WAGENINGEN UNIVERSITY – LAND USE PLANNING GROUP

Spatial implications of electric vehicles (EVs) charging networks

A case study on the city centre of Utrecht

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Preface

This thesis is written as part of completing the bachelor's degree program Landscape Architecture and Spatial Planning. Starting, constructing and completing this project has revealed an endeavour similar to the subject of this thesis. When assuming this thesis is comparable to an electric vehicle (EV), I have been searching for a charging location that was not yet constructed, without a map or indication of its final location.

Vehicles and transportation have been – and always will be – the main topic in my personal and professional interests. I have been intrigued by cars since I was a few months old, which had numerous effects on life. The sheer freedom of the concept, the noise, the smell, the craftsmanship and the speed have never stopped intriguing me. An electric vehicle is a new development in this concept, which created a personal interest. No noise, pollutants and an infrastructure that offers the possibility to be completely 'green' might not seem as an entertaining idea for a self-proclaimed 'petrol-head'. It is however in my personal opinion the only way forward for daily transport, as the production of fossil fuels reaches its final decades. I believe a shift towards electric mobility is no longer a matter of how, but rather a question of how fast. In the light of this development, this research might even form a useful addition to speed up this transition.

First and foremost I want to thank dr. Claudia Basta for her guidance, criticism and motivational input. In the summer of 2015, I entered her office without any ideas on topics, structure or completion of this thesis. Continuous questions on personal views and interesting topics revealed 'the car' as a missing link. We went from struggling to complete a research proposal, to this 60 page document, by combining personal motivation for the topic of auto-mobility with the professional motivation for researching on spatial developments.

Next to my supervisor, the efforts, support and motivational speeches by Hester (and her mother Maria) kept me on track and focused on the final goal. Hetty, thank you for providing a workspace that enabled me to actually do some work, and going the extra mile for me in finding a solution for my challenges.

Everybody, it is finally finished. You helped me every step of the way, and I will be eternally thankful for your efforts and support.

Thank you.

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Chapter 1

Introduction

1.1 Research context

A shift towards electric mobility is on its way in the Netherlands. The Netherlands Enterprise Agency delivered a report on December 31st 2015 that indicated a rise in the adoption of electric passenger vehicles. Between December 2013 and December 2015 the number of EVs increased from 28.673 vehicles to 87.531 vehicles, an increase of more than 200%. Projections by the Rijksdienst voor Ondernemend Nederland (RVO) indicate that the growth will result in 200.000 electric vehicles in 2020, and 1.000.000 in 2025. (CBS Statline, 2015) (Rijksdient voor Ondernemend Nederland, 2015)

Motivations for the switch towards electric mobility come from the current estimates, which indicate that 90% of the worldwide transport sector is powered by fuels derived from crude oil. Worldwide, the concerns about vehicles' emissions and their correlation with global warming and climate change are creating new initiatives regarding sustainable and less-polluting mobility solutions. Rising uncertainty about the availability, price and socio-environmental effects of oil production cause for other means of transport and power supply to rise in number and sort (Van Vliet, 2010) International protocols, e.g. the Kyoto protocol, promoted the reduction of emissions by 20% in 2020, when compared to the emission levels of 1990. Furthermore, in the Netherlands, a recent verdict by the District Court of The Hague emphasized the need to achieve such carbon emission abatement targets proportionally to the economic and technological capacities of a country. To reach these abatement goals, a number of initiatives have been initiated within the Netherlands and the European Union. (National Resources Defence Council, 2007) An example is the European Green Cars Initiative, focused on promoting electric vehicle mobility. Electric mobility is generally seen as one of the more viable options to reduce direct greenhouse gasses (GHG) emissions. Albeit the sources that 'feed' the electricity network – still consisting, in most cases, of non-renewable sources – shall be accounted in order to determine the total emissions of GHG in the atmosphere. Along the entire life cycle of energy production, supply and consumption for electric mobility, the abatement resulting from electric vehicles is still a significant one.

The 're-fuelling' network for EVs differs from fossil-fuel vehicles, as it is decentralized and does not rely on central supply point (gas stations) to provide a recharge of the vehicle. Charging locations can be positioned at any given location, often at home or company venues. Decentralized supply that can be located at (virtually) any given location creates different spatial implications in comparison to fossil fuel vehicles. Owners of a private parking location can invest in the construction of their own charging spot so to charge the car at home. However, owners of a Battery powered Electric Vehicle (BEV) or a Plug-in Hybrid Electric Vehicle (PHEV) without the option of a private charging location have to rely on public charging networks in the vicinity of their houses to utilize the electric driveline of their vehicle. (Chen, 2013) Both owners, though, will equally need to rely on the availability of a network of charging facilities – sufficient in number and efficient in distribution – both for commuting on daily basis, and for travelling, The dependency of BEVs and PHEVs owners on the public charging network will therefore increase as well, considering that the market share of EVs is expected to grow. (RVO, 2015)

It is now common practice to allocate charging facilities to existing parking locations. Installing a charging facility and indicating the special status of the parking area creates what, in this thesis, corresponds to the definition of 'charging location'. The conversion of a standard parking space into an electric charging location makes the parking space unavailable to fossil-fuel vehicles. (AgentschapNL, 2015). In a situation where parking space is freely available, the effect of such conversions will be limited. However, the Dutch situation for storing and parking vehicles allows 20% of the car owners to park a vehicle on private property. Private property is seen as a parking location on private or commercial land, i.e., not in the public area. As 20% is parked on private locations, 80% is parked in public space (Allego, 2015). Private charging facilities are therefor hard to realize for the majority of the car owners in the Netherlands.

Dutch city centres vary from planned cities (Almere) to cities that have expanded around an historical inner city (e.g. Utrecht, The Hague, and Amsterdam). The latter category is characterized by an ancient core, constructed centuries ago, and known in Dutch as 'Binnenstad'. These inner cities were, of course, never designed for supporting auto mobility, and have therefore variously adapted to the daily flows of cars and the demand of parking facilities. Within such historical, and often vulnerable city centres, parking facilities 'claim' public spaces located near squares, alleys and canals of inestimable aesthetic and historical value. Due to the high demand for 'appropriating' these sensitive spaces for parking purposes, parking in a city centre is often priced per hour, is generally costly, and highly regulated through limited permits for residents. (Parkeerwet Utrecht, 2015)

Furthermore, city centres that are already under much pressure by a range of spatial demands, have seldom invested in the addition of charging locations – and resumed to conversion of regular parking spaces into charging locations – proportioned to the growing share of EVs. Parking an EV in city centres with a possibility to recharge the vehicle is paradoxically more difficult than parking a fossil fuel vehicle, despite the significant lower local GHG emission and noise reduction. (Gemeente Utrecht, 2012).

The network of electric charging facilities has not reached the level of coverage, flexibility nor 'charging speed' that is offered by fossil fuel stations. Fast-charging possibilities are showing up in the charging networks, which come close to the regular practice of 'filling up the car'. These fast-charging facilities are, however, very scarce, and do not support all BEVs and PHEVs, forcing the majority of EV users to use slower but more commonly available slow charging points. Slow-charging points results in EVs that have to remain stationary for a longer period of time, varying the spatial implication of these vehicles per type or model of vehicle. (Oplaadpalen.nl, 2015).

These problematic aspects, several conflicting stakes related to the desirable expansion of electric powered mobility in the Netherlands, and the crucial problem of accommodating the expected growing demand of charging locations in city centres, are at the core of the investigation conducted in the framework of this thesis.

1.2 Problem definition

1.2.1 Spatial implications of Electric Vehicles within city centres: an in-depth analysis

Earlier studies in the field of electric mobility networks have only partially addressed the spatial implications of a recharging network sufficient for sustaining a partially or full-electric fleet at the urban scale. In the context of this research, the notion of a 'spatial implication' represents the changes of and adaptation in the urban environment in which the development of EVs recharging network takes place.

A research conducted by de Gennaro et al. (2015) on the city of Modena generated a model that provided the possibility to create a configuration of a recharging network able to provide sufficient charging possibilities in the research area.. This model was based on the driving patterns of drivers using conventional fuel vehicles, and provided a method to calculate which part of local trips could be replaced by BEV's. Furthermore, the study delivered a grid of ideal charging locations and enabled to calculate the change in energy demand that this shift from fossil- to electric-fuelled vehicles would have created in the examined area. A very interesting statement in the study reads as: "*([*The model] *results in a fully developed infrastructure accounting for a number of charging spots three-to-six times higher than the number of circulating electric vehicles"* (Gennaro, 2015). This research, however, did not address the spatial implications of this development for the city of Modena; furthermore, it assumed that the charging demand would consist of Full Electric Vehicles (another definition of the BEV), where reality shows that the largest share of electrified vehicles is a Plug-In Hybrid Electric Vehicle.

A study conducted in Germany by Gnann et al. (2015) showed that the best option for the German mobility situation would be to steer towards private charging points at home and the working place, with subsidized charging points as an additional form of investment in the future of the BEV market. Their research aimed at investigating whether the charging infrastructure should have been constructed first, as form of market-incentive, or whether the electric car market itself should have expanded first in order to prime the creation of charging infrastructure. The researchers concluded that the BEV market can only expand by promoting a combination of domestic and public charging spots development. One charging point at the most common parking spot is sufficient for a large number of users; the second best option is charging at the work place, as this would increase the adoption of the BEV. Lastly, the researchers concluded that a public charging point can only be a viable option if it is subsidized. However, the research did not address the situation of a city centre with scarce private charging options, and the necessity to use a public charging point because of this scarcity (Gnann, 2015).

A research done by Chen et al. (2013) concluded that "the *best way to promote a BEV success is to simplify the logistics while away from home. Thoughtful siting of public charging points can ease consumer range anxiety while offering a lower cost approach to integrating EV's into the transportation market (versus investing in longer-range batteries* (Chen, 2013). The research provided a behavioural model to predict where and when vehicles would be parked. The study refers to the parking demand as a proxy to predict where charging points would be most necessary. It uses land use attributes as well, and trip characteristics: "*Optimal station locations are determined as a function of parking demand and access (walking distance/costs)"* (Chen, 2013). This indicates the positive effect of a sufficient charging network on the adaptation to FEVs. However, the research was conducted in the United States of America and cannot answer the questions that the Dutch parking infrastructure offers when challenged by a growing charging demand with a following growing spatial implication.

Chen et al. (2013) mention, among others, a research conducted in Lisbon by Frade et al. (2011) that produced a projection for the amount of necessary charging locations by combining the day and night-time demand for the recharging of electric vehicles. This research focused on defining the optimum locations of charging stations in a neighbourhood in Lisbon called 'Avenidas Novas'. (Frade, 2011) The spatial implications when installing the necessary number of charging locations remained undescribed in this research.

To conclude, a cursory review of the available literature reveals that research on charging networks for electric vehicles is mostly focused on determining electric vehicles charging supply, and demand. The spatial implications of the desired networks has received little to no attention, especially in an urban setting where numerous spatial views and interests conflict, i.e. an ancient city centre. This thesis adds to the existing scientific literature by exploring the spatial implications of charging locations in urban settings with multiple and (possible) conflicting spatial implications.

1.2.2 Problem statement

One of the main problems examined by this thesis is related to the current spatial policies as promoted by the city council of Utrecht. The construction of charging locations is currently managed in terms of 'replacement', which consists of the construction of a public charging location based on the conversion of a regular parking space. Such conversion results in a restricted parking location, which is only accessible to EVs users, during the time of charging. Creating such hybrid 'parking-charging' locations where before there were standard parking spots reduces the availability of regular parking space. (AgentschapNL, 2015)

Reducing such publicly available parking space within the Binnenstad is, one of the objectives mentioned in "*Utrecht Aantrekkelijk en Bereikbaar*" (Gemeente Utrecht, 2012). At the same time, the objectives of promoting electric mobility as well improving the spatial quality of the city centre are central to the ambitions of the city, and are represented by a number of measures aimed in that direction. The evident paradox is that the promotion of electric mobility will imply a growing demand for parking-charging spots, while the ambition of reducing parking space in the city centre will constitute a dis-incentive for shifting towards EVs; unless, of course, the promotion of EVs from the side of the city is accompanied by a consistent charging locations and parking policy which could satisfy a growing demand which – with the demand for charging networks- would result in an even further reduction of parking spaces.

Growth of the EVs-market would have more consequences than merely affecting the demand for charging locations. Objectives in '*Utrecht Aantrekkelijk en Bereikbaar'* (Gemeente Utrecht, 2012) include further measures aimed at increasing spatial quality in the city centre. One of these measures is to reduce the presence of (polluting and fossil-fuel) vehicles and increase the presence of non-polluting electric vehicles. Shifting towards electric mobility in the city centre would decrease the direct GHG emissions in the city centre, but would not reduce the presence of vehicles if the EVs-market grows as predicted. EVs would merely replace the presence of fossil-fuel vehicles, thereby retaining the spatial implications of vehicles in the Binnenstad. With the addition of the desired parking and charging locations, the apparent conflicting natures of desires within the mobility vision forms the main critical point of this thesis, and will be investigated by providing the necessary insights mentioned above.

1.3 Research methodology

1.3.1 Research questions

The following main research question is used to structure this research and to formulate, in a succinct form, the problem statement reported above:

"How does the growing market of electrically powered vehicles (EVs), and the relevant charging network, influence the overall availability of parking spaces in Binnenstad district of Utrecht?"

This main research question is is subdivided in the following sub-questions:

1. *What is the "status-quo" regarding parking both non-electric and electric vehicles in the Binnenstad district?*
2. *What is the current demand for an electric vehicles charging network in the Binnenstad district?*
3. *How does the expanding EVs-market affect the demand for electric vehicle charging networks?*
4. *Which consequences does an expanding EVs-market have for the availability of parking space in the Binnenstad district?*
5. *How does the growing EVs-market affect the mobility and spatial visions for the district Binnenstad?*

1.3.2 Methods of investigation

The objective of answering the sub-questions and, thus the main research question will be achieved by using a combination of research methods, described in the following.

Literature review: Establishing the status-quo on EVs, charging and parking

Research sub-question 1 is answered by a review of relevant literature. A thorough analysis of electric vehicle configurations, charging network configurations, EVs-market mechanisms, parking legislation and mobility visions will be subject to research and inventory. For this, the city of Utrecht's legislation on parking and visions on mobility will be investigated. Configuration of vehicles and the corresponding charging network will be researched from academic sources. The government of the Netherlands provides resources on stimulation methods for adaptation to electric mobility, and the current adaptation in 2015. This review will provide an overview of current legislation for parking and its future developments within mobility visions, which provides the "status-quo" with regards to legislation. Studying the configurations of vehicles, the vehicle sales constructions and charging network delivers an insight in the adaptation to electric mobility, the desires and the needs of EV users and the perception of this mobility choice by the city of Utrecht.

Calculation: The future development on charging demand and EVs-market share

Current demand for charging networks can be derived from literature, whereas the expectations for future charging networks demand will require a method able to create a demand projection. For this demand projection, the research by Frade et al. from 2011 will be adapted to the situation of the Binnenstad. The main topic of this research was the Avenidas Nova neighbourhood of Lisbon, which shows multiple similarities to the district Binnenstad.

Although the research itself does not take into account which spatial changes these charging locations could imply, it comes closer to the reality of the old city centre of Utrecht, as it uses existing parking spots as a reference point. This study is therefore a primary reference for the research that will be conducted to examine the case of Utrecht's city centre.

