step that needs to be taken before the regression analysis can be executed is to check if the data is normally distributed [Triantaphyllou, 2000]. There are multiple tools available to check for normal distribution. To increase the reliability two tests/tools are used of the SPSS program: Kolmogorov-Smirnov test and Q-Q plot. The Kolmogorov-Smirnov test uses the null-hypothesis that the data is normal distributed. If the significance is below 0,05 the data is not normally distributed. A Q-Q plot is a graphic representation of the expected values, when a normal distribution is assumed and the actual values [Triantaphyllou, 2000]. The result of the tests Kolmogorov-Smirnov test for the distribution of the amount of charging places per km2 in neighbourhoods is shown in table E-1. The Q-Q plot is shown in figure E-1.

The significance of the Kolomogarov-Smirnov test should be above the 0,05 to be able to assume a normal distribution [Triantaphyllou, 2000]. Also the Q-Q plot shows that the

Table E-1: Test for normality using Kolmogorov-Smirnov test.

	Kolmogorov-Smirnov		
	Statistic	df	Sig.
C_N **per** km^2	0,316	275	0,000

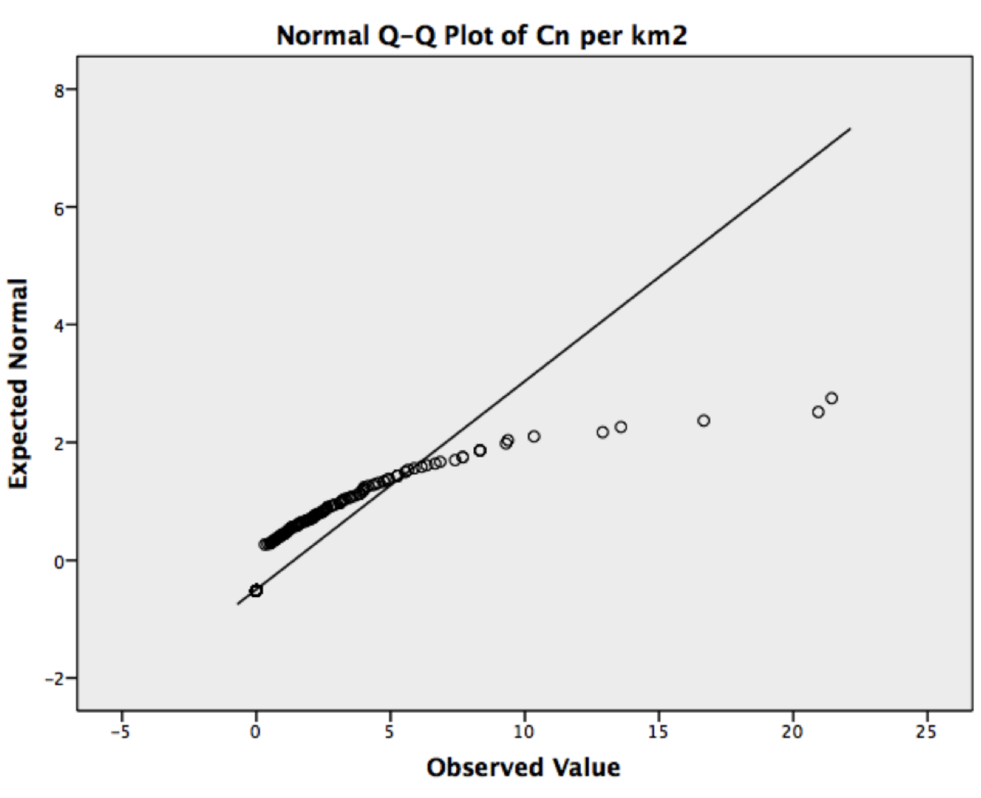

Figure E-1: Q-Q plot to check normal distribution for charging places in neighbourhoods.

data points are not in accordance with the expected results for a normal distributed variable. Therefore we are not able to assume normality. This means that the results of a normal linear regression analysis are not valid [Triantaphyllou, 2000]. Therefore another method should be selected to investigate the relation between the different variables. It is possible to execute a quantile regression in the form of simultaneous quantile regression [Stata, 2015] but the robustness of this method to use for the predicting purposes of the model is not very strong. Therefore the data is used to identify different types of neighbourhood groups according to the different influencing factors. This is done by determining different categories and comparing the distributions of the different categories. The steps taken to do this are:

- Check if the amount of charging places per km2 for the different categories of a variable are equally distributed or not using the Mann-Whitney U test [Laerd statistics, 2013].

- Compare the medians (if equally distributed) or mean ranks (if not equally distributed) using the SPSS methods: Mann-Whitney U and Wilcoxon W to identify if the categories significantly differ.

The categories of variables are shown below. The categories are selected by analysing the values of the variables and testing for significant differences.