Calculating the demand projection will be performed for the year 2015, 2020 and 2025, as these years have a target for EV adaptation for the Rijksdienst voor Ondernemend Nederland. (Rijksdient voor Ondernemend Nederland, 2015) Furthermore, by calculating the demand projection for 2015 this method provides a possibility to check if supply of public charging points meets the demand in 2015, thereby adding to the status-quo investigated in the literature review. The future demand projection provides insight in the future demand and corresponding spatial implication. Necessary data as required by the model of Frade et. al. is available from trustworthy governmental and market party sources, such as the Central Bureau for Statistics (CBS), Kadaster, City of Utrecht, BOVAG and other parties.

Comparison: Analysis of spatial planning goals, EV developments and conflict of interests

Investigating the effect of a growing EVs-market share on the Binnenstad Utrecht asks for a comparison of figures, policies and projection. Comparison of the current supply of electric charging networks supplied by the literature review with the demand projection for 2015 provided by the demand projection can determine if the current supply is sufficient. Results of the future demand projection expressed in desired charging locations are compared to the expected available supply of regular parking spaces to determine the impact (reduction) caused by the development of the EVs-market. Impact and effect of this development can be compared to the mobility vision for the district Binnenstad, to determine if the projected parking space developments align with the desired development of the district as expressed in the mobility vision, and if not, what the consequences can be. The combination of these methods provides sufficient data and resources to answer the research sub-questions, and by that, enable the author to sufficiently answer the main research question. Findings from all methods are combined to create a short but indicative policy advice for the city of Utrecht, to provide awareness and advice on the effectiveness of the chosen policies.

1.3.3 Research objectives

The aim of this thesis is to conduct a case-study on the spatial implications of a public electric-car charging networks in a representative Dutch city centre. With the growth of the EVs market share comes a growth in demand for charging networks. In a situation where public space is limited by multiple factors, the effect of a growing charging network could extend further than solely constructing sufficient charging points. One of these multiple factors, in the specific case of the city chosen for conducting this research, is the tension between the ambition of achieving a car traffic-free city centre, and the ambition of shifting towards electric mobility as alternative to fossil-fuelled mobility; an ambition for whose achievement the availability of public charging locations, and parking areas, are crucial factors of success. The case chosen consists of the district Binnenstad of the city of Utrecht

This thesis will use a combination of methods to analyse the current and future situation for electric-car charging networks. The network under consideration will be the future network, in the city centre, that could sustain the projected higher share of EVs in 2020 and 2025, as expected by the Rijksdienst voor Ondernemend Nederland (2015)The research will assess the impact of this future situation on the public parking facilities in the 'Binnenstad' district and will discuss its relation with spatial policies of the city of Utrecht. With this analysis, the author aims to create a policy analysis for the Utrecht city council regarding the electric-car charging network. Key focus in this advice will be the current and future supply and demand situation with regards to the charging network and the implications of eventual changes in supply and demand on the public parking locations and spatial policies in the city centre.

Research on this subject is not just beneficial from a scientific point of view, but serves a societal purpose as well. Electric vehicle users are a very specific group of users on the road and in the public space, as the GHG emissions and other side-effects of cars are absent, but have specific needs for recharging their vehicle. By investigating the impact of this group of users on the public space, the implications for the all users of the public space in the Binnenstad will become clear. With an accurate representation of these implications, cities and their citizens have an instrument to implement these networks in the public space in a sustainable and acceptable manner. The focus of the recommendations of this research will be on current and future charging supply and demand with regards to:

1. Charging networks
2. Implications for supply and demand of public parking locations
3. Repercussions of these developments on the current spatial planning objectives, aimed at the next 10 years of development in the city centre.

The first part will deliver an overview of the status quo by providing the following insights:
First, for a complete and correct overview, it is essential to investigate the current options for -and consequences of- electric mobility, the mechanisms that form the current situation and the corresponding charging network configurations. Furthermore, an assessment of the current possibilities and legislation for parking vehicles and the current facilities to charge electric vehicles within the research area will complete the overview.

The second part of the research aims to calculate a projection for charging demand in the current situation and a projection that takes the eventual growth in EV market share into account. The projection of charging demand can be related to the spatial implication of a charging location, creating a projection of the current and future spatial implication by charging locations. The analysis of the relevant data will be conducted with the research by Frade et. al in 2011, in Avenida Novas. Frade et. al (2011) chose a research area with many similarities to the Binnenstad district of Utrecht, enabling this research to calculate the relation between the growing fleet and the need for charging locations in the district of 'Binnenstad'. Simplified, it will be able (with the necessary adaptation) to calculate the demand for charging locations in the 'Binnenstad' in future scenarios.

The third part of this research is a combination of part 1 and 2, as described above. Assessing the 'status quo' and calculating the current and future demand for charging locations provides two overviews of the 'Binnenstad' in relation to the growing EVs-market: one of the current situation and one of the eventual future situations. These two images are now compared to see the effects of a growing electric fleet on the parking location availability in the 'Binnenstad', and the impact on mid-term spatial planning objectives in the city of Utrecht. An image of demand in the 'Binnenstad' will be constructed for the future and the current situation and a comparison of these will be discussed to produce an advice on the different perspectives of this topic.

1.3.4 Introduction of the research area

Focusing on the spatial implications of charging networks in a situation where public space is limited, the research area of this research is a Utrecht, a Dutch city with an ancient city centre that has numerous spatial interests.

Founded as the Roman outpost 'Traiectum' in 40 AD, the city of Utrecht grew during the following centuries as a religious and economic node, with many churches, monasteries and harbours. Between 1600 and 2000, the city of Utrecht took a central role in the Netherlands. With the ancient city centre, known as the Binnenstad, it forms a tourist attraction that offers numerous historic artefacts and buildings. The city centre offers shopping and recreation possibilities for residents and tourists, with the ancient canals and medieval streets as a valued décor. The layout has remained largely similar during the centuries, resulting in on-street parking of vehicles and limited accessibility by car. On a national level, the city of Utrecht houses an internationally renowned university (Utrecht University and University College Utrecht) and is home to many national and international companies, due to the central position of the city within the Netherlands. Location of the city has also created the role of being a national node, with multiple highways crossing around the city, and the national centre for railway traffic. (Regiocanons, 2015)

These national and local economic and touristic values result in large public and private traffic flows around and in the city on a daily bases, for either professional or private purposes. The Binnenstad district houses the historically valuable locations, the touristic and recreational facilities and a business district. To limit the spatial implications of the mentioned daily traffic flows, especially within the Binnenstad district, the city of Utrecht constructed the mobility vision *'Utrecht Aantrekkelijk en Bereikbaar'*, aimed at streamlining the spatial implications within the city and the city centre. (Gemeente Utrecht, 2012) Main focus points of the mobility vision consist of the promotion of 'spatial quality', in which the validity of claims on the public space are compared to the desired character of the location. According to the mobility vision, the mobility choice per location should be adapted to the desired spatial quality level, resulting in specific measures per city district. District Binnenstad is categorized as a location that should have a high spatial quality, thus reduce automobile traffic and on-street vehicle parking, promoting electric vehicles and improving public transport. (Gemeente Utrecht, 2012)

Current implementations of this policy can already be found in the limitation of on street parking by permit-based and price-based restrictions, which intensify for locations closer to or in the city centre. The city of Utrecht also aims to promote the use of 'clean mobility', which aims to promote bicycle and public transport use. If these mobility choices are not sufficient, the Action Plan Clean Mobility" states that, "*if there is no other option, the best option is electric"* (Rijksdienst voor Ondernemend Nederland, 2011)

Chapter 2

Electric vehicles in the Netherlands: a review of concepts, trends and parking legislation.

Electric vehicles are the main subject and driving force for this research, which forces this research to elaborate on the aspects of this mobility choice. This chapter is divided in three parts with specific aspects of electric mobility and possible spatial implications. Electric vehicles are discussed by explaining motivations for creation, current configurations and market mechanisms. Networks and installations necessary for recharging these vehicles are discussed in the second part of this chapter, after which this chapter concludes with discussing the policy and legislation on vehicle parking in the Netherlands for regular and electric vehicles.

2.1 Electric vehicles: Creation, configurations and market position

2.1.1 Creation and upcoming

The world in current day and age chooses fossil energy sources to power processes, transport, homes and numerous other facilities, as mentioned in the research proposal,. Fuels derived from oil power 90% of the transport sector that alone forms 14% of the global GHG emissions output. (Engbue, 2012) (Van Vliet, 2010) In most western countries the car is the prevalent means of transport for local mobility. However, the use of fuels derived from finite/fossil resources is becoming increasingly problematic due to higher costs of production, uncertainty of resources and GHG emissions with other air pollutants are creating a public awareness. In 2009, Pierre et al. predicted that these two trends, individual mobility and a reduction of the negative side effects in fossil fuel usage, would result in energy efficient vehicles being offered by the automobile production sector.

Electric Vehicles (hereafter EV) can form a viable and short-term answer to the question of reducing the emissions in the transport sector. EV's are capable of offering comparable mobility, while significantly reducing the direct and indirect emissions. (Engbue, 2012) Introduction of EV's in the U.S. market could have a significant effect in reducing these emissions. (National Resources Defence Council, 2007). Government initiatives around the world indicate the state of mind with regards to electric mobility. In the U.S., the federal government allocated over $2 billion dollars to stimulate the production of electric vehicles and the development of battery technology National Resources Defence Council. (2007). In Europe, owners and drivers of EV's are rewarded with an array of stimuli to stimulate the adoption of this new personal mobility solution. These stimuli vary from direct subsidies to tax reductions, depending on the state and form of ownership. (Rijksdient voor Ondernemend Nederland, 2015) (ANWB, 2015)

2.1.2 Distinguishing vehicle configurations

Automobile manufacturers have responded to these stimulating initiatives by creating an expanding supply of electric, semi-electric and electrically assisted vehicles. This array of electrically assisted, full electric or plug in electric vehicles is still expanding in forms, technology and typology. To create clarity in this landscape of typology, commercial slogans and promises, this research uses the distinction between (electric) vehicles as created by Egbue et al., 2012 to categorize the vehicles available on the global market.

Vehicle type	**Description**
Conventional vehicle (CV)	Operates with an internal combustion engine (ICE), highly inefficient
Alternative Fuel Vehicle (AFV)	Operate on at least one alternative to petroleum and diesel. Contains Fuel Cell Vehicles (FCV), Compressed natural gas, bio-fuel/bio-diesel, hydrogen, etc.
Electric Vehicle (EV)	Operate fully or partially on electric power, in varying configurations

Table 1: Categorization of vehicles by power source (Engbue, 2012)

2.1.3 Electric vehicle configurations

The electric vehicle (EV) as described in table 2 has multiple configurations, which will be further specified in this chapter. Furthermore, a market example of each configuration will be given for further reference.

Vehicle type	Description	Positive / Negative aspects
Hybrid Electric Vehicle (HEV)	ICE powered, with assistance from electric motor. Collects electric energy from regenerating wasted ICE energy.	+ Improves ICE efficiency - Relies on fossil fuels - Cannot drive fully electric
Plug-in Hybrid Electric Vehicle (PHEV)	Comparable with HEV setup, or ICE present as range extender. Both varieties can recharge the battery pack via an external source. Can drive in full electric mode	+ Can drive fully electric + Higher acceptation due to extended range - Uses fossil fuels as range extender - Certain configurations aimed for economic benefits, with low reducing impact on GHG emissions
Battery-powered Electric Vehicle (BEV) or Full Electric Vehicle (FEV)	Full electric driveline, powered by on-board batteries. Recharges from external source, no ICE.	+ Full electric propulsion + No direct emissions - Limited range

Table 2: Distinction of Electric Vehicle configurations (Engbue, 2012)

Hybrid Electric Vehicle (HEV)

The Hybrid Electric Vehicle (HEV) utilizes the Internal Combustion Engine (ICE) of a Conventional Vehicle (CV), which is paired to an electric motor to improve efficiency of the drivetrain. This vehicle uses oil-derived fossil fuels as the main power source power source. The electric part of the drivetrain collects wasted energy (braking energy, heat, transmission energy) by storing it as electric energy in on board batteries. The stored electric energy is used by the on board electric motor (often during acceleration) to assist the ICE, which decreases fuel consumption and therefor, emissions. Internal batteries of the HEV cannot be charged with external charging networks, the vehicle will always rely on a form of regular fossil fuels. Examples of this vehicle are the original Toyota Prius and the Honda Civic Hybrid.

Plug-in Hybrid Electric Vehicle (PHEV)

A Plug-in Hybrid Electric Vehicle (PHEV) was originally specified as the following: "*The Plug-in Hybrid Electric Vehicle (PHEV) has a smaller internal combustion engine than the HEV and has a larger battery capable of powering the vehicle for distances between 20 and 60 miles*" (35 to 90 km) (Engbue, 2012). The market in 2015 has stretched this definition, shown by the introduction of PHEVs in varying specifications. New configurations have divided the PHEV market in two groups, distinguished by the setup and role of the electric drivetrain.

The first category is a PHEV with an HEV setup. These PHEVs are vehicles powered by an ICE, assisted by an electric motor that draws energy from the internal battery package. The difference between an HEV and a PHEV is the added term “Plug-in”. The PHEV offers the possibility to charge the battery pack from an external source, as well as recharging from energy wasted by the ICE. Furthermore, a PHEV offers a Full-Electric mode, in which the electric motor is used as the main propulsion source and the ICE remains switched off. This Full-Electric range varies between 30 and 100 km, after which the ICE re-takes the role of main propulsion source. The main criterion to be specified as this category is the layout of the drivetrain. The electric motor assists the drivetrain and can take the role of main propulsion source, but there is still a fixed connection between the ICE and the powered wheels. The market has created varying concepts, where the ICE is often not restricted to a small and economic setup. Examples of these new concepts are the Mitsubishi Outlander PHEV, the Volvo V60 Hybrid, the Volvo XC90 hybrid, the Volkswagen Golf GTE and the Toyota Prius Hybrid Plug-in. These models combine a powerful and not necessarily efficient ICE with a relatively small electric drivetrain. This setup provides the owner with varying financial benefits, as the vehicles meets demands set by governments for electric and semi-electric vehicles. However, due to their large ICEs, this category of PHEV has been criticized, as the emissions output in real life use is barely reduced in comparison to CVs. (ANWB, 2015)

The second category PHEV is a vehicle with a BEV setup, with the addition of an internal ICE that is able to extend the range of the vehicle. The difference between the before mentioned specification and this category is quite simple. A PHEV of this category has a full electric drivetrain, which operates from an internal battery. This internal battery is charged via an electric car charging point. As an addition to the electric drivetrain, the vehicle has a small ICE. If the internal battery is depleted beyond a certain threshold, the ICE will function as a ‘range extender’. The ICE will function as a generator for the electric drive train, which improves the range of the vehicle, but the ICE cannot recharge the battery. Recharging will still have to be done at a charging location. This category of PHEV is closer related to a BEV concept, as the drivetrain remains completely electric, even with the range extender in use. Due to the nature of the electric drivetrain with less moving parts, the drivetrain offers a higher energy-efficiency in comparison with the first mentioned PHEV configuration. (BOVAG, 2015)Examples of this concept are the BMW i3 ReX (Range Extender) and the Opel Ampera/Chevrolet Volt.

Battery powered Electric Vehicle (BEV) or Full Electric Vehicle (FEV)

The battery-powered electric vehicle, or BEV, forms the final category. Vehicles in this category operate solely on internal battery power. The drivetrain, in this case the battery and the electric motor, have no direct harmful emissions. The battery is charged on a charging location, where the origin of the electric power defines the indirect emission of GHG and other pollutants. Battery technology is advancing, but the range of BEVs is still limited, depending on the choice of vehicle. Car manufacturers have chosen two general approaches to the production of BEVs. The first option is ‘retro-fitting’ an electric drivetrain in an existing regular ICE-powered vehicle. The vehicle is functioning as a full-electric vehicle, but generally gains weight in comparison to the ICE powered version. Examples of this approach are the Ford C-Max Electric, the Mercedes-Benz B-Class Electric and the Volkswagen E-Up!. The second approach is a full-electric design from start to production. Examples of these vehicles are the Renault Zoe, the Tesla Model S (in varying specifications) and the Nissan Leaf.

This overview offers a factual distinction between the available options for electric or electrified vehicles. To determine the future presence of different types of vehicles this research needs a detailed insight in the presence of different configurations in the Dutch vehicle fleet. To add to this, an overview of the motivations to choose an electric vehicle is introduced, to provide further insight in the mechanisms behind vehicle choice, and with that, adaptation to electric mobility.

2.1.4 Market position and market mechanisms of the EV on the Dutch car market.

The Dutch vehicle fleet consists of roughly 8 million passenger vehicles. Of these 8 million vehicles, 9.368 vehicles were registered as FEV and 78.163 as PHEV on December 31st 2015. (Rijksdient voor Ondernemend Nederland, 2015). A remarkable aspect of these figures is the difference in numbers between BEV and PHEV, with 90% vs 10% share in the EVs-market total. The Dutch vehicle market is influenced by multiple factors, of which the tax-rules regarding the personal use of company vehicles are a substantial driving force. (ANWB, 2015)

An employed person is allowed to use a company vehicle for personal use, under the condition that a tax is payed related to the value of this vehicle. This system - better known under the name '*Bijtelling'* - is one of the big stimuli in the vehicle leasing market. *Bijtelling* is a tax form consisting of a percentage company vehicles value that is added to the taxable income, if the vehicle is used outside worktime for personal purposes. A company vehicle used personally is seen by the Dutch government as additional income, and is considered taxable. The addition of the value of the vehicle creates a higher tax payment for the user, indirectly taxing the user for the use of the vehicle. *Bijtelling* percentages up to December 31st 2015 consisted of 5 classes, 0%, 7%, 14%, 20% and 25%. Vehicles received a percentage depending on GHG emission figures according to the commonly used NEDC test, where a 'cleaner' rating was rewarded with a lower percentage. (ANWB, 2015) As PHEVs were able to undergo this NEDC test mostly with the electric drivetrain, the NEDC rating granted the vehicles a very clean rating. This translated to a *bijtelling* percentage of 7% for most PHEVs on the Dutch market.

Fiscal benefits of EVs translated to high sales for PHEVs and the introduction of many 'plug-in' models, varying from large SUVs with a small electric motor to small hatchbacks with a completely electric drivetrain and a range extender, as the law saw both configurations as electric vehicles. The FEVs available on the Dutch market had an even lower *bijtelling* percentage, 0%, but were not as popular due to their limited range, with one exception. The Tesla Model S, a high-end FEV with a base-price in the €100.000 range offered a substantial range (+/- 350 km) and still offered the 0% bijtelling. Benefits from other subsidies (*investeringsaftrek* created 'electrification' in the high-end company car market. (ANWB, 2015)

Due to the low taxation and large driving range, PHEVs in 2015 form the largest part of the EV fleet in the Netherlands. FEVs form a smaller share, as their ranges are still limited. The start of 2016 introduced new *bijtelling* percentages, which –in comparison to the FEV- raise the tax percentage on PHEVs. Heavier taxation of PHEVs is expected to shift the preference more, not universally, to the available FEV configurations. (BOVAG, 2015) (Rijksdient voor Ondernemend Nederland, 2015) Not all vehicles with an electric drivetrain are company owned vehicles, but the private owners market for FEVs is still a pioneers market, where high initial investments for the vehicle and a limited driving range form common objections. The number of PHEVs in personal possession is also limited, as the investment for these vehicles is high compared to the regular configurations of these vehicles. As an example, a regular CV diesel Mitsubishi Outlander is priced at €34.990,-, where the PHEV configuration of this vehicle in comparable trim is priced at €43.000,-. The difference between the two (€8000,-) was compensated up to the end of 2015 with road tax exemptions for PHEVs, until the Dutch government decided to stop these reductions for PHEVs as of January 1st, 2016, which makes the PHEV version of a regular vehicle less attractive. (ANWB, 2015)

In short, the Dutch vehicle market consists of +/- 90.000 electric vehicles, of which 10% is fully electric, and 90% is a PHEV configuration. The main driving force is the company vehicle used for private use, and the taxation of this construction. The future market share of these vehicles is unknown, new taxation rules do however aim towards a shift from PHEV to FEV, which would increase the dependency on charging networks - the additional CV is not present in a FEV configuration - and if PHEVs need to perform in the most economic and emission reducing manner, a sufficient charging network is a main priority. Even further dependency on charging networks for FEVs could be a motivation to provide sufficient charging networks for now, but even more so in the near future.

As the technical and financial side of the vehicles have been explained, the factors that make EVs differ from normal vehicles, refilling or recharging of these vehicles is next on the agenda. As mentioned, a system that relies on decentralized charging locations that appear in multiple configurations and standards, on a diverse spectrum of locations.

2.2 Recharging of EVs: Methods, configurations and distribution.

Electric vehicles – either FEV or PHEV- differ from conventional vehicles on a number of levels, with a prominent role for the recharging process. CVs can be recharged/refuelled at a distribution point of fossil fuels, or gas stations. These distribution points are centralized, and widely spread across the country. Due to the hazardous characteristics of the medium, distribution points are located in dedicated areas and residential refuelling is deemed unsafe on a large scale. Recharging possibilities are available at all times of the day - offering a full recharge within 3 to 5 minutes- and can reinstate the full driving range of the vehicle. Owners and users of an EV have different patterns of recharging. First, the vehicle uses a method of energy storage -the on-board battery package- that is less volatile. For recharging, EVs rely on a different network, the commonly available electricity grid. The distribution chain is decentralized, as vehicles can be charged at home and at charging locations, which can be located in all types of residential and business districts, either accessible to the public or restricted to private users.

A common public recharging situation for EVs in the Netherlands starts with the arrival of an EV at a charging location. The EV user connects the vehicle to a charging station with a charging cable to transfer energy from the charging point to the vehicles battery package. An authorization of charging is handled with card systems, which recognizes the authorized user and validates the charging process. Private charging points will function in a comparable way, often without the interference of a card system, as these are located on private property. Charging locations can be found in varying configurations and configurations, with different demands towards the vehicle and the network, therefor this chapter will elaborate on the recharging options for BEVs and PHEVs, their accessibility with regards to EV configuration and the current availability and presence of these recharging options.

2.2.1 Key concepts in an electric vehicle charging network

Recharging of electric vehicles has two main configurations, which are distinguished by charging speed and the configuration of the charging network between the power source and the vehicle. As Hatton et al. stated in 2009, “An important distinction must be made between ‘chargers’ and ‘charging stations’, as the two terms cannot be used interchangeably”. A charger is a device that optimizes incoming current from an external power supply, to create the optimal algorithm to recharge the on board battery. This charger is used for slow charging, with lower voltages and currents, and is often located within the vehicle. (Hatton, 2009). All public electricity networks worldwide provide AC (Alternating Current), which is converted to DC (Direct Current) by the charger. A charging station serves a different purpose for an EV with regards to charging time. The charging station reduces charging time, by increasing the flow of current from the power source (Hatton, 2009). A larger charger is needed for this process, which cannot be located within the vehicle. A charging station can best be described as a charger that is located in an external construction, and feeds optimized AC current to the vehicles battery. The internal charger of the vehicle is the limitation in this configuration. The rapid-charging station is the final category, which has similarities to a normal charging station. A difference is found in the distribution of current, a rapid-charging station directly provides the internal battery with DC current. The internal charger of the EV is not used, and does not form a limitation to charging speed. Not all battery packs are able to handle the rapid-charging configuration. (Oplaadpalen.nl, 2015)

From this point onwards a number of typologies and configurations will be explained, using the following terms.

- **Charging station**: a power source that is able to charge a vehicle with optimized current and capacity by using AC current and the vehicles on-board charger.
- **Charger:** explained by Hatton et al. (2009), the on-board current conversion device that is used for charging an EV.
- **Charging location:** a location that provides a parking space, with a charging station dedicated for charging electric vehicles.
- **Fast-charging location:** location that provides a parking space, with a fast-charging station. This location provides fast-charging station that is able to recharge the vehicles battery at a faster pace.

2.2.2 Available charging network configurations

This research is focused on the city centre of Utrecht, located in the Netherlands. A full overview of all charging options within the Netherlands is essential to create a full insight of the demand and supply for charging FEVs and PHEVs. Note, this overview consists of charging options available to the general public of FEV and PHEV users. As charging technology is still a growing sector, developments shall be mentioned, but will not be used in this general overview.

The overview will be categorized by power source (i.e. residential network, public, etc.), charging standard, accessibility and accepted categories of EVs. The categories used are the industry standards, named 'Mode 1' to 'Mode 4', which comply with ICE 61851 (Siemens, 2015) Furthermore, a short overview table will be supplied.

Mode 1: Domestic electricity network
Mode 1 is characterized by its simple layout and absence of chargers. The vehicle is parked for charging, and the battery pack is connected to the 230V AC residential electricity network. This configuration uses a basic charger, without a limiter or harmonizing element, allowing over-charging and other undesirable effects. The EV producing industry abandoned this method, as it forms a fire-hazard and is illegal in numerous countries. (Siemens, 2015) (Oplaadpalen.nl, 2015)

Mode 2: Limited charging
Mode 2 or 'Limited charging' uses a network that is comparable to Mode 1 charging. The vehicle is connected to the same residential 230V residential electricity network, but is safer in comparison to mode 1 due to an added safety feature. An inline module monitors charging, by harmonizing the 230V AC current for optimal use by the on-board charger. Furthermore, it ends the charging cycle when the vehicle is fully charged, to avoid the fire hazard mentioned in Mode 1. The power source in this case can be a single-phase (230V AC) or three-phase (400V) outlet, depending on the charging cable. Theoretically speaking, this connection could provide a current of 2A to 32A, however, the real-life charging speed often does not exceed 10A. As the current of 10A on a 230V network offers a charging capacity of 2.3kWh, recharging times for a 25kW battery (Nissan Leaf) will reach up to 11 hours. This method can be used for recharging all EV and PHEV categories available on the Dutch Market, under the condition that a Mode 2 cable is supplied with the vehicle. (Oplaadpalen.nl, 2015) (Siemens, 2015)

Mode 3: Controlled charging
Controlled charging is, as the name states, a charging cycle that is controlled on all levels. A charging point consists of an external charger - placed between the vehicle and the power source- which is able to communicate with the vehicles on-board charger. If the vehicle is connected to the charging station, the on-board converter will exchange information with the charging station. This information consists of the ideal current for charging the specific vehicle and acknowledges if the vehicle can handle single-phase or three-phase charging.

The external charger will only provide power if all this information is received, to ensure optimal and safe charging conditions. If all information is received, the external charger will provide a single-phase 230V AC or three-phase 400V connection, which is converted by the on-board charger to DC current. This method allows charging with higher speeds, and can be found in public charging locations. Domestic versions of this technology do exist, but require extra safety constructions within the residence to provide three-phase current. Mode 3 charging offers two options for charging – Level 1 and Level 2 – that are characterized by the single- or three-phase power supply. Level 1 charging provides charging with 4,1 kWh, where level 2 can provide 11 to 44 kWh charging speeds. Charging speed is often limited, again, by the on-board charger, but examples of vehicles with faster on-board chargers are appearing on the market, which are able to handle the higher Level 2 charging speeds. Mode 3 level 1 and 2 charging is the common standard for the Dutch EV market. Nearly all configurations of EV and PHEV are able to charge on mode 3 charging locations, making the Mode 3 the most common charging layout. (Oplaadpalen.nl, 2015) (Rijksdienst voor Ondernemend Nederland, 2011) (Siemens, 2015)

Mode 4: Rapid-charging
The fourth category defines itself by a different configuration than Mode 1, 2 and 3. First, the charging layout relocates all chargers and optimizers to the charging station, which eliminates the on-board charger restrictions. Second, as the on-board charger does not take part in the charging process, the charging stations directly chargers the battery pack, allowing for higher charging speeds. Charging stations in the Mode 4 category harmonize and convert the AC network standard to a direct supply of DC. This layout offers dramatically higher charging speeds, reaching to 100 kWh. The only vehicle capable of charging with this configuration is the Tesla Model S -only by using the dedicated Tesla Superchargers- that is free to use for Tesla owners and provided by the manufacturer as a customer complementary service. (Oplaadpalen.nl, 2015)

Charging stations manufacturers are developing other fast-charging configurations, but these configurations do not directly charge the battery. The lay-out is still the same as mode 3 level 2 charging, but charging stations offer a higher charging capacity. This higher charging speed can be used by EVs with compatible high capacity on-board chargers. Mode 4 charging is inaccessible to PHEV-users, as the configuration of the vehicles is not able to process these charging speeds. (Siemens, 2015)

2.2.3. Configuration, layout and distribution of charging locations in the Netherlands

The common charging standard in the Netherlands is Mode 3, or controlled charging, as mentioned in the overview of charging locations. Most public and private charging locations use this technology with varying charging capacity. In general, public charging locations offer level 1 and level 2 charging speeds, automatically defined by the vehicle being connected. Private charging locations often operate at level 1, but can charge at level 2 with alterations to the private electricity network. Mode 2 charging is considered an emergency solution, and relies on the correct in-line charging module cable. Mode 4 is only accessible for Tesla Model S users on the Tesla superchargers, or the compatible EVs for AC-fast charging. (Oplaadpalen.nl, 2015)

A charging station is often combined with a dedicated parking location, to create universal access to charging stations. On October 31st, the 'Rijksdienst voor Ondernemend Nederland' announced the figures on development of the electric vehicle fleet and the public charging network. The report states that, with the exception of private charging, the Netherlands has 17.104 charging locations. This figure consists of 7.189 24/7 available public charging locations, 9.637 semi-public charging locations and 458 rapid-charging locations. (Rijksdient voor Ondernemend Nederland, 2015). Distribution and location of these public charging locations is currently not registered by the governmental agencies. However, private initiatives like the webpage www.oplaadpalen.nl (started by charging station suppliers, energy companies and users of BEVs and PHEVs) have registered charging locations in the Netherlands. The locations have been visualized on a map, which shows a potential user the location, charging standard and availability in real time.