- The four different types of neighbourhoods:
  - Residential
  - Commercial
  - Working
  - Countryside
- Four national regions:
  - North
  - East
  - West
  - South
- Two categories for average income per worker for above average and below average (only residential neighbourhoods) [CBS, 2015a]:
  - High (neighbourhoods with more than €30.700 average income per worker)
  - Low (Neighbourhoods with less than €30.700 average income per worker)
- Three categories for average age in neighbourhood (only for residential):
  - High (older than 43)
  - Medium (between 38 and 43)
  - Low (younger than 38)
- Two categories for amount of cars per household (only for residential):
  - High (more than 1)
  - Low (less than 1)
- Three categories for amount of persons per household (only for residential):
  - High (more than 2.5)
  - Medium (between 2.0 and 2.5)
  - Low (less than 2.0)
- Two categories for the amount of commercial (shopping) companies (only commercial):

  - High (more than 130)
  - Low (less than 130)

- Two categories for the amount of working companies (only for working neighbourhoods):
  - High (more than 130)
  - Low (less than 130)

The different types of neighbourhoods are compared in categories. Category 1 is residential, category 2 is commercial, category 3 is working and category 4 is countryside. The fourth group is added to check if the assumption to exclude neighbourhoods with a density of population less than 2000 people per square km is correct. For the comparison the Mann-Whitney U test is used and because the values are not equally distributed mean ranks are compared. Differences between groups are significant when the significance value is below 0,05. The significance value is marked in each table.

Table E-2: Type group 1 and 2 variables

	Type	N	Mean Rank	Sum of Ranks
C_N	1	336	176,18	59196,50
	2	33	274,80	59196,50
	Total	369		

Table E-3: Type group 1 and 2 test

	C_N
Mann-Whitney U	2580,500
Wilcoxon W	59196,500
Z	-5,621
Asymp. Sig. (2-tailed)	0,000

Table E-4: Type group 1 and 3 variables

	Type	N	Mean Rank	Sum of Ranks
C_N	1	336	186,80	62765,50
	3	50	238,51	11925,50
	Total	386		

All the differences between the categories in type of neighbourhood are significant. This also implicate that the assumption to exclude neighbourhoods with a population density

Table E-5: Type group 1 and 3 test

	C_N
Mann-Whitney U	6149,500
Wilcoxon W	62765,500
Z	-3,392
Asymp. Sig. (2-tailed)	0,001

Table E-6: Type group 1 and 4 variables

	Type	N	Mean Rank	Sum of Ranks
C_N	1	336	185,25	62244,00
	4	24	114,00	2736,00
	Total	360		

Table E-7: Type group 1 and 4 test

	C_N
Mann-Whitney U	2436,000
Wilcoxon W	2736,000
Z	-3,743
Asymp. Sig. (2-tailed)	0,000

of less than 2000 people per square km was correct. The value in countryside neighbourhoods is lower than in residential neighbourhoods. The values in commercial and working neighbourhoods are higher than in residential neighbourhoods.

E-3 National region

The national regions are compared to the total group of neighbourhoods. In this case category 1 is west, category 2 is east, category 3 is north and category 4 is south. The category 5 is all the neighbourhoods together.

Table E-8: Region group 1 and 5 variables

	Region number	N	Mean Rank	Sum of Ranks
C_N	1	216	351,59	75942,50
	5	443	319,48	141527,50
	Total	659		

Table E-9: Region group 1 and 5 test

	C_N
Mann-Whitney U	43181,500
Wilcoxon W	141527,500
Z	-2,227
Asymp. Sig. (2-tailed)	0,026

Table E-10: Region group 2 and 5 variables

	Region number	N	Mean Rank	Sum of Ranks
C_N	2	92	253,07	23282,00
	5	443	271,10	120098,00
	Total	535		

Table E-11: Region group 2 and 5 test

	C_N
Mann-Whitney U	19004,000
Wilcoxon W	23282,000
Z	-1,135
Asymp. Sig. (2-tailed)	0,256

Table E-12: Region group 3 and 5 variables

	Region number	N	Mean Rank	Sum of Ranks
C_N	3	31	195,98	6075,50
	5	443	240,41	106499,50
	Total	474		

Table E-13: Region group 3 and 5 test

	C_N
Mann-Whitney U	5579,500
Wilcoxon W	6075,500
Z	-1,948
Asymp. Sig. (2-tailed)	0,051

The differences between the different regions are only significant in the case of the region west. North is with a value of 0,051 almost significant. Because the income level also is

Table E-14: Region group 4 and 5 variables

	Region number	N	Mean Rank	Sum of Ranks
C_N	4	104	254,75	26494,50
	5	443	278,52	123383,50
	Total	547		

Table E-15: Region group 4 and 5 test

	C_N
Mann-Whitney U	21034,500
Wilcoxon W	26494,500
Z	-1,536
Asymp. Sig. (2-tailed)	0,125

higher in the west the main difference is assumed to be in income and the difference between west and the other regions is not taken into account in the definition of different types of neighbourhoods.