The map reveals a pattern when studied on a national level. The distribution of public charging locations, in any form or Mode, is skewed towards the western part of the country, the 'Randstad'. Amsterdam, Rotterdam, Utrecht and The Hague form the more densely populated areas of the Netherlands. The map shows that these cities offer 5.412 charging locations. As a comparison, the total amount of charging locations in all other province capitals combined comes to 1.419 charging locations. (Oplaadpalen.nl, 2015) Another pattern can be recognized by comparison of the centres of Utrecht and The Hague. one can see a high density of charging locations in The Hague, where the centre of Utrecht stands out with a low density of charging locations. Now that the common layout and configurations of charging electric vehicles has been clarified, a further exploration of charging locations is necessary. Up to this point, the typology of vehicles has been explained, as is the charging configuration. A charging station is often combined with a parking location, as mentioned in Chapter 2.2.2,. This charging and parking creates a spatial implications, which is regulated in parking policies.

2.3 Parking and charging of (electric) vehicles

Parking regulations, zoning laws and vary per country, state, province and city. This chapter will discuss the origins of parking legislation in the Netherlands, the current situation and the situation in the Utrecht Binnenstad district. The parking of an electric vehicle will also be discussed, to create insight in the rights of a PHEV or BEV in comparison to CVs.

2.3.1 Policy on public parking

The Dutch policy on vehicle parking in the 20th century can roughly be divided in three phases. As van Dijken described in 2002, we can identify the era up to the late 1970s, the era between 1980 and the early 1990s and the era of the early 1990s to 2000.

The era till the late 1970s distinguishes itself by a trend-following character. The local councils aimed to providing as much parking space as demanded, to provide parking facilities on all locations, when necessary. The growing amount of cars in the 1960s and 1970s presented a problem for inner cities, as the amount of parking spaces interfered with the accessibility of the city centres (Van Dijken, 2002)

The reduced accessibility of the city centres and other public spaces introduced a national policy on parking that aims to reduce car-mobility. One of the main aspects in the policy is a control-aimed parking legislation. The legislation shifted the main focus of parking legislation from demand-based parking policies towards improving the functioning of the traffic system within a city. Local and national governments wish to reduce the amount of 'unnecessary' moments of car use by controlling the maximum supply of parking locations. Hourly parking rates were introduced, as well as limits to creating parking spaces in the public area to discourage car users from driving their vehicle in the city centre. Discouraging the car user also expanded to limiting car spaces for companies, by allocating a fixed amount of parking spaces to commercial plots. Municipalities wanted to attract commercial parties, thus offered large parking facilities with commercial plots, undermining the original idea of limiting car use. Parking spaces for residents of densely populated areas were not part of the policy, which can be seen as remarkable. Availability of parking locations in residential areas has an influence on the choice of transport for short distances. (Van Dijken, 2002)

The early 90s mark a change towards parking legislation. As the parking penalty becomes a financial penalty, more and more municipalities improve the legislation and enforcement of this legislation. Municipalities can create financial benefits for themselves with enforcement of the legislation. Furthermore, regulation of the parking demand creates the option of creating parking fees as a control instrument. The parking fees create inequalities with regards to accessibility. Local residents, companies and visitors pay different amounts of parking fees. Residents in densely populated areas or permit-controlled areas have to pay more for a permit than residents in non-regulated areas. The National Traffic and Transport plan 2001-2020 (NVVP) changed this direction. The NVVP changed the perception of the citizen and its mobility choice from a restrictive perception by controlling mobility to a responsibility perception. The choice of mobility should be respected, as long as the user carries the societal costs of his/her choice.

2.3.2 Ambitions and vision documents for Utrecht

As this thesis focuses on the city centre of Utrecht, a detailed insight in the parking policy of the municipality of Utrecht is essential. As mentioned in chapter 2.3.1, councils have the authority to create specific parking legislation within their municipality. Common parking legislation will be clarified, which applies to all CV owners with a desire to park their vehicles in the "centrum" district. The general strategy behind this legislation is explained in the second part of this chapter.

The mobility vision "*Utrecht: Aantrekkelijk en Bereikbaar*" (Utrecht: Attractive and Available), created in 2012, forms the basis for a redevelopment strategy in the city of Utrecht. The main goal, as the title suggests, is to keep Utrecht attractive and accessible. The vision document confirms the economic status of the city of Utrecht and the necessity to create optimal mobility choices for every visitor, resident and user. Visitors to the city centre utilize the excellent public transport facilities to reach their destination, according to the report. A noticeable statement (also for later on in this document) in the document is the following (translated from Dutch). "*For the settlement climate in the city centre, the challenge is to conserve the accessibility by car".*

The main goal of the vision is to create quality in the public space. Quality is defined as a situation where all stakeholders involved in the public space can use and live in the space as they desire. The council has created a scale of quality to create distinction between different situations,. This scale is based on the intensity of pedestrian and bicycle traffic, and the attention to the "spatial quality". (Gemeente Utrecht, 2012) The image below shows the scale, as used in the vision document. The y-axis expresses the attention level necessary for the spatial quality, the x-axis expresses the intensity of pedestrian and bicycle traffic. '*Exclusief*' (exclusive) is a situation comparable to the Binnenstad, where the necessary attention to the level of spatial quality and the intensity of pedestrian and bicycle traffic is very high.

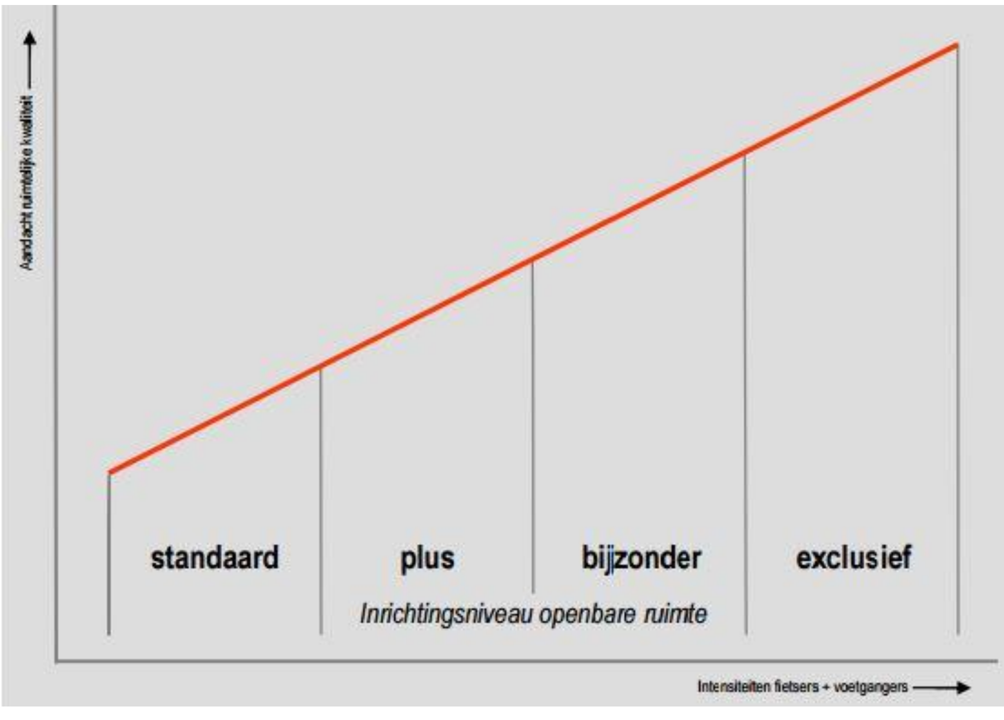

Figure 1: Graph for spatial quality (source: Nota Utrecht Aantrekkelijk en Bereikbaar 2012)

The vision document expresses a clear statement for the city with regards to mobility: "*The place defines the mobility choice*". Areas within the city limits are marked with a category, which defines the desired traffic pattern in the zone. The city centre is marked as zone A, which is defined as a high-quality, high pedestrian and bicycle traffic area. (Gemeente Utrecht, 2012)

The demands set for this category are defined as:

- Only local traffic
- Area for pedestrians and cyclists
- Public transport with reduced speed
- No cars on the streets
- Maximum spatial quality
- Mixture of traffic types (shared space).

The vision document presents a strategy for parking to create this situation. The closer the user comes to the city centre, the more the user will have to pay for parking a vehicle. Next to this negative measure, the council aims to stimulate users to park a vehicle in the areas outside the city centre. Stimuli include parking garages in these areas, which have a dedicated public transport connection to the city centre. Furthermore, the parking policy projected in this document aims to reduce the use of public space for parking vehicles. Next to this policy, the city aims to reduce the amount of on-street parking locations, to shrink the availability of parking locations overall. Solutions include the use of underground and multi-story parking garages, as well as the promotion of electric mobility.

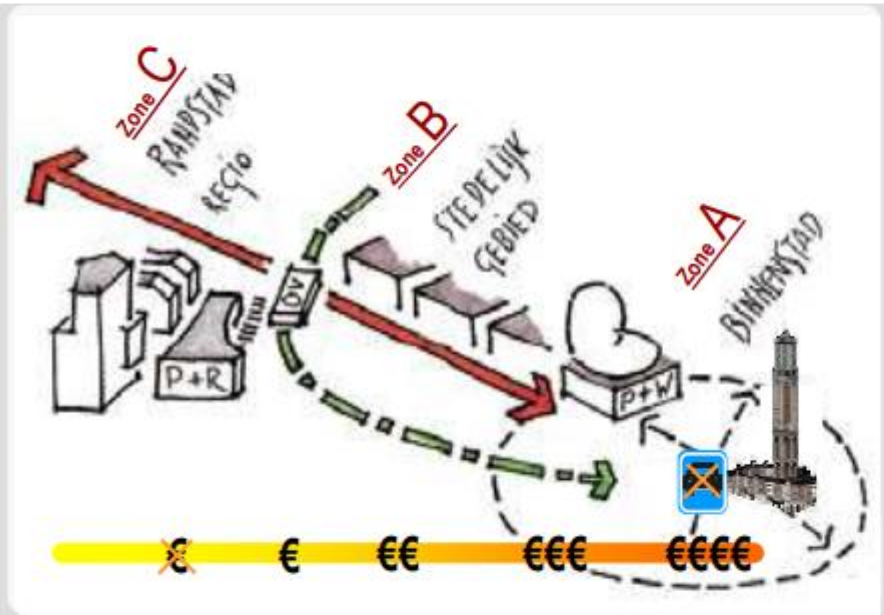

Figure 2: Scale for hourly parking rates, showing an increase when approaching the city centre (Zone A) (source: Nota Utrecht Aantrekkelijk en Bereikbaar, 2012)

2.3.3 General parking legislation in Utrecht

The vision document creates a clear image of the strategy for the inner city of Utrecht. Clear parallels can be found between vision and the actual policy, when looking at the legislation for parking a vehicle in Utrecht. Within the city of Utrecht, an owner or user of a CV can park this vehicle in public parking spaces. Parking spaces are created and indicated by the council. The use of a parking space is either granted by paying an hourly fee, or by obtaining a parking permit. Technically, the fee paid by the user of a vehicle is a parking tax, intended to reimburse the municipality for the construction and maintenance of the locations. As part of the mobility plan for the city of Utrecht, the council has created three parking zones, indicates by A1, A2 and B1. The image below shows the map for the city of Utrecht, with a red A1 zone, a yellow A2 zone and the green B1 zone.

Regulated parking zone	Hourly parking fee (€ / hour)
A1	4.48
A2	3.47
B1	2.45

Table 3: Regulated parking zones and hourly fees (source: www.utrecht.nl/parkeren)

Table 3 provides an overview of the regulated parking zones within the city of Utrecht, with the corresponding parking fees. In-house enforcement officers monitor parking and can distribute fines worth €60,- daily if a violation of parking legislation is detected. Figure 3 shows the map with parking zones. A1 is highlighted in red, A2 in yellow and B1 in green.

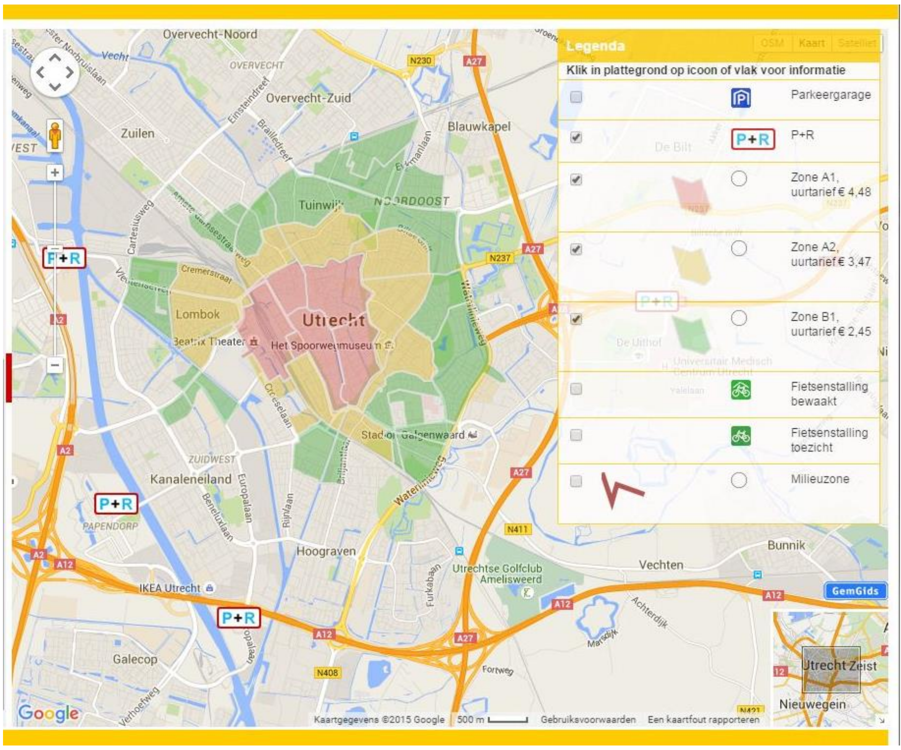

Figure 3: Map of parking zones in Utrecht (obtained from http://www.utrecht.nl/parkeren/parkeren-bezoeker/parkeerplattegrond-utrecht/)

Residents and business owners in the city of Utrecht have the option to apply for a parking permit that grants the owner/user the right to park his/her vehicle on a parking location without paying the hourly fee. Parking permits are granted for a vehicle, not on a person, and are valid for 1 year. Residents in zone A1 can apply for 1 vehicle per cadastral household, residents in zone A2 and B1 can apply for two permits. The households lose the right to 1 permit per privately owned parking space. (Parkeerwet Utrecht, 2015) The annual costs for a residential permit vary between €87,60 for zone B1, and €254,64 for zone A1. Additional permits in zone A2 and B1 will cost the user twice the amount stated for a single permit. For businesses, permits are available if the company is registered on an address in one of the regulated parking zones. The annual costs vary between €417,84 for zone B1, to 778,84 for zone A1. Permits for businesses are not restricted to one vehicle, but can be used on multiple vehicles.

The city of Utrecht conducts yearly inquiries on numerous topics regarding spatial quality, including the availability of parking spaces. Results of the inquiry in 2014 stated that 23.8% was satisfied with the availability of parking spaces in the district Binnenstad, 26% of the residents remained neutral, and 50.3% of the residents were dissatisfied. (Wistudata, 2015)

2.3.4 Electric vehicle parking legislation in Utrecht

Electric vehicles (in this case, both PHEV and BEV configurations) are subject to the same parking legislation in Utrecht. If the user of an EV wishes to park on a public parking spot, the user has to pay the same parking fee as described in the part "General legislation". The city of Utrecht has created dedicated charging locations in the city to promote the adoption of the EV. These charging locations are created by the council and replace existing parking spaces. Charging locations are clearly marked with a sign, striping on the pavement and provide access to a *Mode 3* charging network. The user of an electric vehicle is allowed to use this charging location for the duration of the charging cycle and can park the vehicle for free. A vehicle is charged for a fixed tariff, consisting of an hourly charging fee. If the vehicle is fully charged, but still located on a charging location, the user can be fined with the same fixed penalty of €60,- for not paying the before mentioned parking tax. However, parking a CV on a charging location is punished with a fixed penalty.

The city centre of Utrecht offers a number of charging locations. The Dutch website www.oplaadpalen.nl offers an up-to-date map of all charging locations in the Netherlands. Data for this map is provided by facilitating energy companies, city councils and EV users to create this overview. The following image is created by the website, when looking at the city centre of Utrecht. Note: the map shows only publically accessible charging locations.

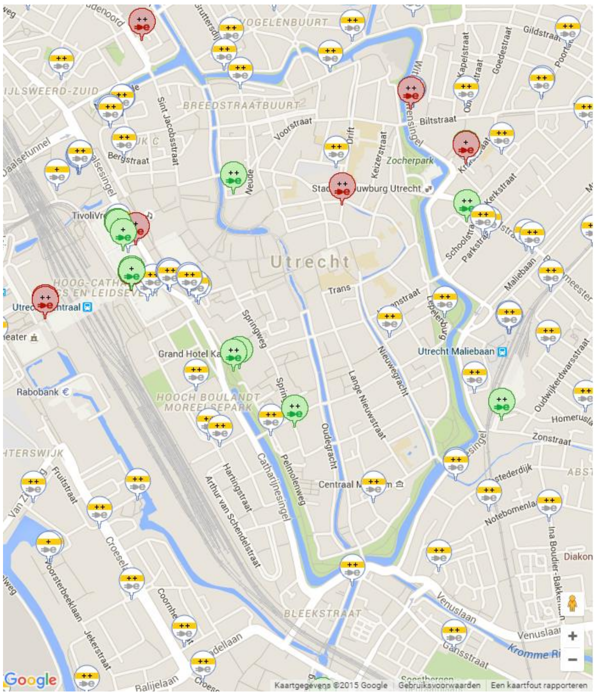

Figure 4: Location of charging stations in Utrecht Binnenstad district (source: www.oplaadpalen.nl)

When using the map application, zooming out to the same level as the "Parkeerkaart Utrecht" shows the following pattern, where the surrounding neighbourhoods seem to house more charging locations than the Binnenstad district.

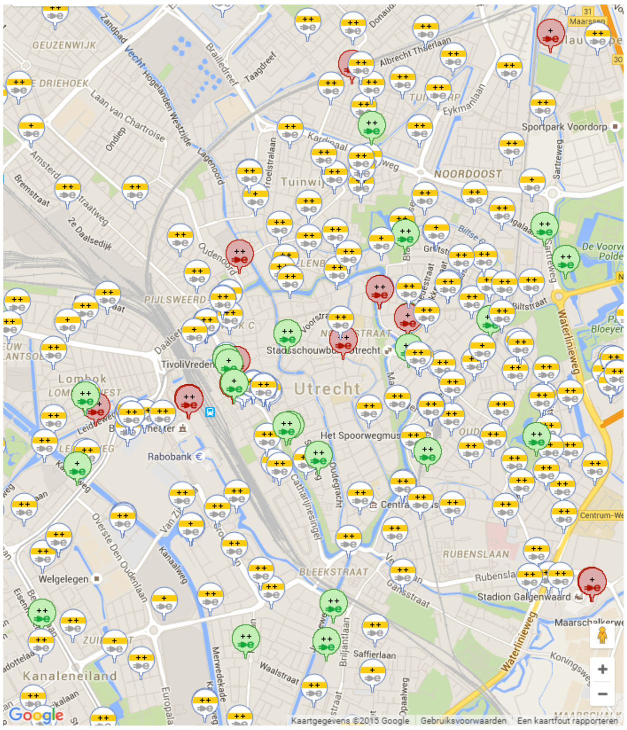

Figure 5: Overview of charging locations for the city of Utrecht (source: www.oplaadpalen.nl)

After a careful examination, an inventory of the charging station map provides a figure of 72 charging locations. Of these charging locations, only 48 can be identified as universally accessible to the public. (Oplaadpalen.nl, 2015) The other 24 charging are either located within paid parking garages (around the NS railway station), or are located on private property. Note, these charging locations are both facilitated by the city of Utrecht and private parties. Between 2015 and 2020 the city aims to increase the number of public charging locations by adding 90 charging locations every year. The expressed growth is focused on the whole city, not specifically on the district Binnenstad, but would result in a growth of 450 charging locations.

Chapter 2 has discussed and explained varying concepts related to the problem statement. The varying configurations of EV's have been explained and the market mechanisms promoting the EV and PHEV in the Netherlands. Accompanying network configurations were explained and the main charging network options in the Netherlands have been identified. Finally, an insight in the Dutch and Utrecht policy on vehicle parking created a clear image of the legislation and methodology for vehicle parking in the research area, with an expansion on the parking and charging of electric vehicles. As the current situation for the research area has been established, this research continues with the introduction of a calculation model by Frade et al. (2011), to initiate the demand calculation for the district Binnenstad.

Chapter 3

Spatial implications of a growing EVs-market: The example of charging demand for Avenidas Nova

In the conceptual framework, the vehicle configurations in the EV Market, the configurations in charging networks and the legislation for parking a vehicle in the research area have been defined. To answer further sub-research questions, a calculation of the actual charging demand is necessary. Furthermore, with the fast developing of the electric vehicle, and the rising adoption of FEV and PHEV configurations (Rijksdient voor Ondernemend Nederland, 2015), a projection for the foreseeable future will provide further insight in the future charging demand. The case of district 'Binnenstad' is a specific case. As described in the conceptual framework, the options for users of a BEV or PHEV to create private charging points are quite rare. Buildings and street possess historic value, residents do not all have the space to park their vehicle, or the right to install charging facilities on their residential address. (Gemeente Utrecht, 2012)

3.1 Comparing Portugal to the Netherlands: Avenidas Nova vs. Binnenstad

The scientific research in the field of electric vehicle charging networks is quite limited, as established in the research proposal. General research has been able to define a correlation between adoption of EVs and charging networks (Gnann, 2015) (Chen, 2013) and indicates the need for charging locations at home and at the workplace (Gnann, 2015). Furthermore, research indicates that: "*The best way to promote a BEV success is to simplify the logistics while away from home. Thoughtful siting of public charging points can ease consumer range anxiety while offering a lower cost approach to integrating EV's into the transportation market (versus investing in longer-range batteries)*" (Chen, 2013) Frade et al. created in 2011 one of the first models that is able to predict the amount and optimum location of charging points, necessary in an area that offers little to no private charging options. For their research, Frade et al. dealt with the neighbourhood of Avenidas Novas, one of the main neighbourhoods in Lisbon, Portugal. The neighbourhood is characterized by a layout that was constructed in a time when car ownership rates were much lower than today. Buildings were constructed without parking spaces. Street parking, parking lots and parking garages (i.e. public parking) are the dominant parking solutions and the absence of private parking options in their case pointed towards the importance of public access charging stations. Chapter 2 elaborated on the general characteristics of EVs, charging and vehicle parking in Utrecht. Especially when elaborating on the subject of parking, the scope has been lowered on the research area of the '*Binnenstad*' district in Utrecht, which shows multiple similarities with the research area Avenidas Nova of Frade et al.

First, the choice of location with regards to parking space. In both Avenidas Nova and the Binnenstad, the main choice for parking is in the public space. Linked to this is the absence of possibilities to install private charging stations. Second, the area shows similarities in population and use. Utrecht city centre, as Avenidas Nova, combines residential, commercial and touristic use of the public space.Third, the local and national government for both areas name the promotion of electric mobility as an important criterion in the development of the area. (Gemeente Utrecht, 2012) (Frade, 2011) (Rijksdient voor Ondernemend Nederland, 2015) As the areas have these similarities, the mathematical model by Frade et al. created in 2011 will be used and adapted to create a charging demand projection for the research area "Binnenstad".

3.2 Demand projection model for Avenidas Nova

One must be able to create a function that describes potential demand for charging during the day, to calculate the number of charging points/locations in the subject area. This makes the case slightly more difficult, as Frade et al. state, as "*one cannot rely on observations of actual users".* With the novelty of the infrastructure comes an uncertainty with regards to users, according to the researchers. (Frade, 2011)

To estimate the charging demand, two different types of users are distinguished. The daytime user uses the charging network between 7:00 and 19:00. The night-time user uses the charging network between 19:00 and 7:00. The reason for this distinction lies in the characteristics of the area Avenidas Nova. As it combines residential and commercial functions, the demand will correspond to different users depending on the time of day. The night-time demand is related to the characteristics of the population in the study area (the households), as the population parks their vehicle at night in the available public parking locations. Daytime demand is related to the employment in the area, as the cars parked during daytime hours belong to the people working in the area. The amount of charging moments on every moment of the day will form the assessment of charging demand.

3.2.1 Night-time Demand in Avenidas Nova

As stated, the model by Frade et al. relates the night-time demand to characteristics of households. "To estimate the night-time demand, first a relationship was established between the number of cars per households and the characteristics of households" (Frade, 2011)the relationship was defined by the use of regression analysis, information and data on households was obtained from a mobility research in the 51 municipalities in the Lisbon and Tagus region. Frade et al. defined the number of cars per household (v_h) as a linear function of household size, building type, average age, education level and employment sector, resulting in the function:

$$v_{h} = \quad f\,(\,size_{household}, type_{building}, pop_{age}, pop_{education}, pop_{employment}) \qquad (1)$$

Which, after stepwise elimination of nonsignificant variables and forcing the intercept through 0 creates the following regression equation:

$$v_h = \quad 3.90 \times p_H - 1.18 \times p_T + 3.41 \times p_{20} + 3.28 \times p_{64}$$

where

- pH = proportion of population older than 17 years that completed high school
- pT = proportion of residents working in the tertiary sector
- $p20$ = proportion of residents younger than 20 years of age
- $p64$ = proportion of residents older than 64 years of age.

the regression equation indicated significant variables with regards to the amount of vehicles per household for the situation of Avenidas Nova,

- Higher educated households tend to own more vehicles, indicated by the positive factor (3,9) in function 2.
- Households employed in the tertiary sector tend to own less vehicles, as the negative factor (-1,18) indicates in function 2.
- Individuals below 20 years of age and above 64 years are associated with a higher number of vehicles in the household.

To calculate the number of cars during night-time within area J (the census block for input data), V_{Nj}, the number of vehicles per household (expressed as v_h) is multiplied by the number of households within the given area j (expressed as H_j), which leads to function 3:

$$V_{Nj} = v_{hj} \times H_j \qquad (3)$$

where is v_{hj} the number of cars per household (function 2) in area j, and Hj is the number of households in area j.

By calculating V_{Nj}, the researchers calculated the amount of vehicles that are present during the night-time in a given census block for the region of Lisbon. To determine the share of electric vehicles among the total number of cars, the model uses the automotive market forecasts of the European Commission. These indicate a market share for EVs in 2020 of 1% to 2%, rising to 11% to 30% in 2030. As the Portuguese government is promoting EV implementation, Frade et al. raised the market share to 2% for the end of 2011 and 4% for the end of 2012. The number of cars per household was also taken into account. If the $v_h > 2$, the market share was raised with 1%, as it would be more likely for households with more cars to have an electric vehicle. The information used led to the following equations, where V_{ENj} is defined as the amount of vehicle charging at night in census block j.

$$V_{ENj}\,(2011) = 0.03 \times V_{Nj} \quad (\text{if } v_{hj} \geq 2) \qquad (4a)$$
$$0.02 \times V_{Nj} \quad (\text{if } v_{hj} < 2)$$

$$V_{ENj}\,(2012) = 0.04 \times V_{Nj} \quad (\text{if } v_{hj} \geq 2) \qquad (4b)$$
$$0.05 \times V_{Nj} \quad (\text{if } v_{hj} < 2)$$

The last step of the night-time demand calculation consists of establishing the charging need of electric vehicles. In the mobility research that Frade et al. used as a reference point, the average distance travelled by a vehicle in the Lisbon area is set at 20 km.
The range of an average EV was set at 60 km, creating a charging demand of once every 3 days.
The number of charge-ups necessary during night-time in the research area J, defined as $u_{Nj,}$ is stated as follows:

$$U_{Nj} = 0{,}33 \times V_{ENj}$$

Resulting from this final equation is the demand for charge-ups in census block J during the night-time, which provides a projection on the demand for charging locations during night-time hours, depending on the adopted vehicle – charging location ratio. To continue the demand projection, the research continued with the calculation method for the day-time demand projection.

3.2.2 Daytime demand in Avenidas Nova

The daytime demand calculation is comparable to the night-time demand calculation, as it aims to connect characteristics of EV-users to the number of present EVs at a given moment, but differs on a few important points. Frade et al. established that daytime charging demand originates from EV users that work in the area, and therefor park their vehicle during working hours within the research area.

Establishing this charging demand starts with establishing the assumed relationship between the volume of employment and the type of buildings situated in the area. Data to support this assumption was gathered from the same mobility study in the 51 municipalities of the Lisbon and Tagus region, which was also used for the night-time demand calculation. With regression analysis, a regression equation was obtained by forcing the intercept to be 0.

$$E = -1.42 \times B_R + 14.89 \times B_{RN} + 159{,}20 \times B_N \quad (6)$$

where

- E = volume of employment,
- B_R = number of residential buildings,
- B_{RN} = number of mainly residential buildings, and
- B_N = number of mainly non-residential buildings.

(Frade, 2011)

The calculation encountered some statistical challenges, as some factors were seen as non-significant in the regression calculation. As these factors did influence the Employment volume when changed in the equation, all factors remained present in the equation.

After calculating the volume of employment an assumption is made on the presence of vehicles between 7:00 and 19:00. Frade et al. assume that the presence of vehicles during daytime can be calculated by multiplying it with the share of travel-to-work trips made by car that start and end in Avenidas Nova. In the study area this comes to a share of 20%, as the area is served well by the public transport system.

The number of cars in census block J, defined as V_{Dj}, is then calculated with the following equation:

$$V_{Dj} = 0.2 \times E_j \quad (7)$$

where:

- V_{Dj} = Number of cars during daytime in census block J
- 0.2 = The share of travel-to-work trips within census block J
- E_j = volume of employment within census block J

To conclude the calculation, the same method is used as in the night-time charging calculation. By multiplying the amount of vehicles within the census block with the market share for EVs, the amount of electric vehicles during the daytime is calculated. To calculate the demand for charge-ups, the same factor is used (0,33, recharging once every 3 days), resulting in the following functions:

$$V_{EDj}\,(2011) = 0{,}02 \times V_{Dj} \quad (8a)$$

V_{EDj} (2012) = 0,04 x V_{Dj} (8b)

U_{j} = 0.33 x V_{EDj} (9)

The functions result in a calculation of the daytime and night-time demand for charge-ups / charging locations, resulting in a minimal demand for charging points for every time of the day within the census area.