E-4 Average income (only residential neighbourhoods)

For three categories of average income (1: <= 25000, 2: >25000 and <=35000, 3: >35000)

Table E-16: Average income group 1 and 2 variables

	Category income	N	Mean Rank	Sum of Ranks
C_N	1	62	111,77	6930,00
	2	208	142,57	29655,00
	Total	270		

Table E-17: Average income group 1 and 2 test

	C_N
Mann-Whitney U	4977,000
Wilcoxon W	6930,000
Z	-3,138
Asymp. Sig. (2-tailed)	0,002

Table E-18: Average income group 2 and 3 variables

	Category income	N	Mean Rank	Sum of Ranks
C_N	2	208	133,56	27779,50
	3	66	149,93	9895,50
	Total	274		

Table E-19: Average income group 2 and 3 test

	C_N
Mann-Whitney U	6043,500
Wilcoxon W	27779,500
Z	-1,610
Asymp. Sig. (2-tailed)	0,107

The difference between the categories low (1) and medium (2) is significant but the difference between category medium (2) and high (3) is not. Therefore the categories are redefined in low (average income per worker below 30.700) and high (average income per worker above 30.700).

Table E-20: Average income group 1 and 2 variables

	Category income	N	Mean Rank	Sum of Ranks
C_N	1	189	154,70	29239,00
	2	147	186,24	27377,00
	Total	336		

Table E-21: Average income group 1 and 2 test

	C_N
Mann-Whitney U	11284,000
Wilcoxon W	29239,000
Z	-3,344
Asymp. Sig. (2-tailed)	0,001

Now the difference between the categories low income and high income is significant with a higher value for higher income.

E-5 Average age (only residential neighbourhoods)

The comparison between different categories of age is based on category 1: younger than 38 years. Category 2: between 38 and 43 years on average and category 3: average above 43 years.

Table E-22: Average age group 1 and 2 variables

	Category average age	N	Mean Rank	Sum of Ranks
C_N	1	109	128,80	14039,50
	2	141	122,95	17335,50
	Total	250		

Table E-23: Average age group 1 and 2 test

	C_N
Mann-Whitney U	7324,500
Wilcoxon W	17335,500
Z	-0,723
Asymp. Sig. (2-tailed)	0,470

Table E-24: Average age group 2 and 3 variables

	Category average age	N	Mean Rank	Sum of Ranks
C_N	2	141	110,82	15625,50
	2	86	119,22	10252,50
	Total	227		

Table E-25: Average age group 2 and 3 test

	C_N
Mann-Whitney U	5614,500
Wilcoxon W	15625,500
Z	-1,065
Asymp. Sig. (2-tailed)	0,287

The difference in categories of average age is not significant.

E-6 Household size (only residential neighbourhoods)

The difference between household sizes is measured between three categories. Category 1 is less than two people per household, category 2 is between 2 and 2.5 people per household and category 3 is more than 2.5 people per household.

Table E-26: Household size group 1 and 2 variables

	Category HH size	N	Mean Rank	Sum of Ranks
C_N	1	105	137,06	14391,50
	2	167	136,15	22736,50
	Total	272		

Table E-27: Household size group 1 and 2 test

	C_N
Mann-Whitney U	8708,500
Wilcoxon W	22736,500
Z	-0,105
Asymp. Sig. (2-tailed)	0,917

Table E-28: Household size group 2 and 3 variables

	Category HH size	N	Mean Rank	Sum of Ranks
C_N	2	167	119,98	20037,00
	3	64	105,61	6759,50
	Total	231		

Table E-29: Household size group 2 and 3 test

	C_N
Mann-Whitney U	4679,000
Wilcoxon W	6759,000
Z	-1,649
Asymp. Sig. (2-tailed)	0,099

Both differences between categories in household sizes are not significant.

E-7 Cars per household (only residential neighbourhoods)

The variable amount of cars per household is divided in two categories. Category 1 is one car or less per household and category 2 is more than one car per household.

Table E-30: Amount of cars group 1 and 2 variables

	Category amount of cars	N	Mean Rank	Sum of Ranks
C_N	1	185	172,69	31947,50
	2	151	163,37	24668,50
	Total	336		

Table E-31: Amount of cars group 1 and 2 test

	C_N
Mann-Whitney U	13192,500
Wilcoxon W	24668,500
Z	-0,991
Asymp. Sig. (2-tailed)	0,322

The difference between the categories in amount of cars per household is not significant.

E-8 Amount of commercial companies (only commercial neighbourhoods)

The amount of commercial companies is divided in category 1 (less than 130) and category 2 (more than 130).

Table E-32: Amount of commercial companies group 1 and 2 variables

	Category commercial companies	N	Mean Rank	Sum of Ranks
C_N	1	20	15,00	300,00
	2	13	20,08	261,00
	Total	33		

The difference between the two categories of commercial companies is not significant. However, the N is very small, it would therefore be interesting to investigate this with a larger amount of commercial neighbourhoods in a future study.

Table E-33: Amount of commercial companies group 1 and 2 test

	C_N
Mann-Whitney U	90,000
Wilcoxon W	300,000
Z	-1,484
Asymp. Sig. (2-tailed)	0,138

E-9 Amount of working companies (only for working neighbourhoods)

The amount of working companies is divided in category 1 (less than 130) and category 2 (more than 130).

Table E-34: Amount of working companies group 1 and 2 variables

	Category working companies	N	Mean Rank	Sum of Ranks
C_N	1	25	24,34	608,50
	2	25	26,66	666,50
	Total	50		

Table E-35: Amount of working companies group 1 and 2 test

	C_N
Mann-Whitney U	283,500
Wilcoxon W	608,500
Z	-0,576
Asymp. Sig. (2-tailed)	0,564

The difference between the two categories of commercial companies is also not significant. However, also in this case the N is small and further research could be done for a larger sample of working companies.

Appendix F

Sensitivity analysis demand for charging infrastructure

For positive changes in the estimated variables, the numbers for the amount of charging places per km^2 in table F-1 are found. The changes are based on extreme cases. Only in the case of an extreme change in the efficiency of Electric Vehicle (EV)s and in the case of an increase of Rn with 10%, large changes are observed.

Table F-1: Sensitivity for different neighbourhoods for positive changes in variables, change in demand for charging places

	Amount of EV		**Change in e**		**Change in d**		**Change in P**		**Change in R_N**	
Change	**105%**	**110%**	**+0,02**	**+0,04**	**+5**	**+10**	**+0,5**	**+1,0**	**+5%**	**+10%**
Residential high income	0	1	1	3	1	2	-1	-1	2	3
Residential low income	0	0	0	1	0	1	0	-1	1	2
Commercial	1	3	3	8	3	5	-2	-3	4	7
Working	1	2	2	5	2	3	-1	-2	2	3

For negative changes the consequences are shown in table F-2. The largest influences in this case is for a reduction of R_N in the residential neighbourhood types and for a change in the efficiency of EVs in the commercial and working type. This seems logical because an increase in the efficiency would be likely to result in less charging sessions at shopping areas or at work because with the increased efficiency drivers are able to extend their range and wait to charge at home instead of at work or at shopping areas.

Table F-2: Sensitivity for different neighbourhoods for negative changes in variables, change in demand for charging places

	Amount of EV		**Change in e**		**Change in d**		**Change in P**		**Change in R_N**	
Change	**105%**	**110%**	**+0,02**	**+0,04**	**+5**	**+10**	**+0,5**	**+1,0**	**+5%**	**+10%**
Residential high income	-1	-1	-1	-3	-1	-2	1	1	-2	-4
Residential low income	0	-1	-1	-1	-1	-1	0	0	-1	-2
Commercial	-1	-3	-3	-8	-3	-5	2	4	-4	-7
Working	-1	-2	-2	-5	-2	-4	1	3	-2	-3

Appendix G

Scores for strategies on different criteria

In chapter 6 different criteria to evaluate the preferences of municipalities on different strategies, are introduced. These strategies are ranked based on their theoretical effects on the selected criteria. In chapter 6 the scores for the criteria cost for the different costs is explained. In this appendix the scores of the other criteria based on the theoretical effects are explained. First this is done for the strategies concerning the facilitation level in figure 6-2. Second the scores of the stimulation strategies will be explained.

G-1 Facilitation strategies

The scores of the different facilitation strategies that municipalities could use are presented in table G-1. The scores are based on a ranking between 1 and 5 of the theoretical effects of a strategy on the different criteria. The score of 5 is the highest (so best) and the score of 1 is the lowest (worst). The scores on each criteria are explained below. The scores on the criteria costs for municipality are already explained in chapter 6.

Safety of charging points
The different models to facilitate the charging places score differently on the certainty the municipality has that the charging points are safe. If the municipality owns and places the charging point, they are able to control the safety. Therefore the rank and score is highest (5). If a commission or a concession model is used the municipality is able to control the safety of the charging points through guidelines. The control of the municipality on the safety is therefore still high but lower than when the municipality would construct the points themselves (4). Some control on the safety can be executed when a licence for the construction of a charging point is provided. However the municipality has less influence in this model than in a commission or a concession. In a regional cooperation the municipality has to negotiate with other municipalities about the requirements and it is therefore dependent on other municipalities, this gives a lower score on safety. Finally if no model and therefore no facilitation of a charging infrastructure is implemented the risk of citizens using other methods to charge their Electric Vehicle (EV) rises and dangerous situations could occur. Besides the control of the municipality is not determined in this case.