3.3 Summarizing the calculation

Exploring the model of Frade et. al. has shown a method that is able to calculate current and future charging demand projection. By calculating this demand for a given area, in this case Avenidas Nova, it provides a projection of the necessary capacity of the charging network under given conditions. The model is not limited to the mentioned day- and night-time demand projection, but continues with a spatial expression with regards to ideal locations for these charging points. Optimizing the physical location of charging network exceeds the scope of this research - although being potentially interesting for future research- and will not be discussed further. Calculation of a current and future demand projection is conducted with this model for the subject area Binnenstad. Despite the mentioned similarities of Avenidas Nova and the Binnenstad, the parameters of the subject areas cannot be universally applied to all European cities. Variation in population characteristics, EV adaptation and different stimulation initiatives for electric mobility require adaptation of this model to fit the situation of the research area. Chapter 4 will continue this research for a demand projection by altering the model for Avenidas Nova to fit the situation of the Binnenstad.

Chapter 4

A growing EVs-market and Utrecht, spatial implications for '*Binnenstad'*

4.1 Applying knowledge on Avenidas Nova to the Binnenstad

Chapter 3 introduced the demand calculation model created by Frade et al. in 2011, which is used to construct a charging demand projection for the research area of Avenidas Nova. The model used local data and was adapting to the regulations of the Portuguese government that promoted the use of EV's, and the characteristics of the local population. As discussed in chapter 2, both the Netherlands and Utrecht have quite specific characteristics with regards to spatial interactions, parking and the promotion of EV's. Adaptation of the model that has been used by Frade et al. to the research area is the next step to provide a current and future demand projection for the research area Binnenstad.

Adaptation of the model will be performed by a re-run of the calculation method by Frade et. al., while replacing the original data for Avenidas Nova with the corresponding data for the district Binnenstad. Selecting more specific data sources for the study area improves the performance of the original calculation model, which relied partially on general assumptions for the E.U. and national figures for Portugal. By specifying the data to the subject area the demand calculation will therefore be able to support a reliable and funded demand projection for the subject area, as the Netherlands has multiple excellent sources – CBS, Kadaster, and RVO – to provide this specified data.

4.2 Adapting Frade et. al (2011) : Data collection and parameter selection

Parameters selected by Frade et al. (2011) for Avenidas Nova

For the night-time demand calculation, Frade et al. established a relationship between the number of vehicles and the characteristics of the households within the study area. The number of vehicles per household was given by information available for all the regions of the Lisbon region. As characteristics, Frade et al chose 5 parameters, with they considered influential for the number of cars per household. Table 4 provides an overview of the parameters and their variables.

Parameter in original model	Variable in original model
Household size	N_o of persons in a household
Building type	Type of building (residential, non-residential)
Average age of the population	Age classes
Education level	Finished high school, higher education, etc.
Employment sector	Primary, secondary, tertiary and quartery sector

Table 4: Parameter overview for demand calculation model by Frade et. al (2011)

The daytime demand calculation was created by establishing a relationship between volume of employment and the type of buildings. The variable "building type" was quite limited, and consisted of residential, non-residential or partially residential buildings.

Parameters for the district Binnenstad

The extensive gathering of statistical data in the Netherlands provides an advantage with regards to the precision of this research. Where Frade et al. were forced to support the assumed relationship of EV presence and local characteristics by applying linear regression on the data for 52 municipalities, the Central Bureau for Statistics (CBS) provides exact numbers on the parameters mentioned in the original demand projection calculation.

The city of Utrecht, as the city within the municipality, knows divisions and subdivisions. A first subdivision is formed by 10 districts, known as *wijken*. Districts are further divided in to neighbourhoods, or *buurten* in Dutch, which in most cases contain a number of streets. For this case study the area of "Binnenstad" is chosen, as it is the most densely populated district in Utrecht, with limited spaces for actors involved. To improve the performance of the model by Frade et al., the demand calculation for the city of Utrecht will be executed with the variables provided by the Central Bureau for Statistics (hereafter CBS).

Improving the performance of the calculation model is stated the introduction of this chapter, which is possible with the use of CBS data. Data gathering for the parameters in the demand calculation has been performed by the CBS on the neighbourhood level, which enables this research to create demand projections for specific neighbourhoods within the district Binnenstad. Demand calculations for Avenidas Nova were performed with data on focus levels varying from Lisbon-specific to nation- and EU-wide. Using the more specific data for neighbourhoods and districts results in a better performance of the charging demand projection model, and with that, a better estimation of the spatial implications in the light of EVs-market developments. The parameter "market share of EVs" is the only variable specified solely on a national level, as the available databases do not provide information specific enough for the Binnenstad district.

Although the statistical databases of the CBS provide us with exact numbers, only formula 1 and 2 - aimed at the number of vehicles per household (v_h) – are eliminated from the re-run, as this variable is provided for the neighbourhoods of the district Binnenstad by the CBS Statline database. The calculations in paragraph 4.3 from the original model are performed accordingly, with data specified for the research area. The variables necessary to calculate the amount of vehicles that need to charge at night are retrieved from the databases of the municipality, the CBS and the Kadaster.

Daytime demand calculation - the second part of the demand calculation model – is also performed with data from the municipality of Utrecht, CBS and Kadaster. As the factor 'workers travelling by car to the workplace' is not a known figure, the daytime demand calculation starts with the calculation of this parameter. Other calculations in the original model are performed accordingly.

4.3 Charging demand projection in district Binnenstad

4.3.1 Night-time charging demand in 2015

To calculate the night-time charging demand, the starting point will be the third equation of the model by Frade et al.. As the amount of vehicles per household (V_h) is a given factor, the calculation starts by calculating the amount of vehicles at night-time within census block 'b' (for *buurt*/neighbourhood) with the equation:

$$V_{Nb} = v_{hb} \times H_b \quad (10)$$

Where:

- v_{hb} = the average number of vehicles per household in neighbourhood 'b'
- H_b = the number of households in neighbourhood 'b'

District Binnenstad consists of 11 neighbourhoods, listed in the table below. Formula 10 has been performed per neighbourhood, providing a number of present vehicles during night-time per neighbourhood, V_{Nb}. The first column shows the v_h for the corresponding neighbourhood, the second column provides the H_b, and the third column shows the result of formula 10, V_{Nb}. Summing the results of V_{Nb} provides the grand total for the district, hereafter referred to as V_{ND}, consisting of 4200.5 vehicles.

***Buurt* 'b'**	v_{hb}	H_b	V_{Nb}
Domplein, Neude, Janskerkhof	0.3	1647	494.1
L.Elisabethstr, Mariaplaats e.o	0.3	1117	335.1
Hg Catharijne, NS, Jaarbeurs	0.0	331	0
Wijk C	0.5	910	455
Breedstr, Plompetorengracht	0.3	1828	548.4
Nobelstraat e.o.	0.2	757	151.4
Springweg e.o., Geertebrt	0.4	1247	498.8
Lange Nieuwstraat e.o.	0.3	1612	483.6
Nieuwegracht-Oost	0.5	755	377.5
Bleekstraat e.o.	0.4	354	141.6
Hooch Boulandt	0.5	1430	715
Wijk Binnenstad			Total: 4200.5

Table 5: Number of vehicles present during night-time per neighbourhood of district Binnenstad (CBS Statline, 2015) (Wistudata, 2015) (Gemeente Utrecht, 2015)

Electric share of V_{Nb}

V_{ND}, the overall amount of vehicles present during night-time in census block 'Binnenstad', is calculated as 4200.5 vehicles. As Frade et al. stated: "*The next step consisted of estimating the number of EVs to refuel in each census block in the night-time*". Frade et al. used the average marketing share figures for the European Union to calculate the share of electric vehicles. In the case of Utrecht, the Dutch Enterprise Agency (RVO) provides a more specific EVs- market share for the Netherlands. On December 31st 2015, the RVO registered 9.368 FEVs and 78.163 PHEVs. This number takes all configurations of PHEVs into account, including FEVs with a range-extender. (Rijksdient voor Ondernemend Nederland, 2015). CBS Statline states that the Dutch vehicle fleet consists of 7.979.083 registered vehicles, which when combined with the given registrations of EVs, accounts for a market share of 0.11% for FEVs, and 0.98% for PHEVs. Combining both categories results in a 1,09% market share. (CBS Statline, 2015). With this up-to-date market share, the next equation of the model can be performed. The amount of electric vehicles, present at night, in census block 'b' (V_{ENb}) is calculated with the following equation:

$$V_{ENb} = s_e \times V_{Nb} \quad (11)$$

Where:

- s_e is the market share of electric vehicles
- V_{Nb} is the number of vehicles present in neighbourhood 'b', resulting from equation 10.

Table 4 shows the number of electric vehicles present during the night-time per *buurt*, and is an expansion of table 3, which is found in column 2, 3 and 4. Column 5 shows the amount of Full Electric Vehicles during night-time, followed by the Plug-in Hybrid Electric Vehicle and column 7 provides the total amount of EVs present during night-time in neighbourhood 'b'.

Again, the bottom row of the table provides the total amount of vehicles when summing the separate neighbourhoods to a district total. When executing equation 10 – and assuming the total of 4200.5 vehicles – the night-time presence of FEVs will sum to 4.6 vehicles, PHEVs sum to 41.2 vehicles, creating a total of 45.8, rounded up to 46 EVs.

Buurt	v_h	**H**	V_N	V_{ENb} **(FEV)**	V_{ENb} **(PHEV)**	V_{ENB} **(EV)**
Domplein, Neude, Janskerkhof	0.3	1647	494.1	0.5	4.8	5.4
L.Elisabethstr, Mariaplaats e.o	0.3	1117	335.1	0.4	3.3	3.7
Hg Catharijne, NS, Jaarbeurs	0.0	331	0.0	0.0	0.0	0.0
Wijk C	0.5	910	455.0	0.5	4.5	5.0
Breedstr, Plompetorengracht	0.3	1828	548.4	0.6	5.4	6.0
Nobelstraat e.o.	0.2	757	151.4	0.2	1.5	1.7
Springweg e.o., Geertebrt	0.4	1247	498.8	0.5	4.9	5.4
Lange Nieuwstraat e.o.	0.3	1612	483.6	0.5	4.7	5.3
Nieuwegracht-Oost	0.5	755	377.5	0.4	3.7	4.1
Bleekstraat e.o.	0.4	354	141.6	0.2	1.4	1.5
Hooch Boulandt	0.5	1430	715.0	0.8	7.0	7.8
Wijk Binnenstad		**TOTAL:**	**4200.5**	**4.6**	**41.2**	**45.8**

Table 6: Number of electric vehicles present during night-time in *buurten* of district Binnenstad

As a final step, the demand side -in terms of electric driving range and need for recharging- is defined. Frade et. al used a local mobility study to create a factor 'daily driving distance', which states that the average daily distance, travelled by residents of Avenidas Novas, came to 20 km. Combining the average range of an EV with the daily driving distance provides the recharge frequency.
In this final step, the aim is to find an accurate factor to estimate the daily distance covered by EV users in Utrecht. For this, a side-step and estimation are necessary.

Recharging behaviour

Utrecht city council presented a yearly overview of Utrecht in numbers, - the Utrecht Monitor- which reports that the 'E-driver' (a user of a FEV or PHEV) uses their vehicle frequently. Among the E-drivers, 88% uses their electric vehicle between 4 and 7 days a week. Half of this 88% of users drive between 200 km -500 km in one week, where 25% drives more than 500 km on a weekly basis. (Gemeente Utrecht, Utrecht Monitor, 2015). As *"one cannot rely on observations of actual users",* (Frade, 2011), the need or necessity to recharge a vehicle must be derived from data gathering and analysis. The provided data offers a possibility to make rough estimates on the daily distance for an EV-driver living in the city of Utrecht.

For 44% of the EV users, their weekly distance covered lies between 200 and 500 km, spread across 4 to 7 days. Some users will go beyond this figure, as 22% state that cover more than 500 km in the same period of time. The last 33% of EV users will be below the 200 km or uses the vehicle less than 4 days a week. By averaging these figures, results in the statement that 44% of EV users drive their vehicle for an average of 5,5 days per week, for an average distance of 350 km, resulting in a daily average of 63.6 km. Among EV-users, 22% will drive greater distances, and another 22% will drive less than this daily figure, or have a lower driving frequency. For the final 22% of the EV users, this average is unknown. (Gemeente Utrecht, 2015)

To create a valid statement, this value will be assumed to be a conservative 50 km per day. Average electric driving ranges of PHEVs vary per vehicle and configuration, but 30 km is a realistic projection. FEVs are able to cover bigger distances on their battery, also varying per configuration, a conservative 100 km will be assumed. It is assumed that all PHEV owners charge when their battery is empty - even though their vehicle has a secondary energy source - to use the full potential of the electric driveline. FEVs will therefor charge once every 2 days, where PHEVs will charge daily. (ANWB, 2015) (Gemeente Utrecht, Utrecht Monitor, 2015)

With this information the final night-time electric charging demand equations for BEVs and PHEVs are as follows:

$$U_{NBF} = 0.5 \times V_{NF} \tag{12a}$$

$$U_{NBP} = V_{NP} \tag{12b}$$

where:

- U_{NBF} is the charging demand for FEVs during night-time in the 'Binnenstad'
- U_{NBP} is the charging demand for PHEVs during night-time in the 'Binnenstad'
- V_{NF} is the amount of FEVs present during night-time in the 'Binnenstad'
- V_{NP} is the amount of PHEVs present during night-time in the 'Binnenstad'

When executing these formulas, the following results are shown:

$U_{NBF} = 0.5 \times 4.6 = 2.3$ charge-ups

$U_{NBP} = 41.2$ charge-ups

Which results in a total night-time electric charging demand (U_{NB}) of 43,5 charge-ups per night within the district 'Binnenstad' The results of this calculation show the charging demand during night-time hours. To complete the estimation of the total demand, this research continues with the demand calculation for the day-time charging demand.

4.3.2 Daytime charging demand in 2015

The daytime charging demand calculation will follow the course of Frade et al. as well. The model assumes that the majority of the daytime charging demand originates in the amount of workers in a district. Where Frade et al. did not possess the sources to determine an exact number of employed workers in the research area, the researchers again were forced to use linear regression to create an estimate of the volume of employment (E). However, CBS and the council of Utrecht can provide such specific numbers for the district Binnenstad and its neighbourhoods. Calculating the daytime charging demand can be performed without the linear regression phase, starting the calculation at the point where Frade et al. calculate the amount of vehicles within a census block during daytime hours. The following equation shows the method to calculate the amount of vehicles present during daytime (V_{Dj}):

$$V_{DB} = w_c \times E_j \quad (12)$$

where:

- w_c is the share of workers travelling by car to the workplace
- E_j is the volume of employment within a census block 'j'

The volume of employment is a value which can be obtained from the city of Utrecht database, per neighbourhood of the district 'Binnenstad', and sums to a total of 43.153 full-time positions. The factor w_c is a factor that is harder to obtain, as it involves workers from inside Utrecht (travelling by car within the city to the work address), but the employees travelling from outside Utrecht to work within the city have to be taken in to account as well. As Utrecht has a central position in the Netherlands, a share of the workers lives outside the Utrecht region and travels to work within the city of Utrecht on a daily (Gemeente Utrecht, 2012) An overview of the total number of vehicles, either from workers residing in Utrecht itself, or from outside the city, requires a double calculation for either situations.