Simplicity of procedure for citizens
The simplicity of the procedure for citizens is determined using two characteristics:

Table G-1: Scores of facilitation strategies on different criteria.

Criteria	License	Concession	Commision	Ownership	Regional cooperation	No model
Low cost for municipality	4	2	2	1	3	5
Safety of charging place	3	4	4	5	2	1
Simplicity of procedure for citizens	2	4	3	5	3	1
Simplicity of policy for municipalities	4	2	3	5	3	1
Environmental friendly image municipalities	2	3	3	5	4	1
Uniformity in charging places in municipalities	2	4	3	5	3	1
Reaching targets in air quality	2	4	4	4	4	1
Uncertainty about future demand for charging places	3	2	2	1	5	4

- The time it would take to implement a charging place after a request.
- The amount of stakeholders, which influence the process.

Ownership and construction by the municipalities themselves would be the best possible model because the control of the municipality regarding the implementation time would be maximized and the amount of stakeholders involved minimized. The second best model would be a concession because the responsible operator and constructor is known and the municipality could set requirements about the implementation time. In a commission an additional step is needed because the commission for the construction of a charging place should be published and granted first. A Regional cooperation is assumed to score average because the outcomes depend on the negotiation with the other municipalities.

Simplicity policy for municipality

In this criteria the simplicity of the execution of the policy that is implemented is compared. If the municipality constructs and owns the charging places, it will take a lot of time for the municipality because of the high complexity. A regional cooperation or a concession model will require a lot of agreements with other municipalities or stakeholders, this process could be complex as well but less complex than constructing the places. Giving a commission as municipality would require a procedure to formulate the commission but after this is done once it will be relatively easy to repeat. Just providing a license when a charging point is constructed is relatively easy. The only thing needed is a procedure to evaluate the requests. Finally no model requires no work at the moment for the municipality and therefore scores best on this criteria.

Environmental friendly image for municipality
The score on this criteria is based on the visibility of a strategy for citizens. If the visibility that the municipality facilitates charging places is high the environmental friendly image of the municipality will increase. This applies in the opposite direction as well, if the visibility that the municipality does nothing is high the environmental friendly image about that municipality will decrease. If the municipality constructs and owns the charging places, the citizens will notice this and the environmental friendly image will increase. This model gets the highest score. If a regional cooperation is implemented the municipality profits from scale advantages and from regional news items about the cooperation. A concession or commission by the municipality itself will increase the environmental friendly image as well but less compared to the options mentioned above. A license model encounters the risk that citizens develop an image that the municipality does just the minimum that is necessary. If there is no facilitation of a charging infrastructure, a negative image about the importance of the environment for the municipality is developed. This strategy gets the lowest score.

Uniformity in charging places in municipality
The uniformity in charging places depends again on the amount of control the municipality has on the layout of the charging places, which are constructed, like the safety of charging places. Therefore the same scores are used for this criteria excepts the commission model because there is a risk that another operator wins a new commission an another type of charging place will be constructed. In a regional cooperation the change that surrounding municipalities have the same type of charging place is higher because they are part of the same cooperation, which increase the score for uniformity.

Reaching targets for air quality
The chance that targets in air quality are reached is higher when more EVs are on the road. Implementing a charging infrastructure contributes positively to the amount of EVs [APPM, 2015]. Therefore models in which a charging infrastructure is facilitated score higher (4). A model where licenses are provided is ranked less effective and therefore a score of 2 is given. No facilitation strategy scores worst on this criteria.

Uncertainty in future demand
Three arguments are used to characterise the effects of the uncertainty in future demand:

- Amount of control to evaluate the amount of charging places constructed.
- Minimizing the amount of charging places constructed.

- Financial risk of municipality in constructed charging places.

No facilitation strategy minimizes the risk that charging places are constructed which won't be used. Therefore this strategy scores high. In a regional cooperation the risk is shared and the municipality could downgrade or upgrade according to developments in the municipality. Therefore this model scores higher. Providing a license does not include any financial risk about the construction of charging places for the municipality, however the control of the municipality is less, therefore this model scores average. A commission or a concession includes probably financial risks for the municipalities and scores therefore less. Constructing and operating the charging places as a municipality would increase the financial risk and therefore scores worst.

G-2 Stimulation strategies

The same procedure as for the facilitation strategies above is described for the stimulations strategies here. The scores between 1 and 5 for all the criteria can be seen in table G-2. An

Table G-2: Scores for stimulation strategies on different criteria.

Criteria	**Subsidy charging place business**	**Subsidy charging place private**	**Parking advantages**	**Reserving place possible**	**Information for citizens**	**Nothing**
Low cost for municipality	1	1	3	5	4	5
Simplicity of procedure for citizens	2	2	3	2	5	4
Simplicity of policy for municipalities	2	2	1	3	4	5
Environmental friendly image municipalities	3	3	5	2	4	1
Reaching targets in air quality	3	3	4	3	2	1
Uncertainty about future demand for charging places	1	1	3	4	2	5

explanation of the scores is given below.

Costs for municipality
The highest costs for the municipality can be assumed to occur when the construction of

charging places is subsidized, because it is assumed that a substantial subsidy is provided and a higher amount of places will be constructed because of the increased profitability. Providing parking advantages to drivers of EVs implies that the revenue from parking fees is lower. Therefore costs are made but on average substantially lower than in the case of a subsidy. Informing citizens about charging places and the procedure to implement charging places will cost time and therefore some money. But no investments are needed. Providing the possibility to reserve charging places has no financial consequences for the municipality as has doing nothing.

Simplicity of procedure for citizens

Informing citizens about the implementation of charging places and the strategy reduces the complexity for citizens. So this increases the simplicity of the procedure for citizens and therefore the highest score is given. No action means that there are no measures so this would not change anything about the complexity. Parking advantages need to be communicated to citizens before they are clear and so increase the complexity a bit. Subsidies and reserving parking places are assumed to score equal because both cause a substantial increase in the complexity of the procedure but a difference in the complexity is hard to make at this point.

Simplicity of policy for municipality

Parking advantages are assumed to be the most complex policy to implement because a lot of communication is needed and regulations about certain areas should be changed. Subsidizing charging places is assumed to be complex as well because an application procedure should be developed and the requests should be evaluated. Providing the possibility to reserve parking places is less complex since it only needs the permission of the municipality to allow this for charging place operators. Informing the citizens is about communicating the procedures of the municipality and is therefore not considered to be complex. Doing nothing is the strategy with the highest simplicity because nothing has to be done.

Environmental friendly image municipality

The environmental friendly image depends on the visibility of a strategy. The highest visibility is expected when parking advantages are implemented because citizens and visitors see this actively on the street. When the citizens are informed about charging places and the procedure to implement them the environmental friendly image of the municipality will increase as well. Providing subsidies is also increasing the environmental friendly image of a municipality but without informing the citizens this is assumed to be less visible. Providing the possibility to reserve charging places mainly affects the charging place operate and not the citizens itself and will therefore contribute less to the environmental friendly image of the municipality. Finally doing nothing will have a negative impact on the environmental image of the municipality and this scores therefore lowest.

Reaching targets air quality

Reaching the targets for air quality is depending on the percentage of EVs in a municipality.

It is difficult to estimate the impacts of the different strategies on the amount of EVs in the municipality. It is influenced by the visibility of the possibility to drive electric as well. Therefore parking advantages are assumed to score highest. Subsidizing charging places and providing the possibility to reserve charging places are assumed to cause an increase in the amount of charging places which has a positive effect on the amount of EVs [APPM, 2015]. Therefore this is assumed to have a positive effect on the air quality. Informing citizens increases the visibility of EVs but is not directly influencing the amount of EVs. It is therefore assumed that the influence of this strategy is minimal. Doing nothing has no influence on reaching the targets in air quality and gets therefore the lowest score.

Uncertainty in future demand
If the municipality subsidizes the construction of charging points a relative high investment is made. When the charging places are not used because of uncertain developments the investment of the municipality was useless. Because this risk is highest when the strategy of subsidizing charging places is implemented this strategy scores lowest. When citizens are informed and the procedure is changed because of uncertain developments everything has to be changed. This is considered to be a risk. Providing parking advantages to drivers of EVs is requiring a small reduction in the returns from parking fees. Because of the uncertainty it could be the case that the amount of EVs increases a lot and the returns reduce a lot. This is a risk for the municipality, but the impact will be less than with the strategies mentioned previously. If the charging place operator is allowed to reserve charging places no financial risk is taken by the municipality and the consequences in the case of uncertain events are small. Doing nothing does not include any risk in the case of uncertain developments and therefore scores best.

Appendix H

Results survey municipalities

The results of the surveys, which are completed by the municipalities, are shown here together with the results of the Kruskal Wallis test for significant diffences between groups of municipalities. The names of the municipalities and the population are not shown because of privacy reasons. Table H-1 gives the results for the large municipalities, which completed the survey. Table H-2 shows the results for the middle-large municipalities, the yellow bar in here is the completed survey, which is not included in the results. Table H-3 gives the results for the small municipalities.