Volume of employment

The Utrecht Monitor 2015, -constructed by the council of Utrecht - offers a very clear image on employees, their home address, work address and traveling behaviour, dividing these in three categories:

- Working in Utrecht, living outside Utrecht, 122.600 persons
- Working in Utrecht, living in Utrecht, 78.400 persons
- Working outside Utrecht, living in Utrecht, 80.600 persons

District Binnenstad houses 43.153 full-time employment positions, with a criterion of more than 12 hours on a weekly basis. When applying the ratio between home and work locations as described by the Utrecht Monitor, 61 % of the employees in the Binnenstad resides outside the city of Utrecht, the other 39% resides within the city of Utrecht. Applying these percentages to the total volume of employment (43.153 positions) results in an overview of the residential address of employees in the Binnenstad, of which 26.323 are located outside Utrecht and 16.830 are located within the city Utrecht. (Gemeente Utrecht, Utrecht Monitor, 2015)

Mobility choices

The Mobility View 2014, compiled by the Dutch Knowledge Institute for Mobility, provides an overview of the mobility choices within the 17 major cities of the Netherlands, coupled to a motive for transportation. For Utrecht, the motive 'work' displays that 40% of the trips to and from the workplace within the city is executed with either a car or a bike. Public transport and walking share the other 20% of movement to and from the workplace. . When combining this share with the number of employees residing within the city, the share of workers – residing within the city of Utrecht - employed within district Binnenstad arriving by car – or w_c – results in 0,4 / 40%.

Vision document 'Dit is Utrecht 2015', compiled by the council of Utrecht, offers a view on the mobility choices of persons travelling to Utrecht. Findings in the document indicate that 51% of work related movements to and from the city of Utrecht is executed by car, resulting in a share of workers – residing outside the city of Utrecht- employed within the district Binnenstad arriving by car ($w_{c)}$ of 0,51 / 51%. (Gemeente Utrecht, 2015)

Calculating V_{DB}

With the calculation of both 'E' (the volume of employment) and w_c (share of workers arriving by car) completed, formula 12 can be executed. A distinction is made between the two types of employees (based on residential address), resulting in two calculations.

First, the amount of vehicles present that originate from employees residing within the city of Utrecht is executed with 'E' stated as 16.830, and w_c stated as 0.4, resulting in the following calculation of V_{DB}:

$$V_{DB} = 0.4 \times 16.830$$
$$V_{DB} = 6.732$$

The amount of vehicles present originating from Employees - residing outside Utrecht arriving by car at the workplace in the district Binnenstad- is then calculated with the assumption that 'E' is 26.323, and w_c equals 0.51.

$$V_{DB} = 0.51 \times 26.323$$
$$V_{DB} = 13.425$$

Combining the two calculations results in a total presence of vehicles during the daytime of 6.723 + 13.425 = 20.147.47, rounded up to 20.148 vehicles. The amount of vehicles present within district Binnenstad, during daytime hours, is hereafter assumed to be 20.148 vehicles. With the completion of the calculation determining the total present vehicle fleet, the next step is formed by the determination of the number of electric vehicles present during daytime hours within district Binnenstad.

Electric share of V_D

To establish the number of EVs (PHEV and FEV) and their charging demand during daytime in the district Binnenstad (V_{EDB}), the same method will be used as performed in the Night-time charging demand calculation. For this calculation, all necessary data has either been calculated or is equal to the night-time demand calculation, which creates the possibility to make a direct calculation. It is assumed that the same market share for EVs applies during daytime hours.

$$V_{EDB} = s_e \times V_{DB} \quad (13)$$

Where:

- s_e is the market share of electric vehicles
- V_{Nb} is the number of vehicles present in neighbourhood 'b', resulting from equation 12.

After executing the calculation in formula 13 – for EVs, and separately FEVs and PHEVs -, results shows that the daytime presence of all EVs is 219.6 vehicles, rounded up to 220 vehicles. FEV and PHEV individual market share is a given factor s_e - as seen in the night-time demand calculation- which shows that of these 220 EVs, 197.5 (rounded up to 198) are PHEVs, and 22 vehicles are FEVs. Table 5 provides a short overview of these findings, in which the first column states the vehicle type, the second column provides the market share and column 3 shows the calculated V_{DB}. Column 4 shows the day-time presence of electric vehicles within the district Binnenstad, expressed as V_{EDB}.

Vehicle type	**s_e**	**V_{DB}**	**V_{EDB}**
EV combined	0.0109	20.148	220
PHEV	0.0098	20.148	198
FEV	0.00109	20.148	22

Table 7: Number of electric vehicles present during daytime according to formula 13 (CBS Statline, 2015) (Rijksdient voor Ondernemend Nederland, 2015)

Which, when taking into account we will apply the same rules as the night-time demand by using the same formula, 198 PHEV users need to recharge during daytime hours. As mentioned in chapter 4.3.1, 50% of the FEV users will need to recharge during daytime, resulting in a demand of 11 charge-ups. The total potential daytime demand will be 209 charge-ups during daytime in the district Binnenstad.

$$U_{EDB}(FEV) = 0.5 \times V_{EDB}(FEV) \quad (14a)$$

$$U_{EDB}(PHEV) = V_{EDB}(PHEV) \quad (14b)$$

4.3.3 Overall charging demand in 2015

The charging demand has now been established, which answers our third sub-research question: "*What is the current demand for electric charging networks in the Binnenstad of Utrecht?*" . The calculations for night and daytime demand show us a demand for 43.5 charge-ups per night, and 210 during the day, within the district Binnenstad. The current charging demand is therefore assumed to be 210, which, when applying a 1:1 policy with regards to charging demand and charging locations, would result in a demand for 210 charging locations to satisfy the needs of FEV and PHEV users in district Binnenstad.

The status-quo is a useful tool to determine if the current supply meets the demand for electric charging networks. However, due to the growing and evolving concept of the EV, this research will continue with a demand projection, to determine eventual future demand for charging networks.

4.4 Charging demand development: calculation for 2020 and 2025

4.4.1 EV adoption in the Netherlands for 2015-2025

In 2015, the RVO registered 9.368 FEVs and 78.163 PHEVs (Rijksdient voor Ondernemend Nederland, 2015), creating a total number of 87.531 electric passenger vehicles. When inspecting the projection concerning electric mobility of the very same RVO, the expected number of electric vehicles for the end of 2015 was set at 20.000, which is 25% of the actual registrations. As the reality is growing faster than expectations, one could ask, like this thesis, if the public network facilitating this mobility choice is sufficient at this time. With this reality outnumbering the expectations, it is vital to check the future charging demand in this district as well.

As defined in 'Utrecht Aantrekkelijk en Bereikbaar', the promotion of electric city mobility is seen as one of the measures that could provide a more liveable city centre. Assessing the spatial implications of a growing EVs-market is one of the main goals, which is a reason to adapt the calculations made for 2015 to the expectations set by the RVO for 2020 and 2025, as suggested in the masterplan "Elektrisch rijden in de versnelling". (Rijksdienst voor Ondernemend Nederland, 2011) Market share of electric vehicles and the promotion of the vehicles are discussed in this document, setting the figures in 2020 and 2025 at respectively 200.000 and 1.000.000 vehicles.

4.4.2 Developments until 2025 in Binnenstad.

Future charging demand is a concept that forms a challenge, in numerous ways. The model used in chapter 4.2 and 4.3 relies on parameters that are influenced by numerous factors that could be subject to change in the next five, ten or fifteen years. The Utrecht Monitor, which was used to estimate the amount of vehicles during daytime, provides insight in future developments in Utrecht. Population growth is expected until (at least) 2030, which might carry different consequences with regards to traffic, work-to-home trips and mobility choices. However, the same Utrecht Monitor shows us as well that volume of employment within Utrecht has been relatively stable for the past three years, with minor fluctuations measuring 200 to 300 less or more employment positions. It is therefore assumed in this research that these parameters will only change on a minor level, and the parameters known for 2015 can still provide a realistic expectation. (Gemeente Utrecht, Utrecht Monitor, 2015)

For this projection, a conservative approach will be used as a base-line for future demand. In chapter 4.4.1 it was established that the projected market share for EVs in 2015 has quadrupled. Due to this unexpected high adoption rate of FEVs and especially PHEVs, a projection of a comparable extreme scenario could be added to this projection, but would not provide a funded basis for policy change, as the separate parameters of the calculation are subject to different influences.

4.4.3 Future electric charging demand in 2020 and 2025

Projecting a potential charging demand will be done by adopting the potential change market share for PHEVs and FEVs as projected by the Rijksdienst voor Ondernemend Nederland in the masterplan "Elektrisch rijden in de versnelling" (RVO, 2011) . As it is now not possible to create an exact share per EV-configuration, this projection will be created for the entire EV spectrum. As these vehicles can both charge in comparable ways, (Mode 3 charging), it will provide, within the limitations mentioned, a realistic figure.

The current market share in December 2015 for EVs is 1,09% (Rijksdient voor Ondernemend Nederland, 2015). The projection in the masterplan "Elektrisch rijden in de versnelling" assumes the presence of 200.000 EVs in 2020 and 1.000.000 EVs among the Dutch passenger vehicle fleet in 2025.

These figures translate to a market share of 2,5% in 2020, and 12,5% in 2025, when assuming a stable (non-expanding) vehicle market. The Dutch bank 'ING Bank' published a prognosis report, stating a potential growth in 2020 and 2025, due to the larger group of citizens above 65 years old. (ING Bank, 2015) The capital position of this age group is assumed to be the main driving force behind vehicle sales. The vehicle market, as stated in the ING report, would grow to 8,4 million vehicles in 2020, and 8,8 million vehicles in 2025, which results in a growth of 5,27% for 2020 and 10,3% in 2025. To adapt to future situations, the figures projected for the vehicle fleet presented by the ING are adopted for the demand calculation, resulting in corrected market shares for EVs. Market shares of EVs result in a 2,3% market share in 2020 and an 11,4% market share in 2025, after taking the growth of the vehicle market into account. (ING Bank, 2015)

Calculation of the amount of electric vehicles present during day and night-time is executed with equation 11 and 13, found in chapter 4.3.1 and 4.3.2. For these calculations, the same parameters are assumed with regards to vehicles per household, share of employees travelling to work by car, number of households and the volume of employment in district Binnenstad. To create a clear overview, the following table provides the results of these projected market shares.. The amount of vehicles travelling to and from Utrecht will be adapted to the larger national vehicle fleet in 2020 and 2025, by applying the same growth factor that can be identified in the national vehicle fleet.

Year	**National Vehicle fleet (total # vehicles)**	**Overall number of cars in 'Binnenstad': daytime**	**Overall number of cars in 'Binnenstad': night-time**	**Market share EVs (% of National Fleet)**	**Number of EVs in 'Binnenstad': daytime**	**Number of EVs in 'Binnenstad': night-time**
2015	7.979.083	20.148	4200.5	1.09	220	43
2020	8.400.000	21.210	4422	2.3	488	102
2025	8.800.000	22.223	4633	11.4	2533	528

Table 8: Projection EV presence in Binnenstad for 2015, 2020 and 2015 (ING Bank, 2015) (Rijksdient voor Ondernemend Nederland, 2015)

The results of this calculation show us that the Binnenstad district could welcome a larger number of EVs in the future. Daytime presence of EVs could grow to ca. 500 vehicles in 2020, and to ca. 2500 vehicles in 2025. Night-time presence could grow to ca. 100 vehicles in 2020, and ca. 525 vehicles in 2025. Unfortunately it is not possible to make a reliable projection of the recharging regime, as the ratio between PHEVs and EVs in 2020 and 2025 is unknown. It is however possible to make the assumption that the share of EVs will grow, and the share of PHEVs will shrink, as stated by multiple sources (Rijksdient voor Ondernemend Nederland, 2015) (ING Bank, 2015). However, due to the experimental and rapidly developing technology, this shall remain an assumption for now.

4.5 Spatial implications: A growing charging demand asks for a growing network supply

With the presence of these vehicles during day and night-time in the district Binnenstad, comes a demand for charging, and with this demand a corresponding demand for charging locations. Chapter 2.2 provided an overview of the legislation and policy with regards to parking locations and charging locations. As discussed in this chapter, the city of Utrecht now provides charging locations under strict requirements. Furthermore, a new charging location will replace an existing parking location. The calculation in chapter 4.4 provides a figure with regards to charging demand in future situations. These calculations only provide a demand projection, divided over a day or night, but to not yet provide insight on the spatial implications. To answer the fourth sub-research question; "*Which consequences does an expanding EVs-market have for the availability of parking space in the Binnenstad district*?", a spatial context for this demand projection could provide more insight in these assumed implications.

Implications under current policy and legislation

The creation of a public charging location has very simple implications in the current policy; one universal parking location is replaced by a restricted charging location. Chapter 4.3 and 4.4 produced figures for current and future demand projections. If assumed that every vehicle arriving in Utrecht during daytime will need recharging – and thereby assuming a 1:1 ratio for vehicles and charging locations- the calculation with regards to parking locations is quite straightforward. The amount of charging locations will correspond with the daily arrival and presence of EVs in the Binnenstad. In the light of parameter selection this is justified as a logical assumption, as the arrival of employed workers mostly results in day-time parking of a vehicle until the end of the working hours. As the night-time demand appears to remain smaller than the daytime demand, providing sufficient charging locations for the daytime should be sufficient to cover night-time charging demand as well, within the limits of the model by Frade et al.

A comparison with the available parking locations in present day will form the method to assess the 'impact' of these charging locations. With the one-for-one principal, a reduction in parking locations would be the first spatial implications that can be assessed. The current supply of public parking locations is a figure which is hard to obtain, but the council of Utrecht provides figures and projections on current and future parking situations in the Binnenstad district. In table 7 the current supply of universal parking spaces is presented, with the addition of the location and owner.

Location / type	Number of universal parking spaces	Owner
Binnenstad, street level parking	2.300	City of Utrecht
Binnenstad, parking garage	300	City of Utrecht
Binnenstad, parking garage	1.500	Private, Corio, Interlarding and Q-Park
Utrecht CS area	2.300	City of Utrecht
Jaarbeurs	6.500	Private, Jaarbeurs
Utrecht CS area	future: 1.800	City of Utrecht

Table 9: Number of parking spaces in the city centres (Gemeente Utrecht, 2013)

Summing all parking facilities mentioned, the total for the Binnenstad comes to 10.600 parking spaces, with the mentioned future expansion around Utrecht CS towards 12.400 parking spaces. The future expansion is based on the assumption that the council continues expansion projects as described in the Nota Stallen en Parkeren, published by the council of Utrecht in 2013, stating an additional 1.800 parking spaces.

To create a comparison, table 6, presenting the current and future charging demand, is used to create table 10. Table 10 shows the amount of parking spaces available (either 10.600 or 12.800), the amount of EVs for 2015, 2020 and 2025 in the district Binnenstad and the share of parking spaces which could be converted to meet the demand. The first column shows the year, the second column shows the amount of available parking spaces, varying between the current 10.600 and future 12.400. The third column presents the number of EVs during daytime hours and the last column shows – under the assumed 1:1 ratio EV and charging location- the percentage of parking spaces that should converted to charging locations to supply sufficient charging locations.