Municipality	Population	EV policy?	Costs	Safety	Complexity	Complexity	Environmen	Consistency	Targets air q	Uncertainty
[redacted]										
		Yes	6	6	10	10	6	6	10	10
		Yes	9	9	8	5	7	4	7	4
		Yes	8	10	10	10	5	7	6	1
		Yes	8	7	8	7	7	7	8	8
		Yes	8	10	8	7	7	7	9	6
		No, develc	9	10	10	8	8	7	5	5
		Yes	9	9	9	9	2	9	6	7
		Yes (partly	8	9	8	9	7	8	7	8
		No, develc	10	10	8	8	9	7	8	7
		Yes	10	1	6	6	8	5	1	1

Figure H-1: Results of survey of large municipalities.

In the figures below the results of the Kruskal Wallis test are shown for different groups of municipalities. Figure H-4 shows the results for the division in groups as identified in figure H-1 to H-3. H-5 shows the results for the Kruskal Wallis test for a division at 100.000 citizens. H-6 shows the results for the Kruskal Wallis test for a division at 50.000 citizens. H-7 shows the results for the Kruskal Wallis test for a division at 150.000 citizens.

Municipality	Population	EV policy?	Costs	Safety	Complexity	Complexity	Environmen	Consistency	Targets air q	Uncertainty
[redacted]		Yes	9	10	8	9	8	7	9	10
		Yes (not li	10	10	-	5	10	10	10	10
		No	8	5	5	6	7	8	2	7
		Yes	10	8	8	8	8	9	8	8
		No, develc	10	-	8	8	10	7	4	8
		No	8	10	8	6	8	7	7	7
		No, develc	nvt	nvt	nvt	nvt	nvt	nvt	nvt	nvt
		No, develc	9	10	8	8	9	9	8	7
		Yes	10	8	-	5	7	8	3	9
		Yes	10	10	8	8	10	3	3	5
		No	8	5	5	6	7	8	2	7

Figure H-2: Results of survey of middle-large municipalities.

Municipality	Population	EV policy?	Costs	Safety	Complexity	Complexity	Environmen	Consistency	Targets air q	Uncertainty
[redacted]										
		No	8	9	6	8	7	7	7	-
		No	10	10	1	1	5	10	5	7
		Yes	8	8	8	8	8	5	4	8
		No	8	10	8	6	8	7	7	7
		No	10	10	5	5	3	8	5	10
		Not writte	10	10	7	8	7	6	7	7
		No	8	8	8	8	6	6	6	6
		No	8	8	6	8	4	4	-	7

Figure H-3: Results of survey of small municipalities.

Test Statistics[a,b]

	Costs	Complexity citizens	Safety	Complexity municipality	Consistency	Targets air quality	Environment	Uncertainty
Chi-Square	1,985	8,180	,293	2,300	3,358	1,176	8,140	3,195
df	2	2	2	2	2	2	2	2
Asymp. Sig.	,371	,017	,864	,317	,187	,555	,017	,202

a. Kruskal Wallis Test
b. Grouping Variable: Muni size

Figure H-4: Kruskal Wallis test to compare criteria in the three different groups of municipalities, small, middle and large.

Test Statistics[a,b]

	Costs	Complexity citizens	Safety	Complexity municipality	Consistency	Targets air quality	Environment	Uncertainty
Chi-Square	,953	7,147	,207	2,300	,744	2,579	1,017	2,834
df	1	1	1	1	1	1	1	1
Asymp. Sig.	,329	,008	,649	,129	,388	,108	,313	,092

a. Kruskal Wallis Test
b. Grouping Variable: Muni size 3

Figure H-5: Kruskal Wallis test to compare criteria in municipalities when group 1 has more than 100.000 citizens and group 2 less.

Test Statistics[a,b]

	Costs	Complexity citizens	Safety	Complexity municipality	Consistency	Targets air quality	Environment	Uncertainty
Chi-Square	1,985	8,180	,293	2,300	3,358	1,176	8,140	3,195
df	2	2	2	2	2	2	2	2
Asymp. Sig.	,371	,017	,864	,317	,187	,555	,017	,202

a. Kruskal Wallis Test
b. Grouping Variable: Muni size

Figure H-6: Kruskal Wallis test to compare criteria in municipalities when group 1 has more than 50.000 citizens and group 2 less.

Test Statistics[a,b]

	Costs	Complexity citizens	Safety	Complexity municipality	Consistency	Targets air quality	Environment	Uncertainty
Chi-Square	,865	2,037	1,471	,165	3,499	2,808	,067	1,915
df	1	1	1	1	1	1	1	1
Asymp. Sig.	,352	,153	,225	,684	,061	,094	,796	,166

a. Kruskal Wallis Test
b. Grouping Variable: Muni size 3

Figure H-7: Kruskal Wallis test to compare criteria in municipalities when group 1 has more than 150.000 citizens and group 2 less.

Appendix I

Sensitivity multi-criteria analysis

In the sensitivity analysis of the weighted product model conducted in section 10-2 the main uncertainty is caused by the assumption that no practical implications or side effects would occur and strategies will have the expected theoretical effect. To test this assumption the scores of the strategies in each criteria are switched one after another. In this sensitivity analysis an indication of the preferences of municipalities in the case that strategies would have exactly the opposite effect on a certain criteria is given. The sensitivity analysis is conducted for both the facilitation level strategies as the stimulation level strategies.

I-1 Facilitation strategies

In table I-1 the results of the sensitivity analysis for the facilitation strategies are shown. For each criteria the scores are inverted one after another, so a new weighted product model is retrieved for the change in each criteria, so eight times in total. The amount of times a strategy is ranked first, second, third, fourth, fifth and sixth is shown in the table. Regional cooperation is ranked first in most of the times. The case that regional cooperation is ranked fifth is when the scores for uncertainty about the future demand are reversed. So the scenario, which is expected to be able to handle uncertainty in the demand best, is scoring worse when it is assumed to score worst on the uncertainty of demand. Licensing, concession and commission are following the regional cooperation strategy. Ownership of the charging places by the municipality itself is ranked last in half of the times, but also best in two times (in the case the scores for uncertainty in future demand are reversed and in the case the score for the simplicity of the strategy for the municipality is reversed). No model is ranked at the bottom two each time.

I-2 Stimulations strategies

The same procedure as explained above is used for the stimulation strategies. Because the scores for a subsidy are the same it is just included once here. Table I-2 shows the results of the sensitivity analysis. The ranks are more diverted than in the case of the facilitation strategies. A subsidy for charging places scores worst but no clear differences between the other strategies can be identified.

Table I-1: Sensitivity analysis of weighted product model on facilitation strategies. The numbers represent the amount of times a strategy is ranked first, second, third, fourth, fifth or sixth when the scores of the criteria are changed.

	First	**Second**	**Third**	**Fourth**	**Fifth**	**Sixth**
License	1	4	0	1	2	0
Concession	1	2	3	2	0	0
Commission	0	0	5	3	0	0
Ownership	2	1	0	0	1	4
Regional cooperation	4	1	0	2	1	0
No model	0	0	0	0	4	4

Table I-2: Sensitivity analysis of weighted product model on stimulation strategies. The numbers represent the amount of times a strategy is ranked first, second, third, fourth or fifth when the scores of the criteria are changed.

	First	**Second**	**Third**	**Fourth**	**Fifth**
Subsidy charging place	0	0	1	0	5
Parking advantages	1	3	0	2	0
Reserving places possible	1	2	2	1	0
Information for citizens	2	1	2	1	0
Nothing	2	0	1	2	1

Appendix J

Business case charging place

The business case for a charging place for Electric Vehicle (EV)s is explained here. In general the business case is not profitable at the moment. One of the tasks of National knowledge center charging infrastructure (NKL) is to improve this business case. Table J-1 shows the business case. The data on which this business case is based is given here:

- Depreciation charging place: 7 years [Snyder, Chang, Erstad, Lin, Falken Rice, Tzun Goh, and Tsao, 2012]
- Electricity price: €0,24 per kwh [Nuon, 2015], of which €0,07 for energy, €0,035 VAT and €0,12 energy tax.
- Utility rate: 8% (See chapter 8)
- Energy transfer: 7,5 kwh/h ((See chapter 8)
- Hours charging a day: 24 * 0,08 = 1,92 hours)
- Hours charging a year: hours in a year * 0,08 = 700,8 hours)
- Kwh charged a year: 700,8 * 7,5 = 5256 kwh
- Investment charging place: €3.000 including VAT [Snyder, Chang, Erstad, Lin, Falken Rice, Tzun Goh, and Tsao, 2012]
- Maintenance per year: €100 [Snyder, Chang, Erstad, Lin, Falken Rice, Tzun Goh, and Tsao, 2012]
- For the reservation of charging places 10% of the charging times is taken
- Building rights are not included because of differences between municipalities.

As can be seen in the business case, investing in charging places is not profitable yet. There are several options to improve the business model. The most promissing one is include in the business case: providing the possibility to reserve charging places. Other possibilities are to increase the electricity price (difficult because of regulations by government) or reduce energy taxes.

Table J-1: Business case for a single charging place.

Business case charging places					
Costs			**Income**		
	Amount	Cost per year		Amount	Income per year
Construction	€3.000	€428,57	Electricity	5.256 kwh	€1.261,44
Maintenance	€100	€100	(Reserving charging place)	70 kwh	€140,16
Electricity	5.256 kwh	€367,92			
VAT	5.256 kwh	€183,96			
Energy tax	5.256 kwh	€630,72			
Building rights	-	-			
Total		**€1.711,17**			**€1.401,60**

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