Year	Parking spaces in Binnenstad	Number of EVs in Binnenstad (daytime)	Parking spaces converted to Charging locations (percentage)
2015	10.600	220	2.1%
2015	12.400	220	1.8%
2020	10.600	488	4.6%
2020	12.400	488	3.9%
2025	10.600	2533	23.9%
2025	12.400	2533	20.4%

Table 10: Percentage of parking spaces claimed by EVs 2015-2025

Under conservative assumptions – described in 4.2, 4.3 and 4.4 – Table 8 indicates that a EVs-market expanding in the expected pace has a substantial impact on the availability of parking spaces, and creates a substantial spatial implication. EV adaptation was projected as 11.4% of the national vehicle fleet, but makes a claim on the parking space supply that ranges between 20% and 23,9%. in a time span of 10 years.

Implications resulting from EVs-market growth for 2020 and 2025

With a 1.09% market share of the national fleet, the demand during daytime hours in district Binnenstad is defined as 198 vehicles. During night-time hours, this demand is calculated as 43.5 vehicles. Under the assumed 1:1 vehicle-charging location ratio, the impact on the parking infrastructure -with a total of 10.600 spaces – is calculated as 2.1%.

When assuming comparable parameters with regards to households, employment volume and the ratio vehicle – charging locations, the future demand projection shows a growth of the spatial implication by EVs. In the near future – the year 2020 -, the spatial implications of charging locations will double and range from 4% to 4,6%. In 10 years – the year 2025- the spatial implications will have grown to a range between 20,4% and 23,9%, resulting in a spatial implications that is 10 times greater than the current spatial implications in 2015.

Calculating these figures shows that the growth of the EVs-market can have a substantial impact on spatial implications, even though the future market share is set at 11,4% of the national vehicle fleet. This research therefore will continue by comparing the projected spatial implications resulting from the demand calculations to the spatial policies and structure visions for the district Binnenstad in the next chapter, Chapter 5.

Chapter 5

Discussion and Conclusion

5.1 Results: The effects of a growing EVs-market on district Binnenstad

This research was set out to explore the spatial implications of the growing electric vehicles market, and the relevant charging network, in the context of a Dutch historical city centre. The Binnenstad, the city centre of Utrecht, was selected as research area based on a number of noticeable characteristics. First of all, the historical value of buildings, streets and canals in the area create a limitation for spatial developments, as the district was constructed in the course of hundreds of years. Parking vehicles in the district is therefore heavily regulated, so to reduce the impact of traffic. Preserving the historical aspects and spatial quality level is mentioned in policy documents and 'mobility visions' of the city of Utrecht, and will result in further and stricter limitations of developments in the area (Gemeente Utrecht, 2012)

In light of the developing EVs-market, however, research aimed at investigating the spatial implications of such supporting charging networks and their repercussions for policies and visions as those pertinent to the city of Utrecht seems highly necessary. Charging networks for electric vehicles are fundamentally different from regular vehicles, causing spatial implications resulting from vehicles visiting the district. (Chen, 2013) Literature on the effects of electric charging networks is focused on calculating demand and supply standards, implementing charging technology and the rationale of charging locale in the context of a growing electric vehicles fleet.

Relevant scientific literature, however, did not provide information regarding urban situations where space is, as in the case of Utrecht's city centre, limited. Here, electric charging technology has additional spatial implications compared to those documented in literature, as the spatial character of historical centres limits the possibility to place (thus, locate and site) a sufficient charging network within the reach of end-users. The lack of literature specifically focused on the topic of spatial implications led to the formulation of the following main research question:

"How do the growing market of electrically powered vehicles and the accompanying charging network influence the overall availability of parking spaces in Binnenstad district of Utrecht?"

As this main research question is too complex to answer as is, a subdivision of relevant aspects is created by the following sub-questions:

1. *What is the "status-quo" regarding parking both non-electric and electric vehicles in the Binnenstad district?*
2. *What is the current demand for an electric vehicles charging network in the Binnenstad district?*
3. *How does the expanding EVs-market affect the demand for electric vehicle charging networks?*
4. *Which consequences does an expanding EVs-market have for the availability of parking space in the Binnenstad district?*
5. *How does the growing EVs-market affect the mobility and spatial visions for the district Binnenstad?*

To reply to the main research question, the sub-research questions were answered as reported below[1].

1. *What is the "status-quo" regarding parking a non-electric and electric vehicle in the Binnenstad district?*

The current parking situation in the Binnenstad district consists of 10.600 parking spaces. Users of any vehicle either pay an hourly rate to use a parking space, or can apply for a parking permit if conditions set by the local council are met. Rates differ per zone, which are divided in an A, B1 and B2 sections. Sections located closer to the city centre will have higher hourly rates, to discourage parking a vehicle in the city centre. All sections are accessible to vehicles, on the condition of paying the hourly rate. Failing to do so will result in a fine or removal of the offending vehicle. The satisfaction rate for parking a regular vehicle in the Binnenstad district can be considered low, with a positive review by 24,4% of the residents, and a negative review by 50,6% of the residents. (WistUData, 2015).

Users of an electric vehicle are allowed to park at dedicated charging locations without paying the hourly rate, for the duration of recharging the vehicle. Charging locations are clearly indicated by signage and markings and are not to be used by regular vehicles. Parking a 'regular' vehicle on an EV's charging location is sanctioned with a fine of up to €90,-, which excludes regular vehicles from using an EV's charging location. Users of an EV that leave the electric vehicle on a charging location after a completed recharging cycle are sanctionable for the same offense, and are forced to move the vehicle if fully recharged. The current supply of public charging locations was briefly investigated in chapter 2, resulting in a supply of 48 public charging locations on universally accessible locations and 24 charging locations on restricted (i.e. carparks, private property) locations. (Gemeente Utrecht, 2013) (Oplaadpalen.nl, 2015) (Gemeente Utrecht, 2015)

2. *What is the current demand for electric charging network in the Binnenstad district?*

Adapting the model by Frade et. al (2011) for the district Binnenstad first provided a demand calculation for 2015. Results of the calculation resulted in a presence during daytime of 210 electric vehicles[1]. Calculating the daytime presence of any EV configurations resulted in a presence of 220 EVs. Presence was divided between PHEVs and FEVs by applying the accompanying market share percentages per configuration, resulting in a divide of 198 PHEVs and 22 FEVs. PHEVs are prone to faster recharging than FEVs due to their small on-board battery package. The average daily driving distance for an electric vehicle in or to Utrecht was set at 50 km. Assuming each user aims to use the electric range of the vehicle to the full potential, PHEVs are assumed to recharge during each presence within the area, as the battery pack provides a range of 30 km. Recharging an FEV, with an average set range of 100 km is assumed to take place once every 2 days, reducing the recharging demand. Applying the recharging regime to the presence of EVs in the district Binnenstad resulted in a daytime charging demand during daytime hours for 198 PHEVs and 11 FEVs.

[1] Unless specified differently, the data reported in this section are the data calculated in Chapter 4.

Chapter 4 provided a calculation for the night-time demand, which resulted in a calculated presence of 4200.5 vehicles during nightly hours. Applying the market share for EVs, both PHEV and FEV, produced a night-time presence of 41.2 PHEVs, and 4.6 FEVs.[1] Assuming the same recharging regime as described in the daytime calculation, this creates a night-time charging demand for 43.5 EVs.[1]

The results of the calculation show that daytime charging demands in 2015 exceed the present supply of public charging locations. Night-time demand is theoretically satisfied, when assuming the user of an EV is prepared to park the vehicle across the entire district to be able to charge the vehicle. If a 1:1 rationale is assumed in the vehicle – charging location relation, a necessity for 198 charging locations is identified by the calculation.

3. *How does an expanding EVs-market affect the demand for electric vehicle charging networks?*

The Rijksdienst voor Ondernemend Nederland (RVO) projects a growth of the EVs-market share to 200.000 electric vehicles in 2020 and 1.000.000 electric vehicles in 2025. ING Bank expressed a growth projection of the national vehicle fleet to 8.400.000 vehicles in 2020 and 8.800.000 vehicles in 2025 (ING Bank, 2015). Combining these two projections resulted in a EVs market share of 2.4% in 2020 and 11.4% in 2025, which enabled the research to create a charging demand projection for the district Binnenstad. In 2020 the daytime presence of EVs is calculated as 488 vehicles. Five years later, in 2025the daytime presence of EVs grows to 2533 vehicles. The predictive nature of this calculation and the available data did not allow identifying separate market shares for EVs and PHEVs, it was assumed that the majority of EVs would have a charging need when present in the district Binnenstad. Night-time presence of EVs was calculated under the same assumptions, which resulted in a presence of 102 EVs in 2020 and 528 vehicles in 2025. These results support the assumption that a sufficient charging network for daytime presence of EVs is able to supply a sufficient charging network to satisfy the night-time charging demand.

Calculating the daytime presence of EVs supports the statement that a growing EVs-market affects the demand for charging networks positively by increasing the charging demand, and with that, increase the spatial implications EV users will make with their vehicle. District Binnenstad has a significant growth in projected charging demand, which, when adopting the 1:1 rationale for vehicle – charging location, creates a claim by charging locations on 2,3 % of the parking spaces in 2020, rising to 20.1% of the available parking spaces in 2025. A growing EVs-market will affect charging demand in such a way that, when assuming every present EV needs a charging location, the demand for charging locations will grow and reduce the availability of universally accessible parking spaces.

4. *Which consequences does an expanding EVs-market have for the availability of parking space in the Binnenstad district?*

Growth of the EVs market results in a number of implications for the Binnenstad district. First, the spatial implication of a charging location when it is constructed as to replace a regular parking space has a spatial implication for the Binnenstad. (AgentschapNL, 2015) The creation of a sufficient number of charging locations results will claim 20.1% of the parking spaces in 2025. Second, the share of EVs in 2025 is calculated as 11.4% in chapter 4, where the reduction of parking spaces by the charging network is 20.1%. The growth rate of the EVs-market results in a growing spatial implications caused by EVs, when adopting the 1:1 policy on vehicles and charging locations. Third, the growth of the EVs-market will amplify the stress on the parking system in Utrecht. The supply of parking space is limited and 50.6% of end-users (residents) are not satisfied with the availability of parking. (Wistudata, 2015) The addition of a new and vehicle-specific parking location that replaces universal parking spaces will further reduce this supply of universal parking spaces. If the construction of charging locations is aimed at providing sufficient charging locations for EVs present during daytime, the claim on parking spaces by charging locations could affect the availability of night-time parking spaces for residents as well.

5. *How does the growing EVs-market affect the mobility and spatial visions for the district Binnenstad?*

In Chapter 2 the current and future policies on mobility, vehicle parking and spatial quality provided a selection of goals set by the city of Utrecht. The mobility vision '*Utrecht aantrekkelijk en bereikbaar*' expresses the desire to reduce local emissions of Greenhouse Gasses (GHG) by stimulating electric mobility and supplying sufficient networks for electric vehicles in the district Binnenstad. The city of Utrecht aims to expand the supply of electric charging networks by installing 90 charging locations in the years up to 2020. It remains unclear if this addition is aimed at the city of Utrecht as a whole, or solely district Binnenstad. (Gemeente Utrecht, 2015) (Gemeente Utrecht, 2012) Promotion of electric mobility in district Binnenstad is part of the strategy aimed at preserving and stimulating spatial quality. Other measures in this strategy focused on different aspects that supported the realisation of spatial quality. Spatial quality within district Binnenstad is improved by restricting traffic to local traffic and the reduction of on-street parking facilities. Measures from the mobility vision to improve spatial quality - the promotion of electric mobility and supplying sufficient networks- seem to be conflicting with other measures that aim to reduce traffic within the Binnenstad and reduce parking spaces.

The answers of the sub-questions provide the necessary insights to discuss the findings of this research in view of elaborating, in the next section, on the main research question.

5.2 Discussion

Scientific literature provided numerous examples of demand calculation for charging electric vehicles at the start of this research. Topics ranged from an expressed need to exponentially increase the number of electric vehicles or charging locations (the chicken-egg effect described by Gnann et. al (2015) to the experiences and practices of so called 'early adapters / adopters'. This research has added to the existing knowledge by creating a projection of future charging demand and the accompanying charging networks necessary to sustain the growth of this new mobility technology.

The methodology used is not one that has been proven by practice. It is a demand calculation executed under the following assumptions.

- Every vehicle entering the research needs a charging location.
- All arriving traffic during daytime hours is work-related, and is parked in the area for the duration of the working day.
- All vehicles present during night-time will leave during daytime, and vice-versa
- The share of electric vehicles arriving in the subject area will be equal to the share of electric vehicles in the national vehicle fleet.
- EV users want to use the full electric potential of their vehicle at all times

By reviewing literature provided by the city of Utrecht, the RVO and the Dutch government, it became clear a strong desire to reduce GHG emissions is present in current policy. Electric mobility is seen as a measure that could provide immediate emission reductions and should therefore be stimulated and facilitated. Review of the policies by the city of Utrecht also revealed that applications for public charging locations are treated on a user-need basis, and are constructed according to expressed demand from EV users. (Gemeente Utrecht, 2015) (Gemeente Utrecht, 2015)

On the topic of parking spaces, the city of Utrecht acknowledges a non-sufficient supply of parking locations and aims to increase the number of parking spaces in the district Binnenstad to solve these shortcomings. Mobility vision '*Utrecht Aantrekkelijk en Bereikbaar*' contradicts this desire by introducing the measure of reducing on-street parking and restricting traffic to the district to improve spatial quality. Strangely, the promotion of electric mobility and the accompanying networks are seen as a solution to improve spatial quality as well, although the spatial implication of an EV is substantially more complicated and, according to the calculations, larger than that of a regular vehicle. (AgentschapNL, 2015) (Gemeente Utrecht, 2015)Calculating the current and future charging demand of electric vehicles formed the second leg of this research. The results of this calculation provided an indication of a spatial implication in the near future and indicated increasing spatial implications of charging locations.

Although making a projection of the future charging demand, this research is not able to provide a precise figure of necessary charging locations. Further research towards recharging behaviour, electric vehicle adaptation rates within the research area and improving electric vehicle driving ranges would be necessary to create a pin-point demand projection. Conservative estimations of driving ranges, adaptation speed and daytime traffic flows are able to support the final results of the charging demand calculation in a different scope. As an example, the input data for traffic flows towards the research area consisted solely of home-to-work trips, where the reality would show that other reasons for vehicle movement would increase the presence of vehicles within district Binnenstad even further. Assuming conservative values for the parameters did enable this research to support the assumption that the need for sufficient networks will grow exponentially in the near future, and indicates a large and – after analysing current policy- unforeseen spatial implication by the charging networks if the adaptation to electric mobility is conducted under current policies.

Developments on the technological side of the electric mobility concept could influence the spatial implications of a growing EVs-market. Examples in the form of wireless charging technology, fast-charging technology expansion and improved battery packages will however not reduce the projected spatial implication, as these technologies still demand a dedicated parking location to recharge the vehicle. Under the current parking legislation, the vehicle has to leave the charging location after completing the recharging process, leaving a dedicated empty charging location until the next recharging process starts.

5.3 Conclusion

This research was structured with a main research question:

"How does the growing market of electrically powered vehicles (EVs), and the relevant charging network, influence the overall availability of parking spaces in Binnenstad district of Utrecht?"

The answer to the main research question is provided by distilling the answers of the research sub-questions, as they numerous insights in the effects, perception and adaptation of electric mobility. As both the calculation and the literature part of this research provided noticeable results, the answer is a combination of both literature review and calculation results.

A growing market of electrically powered vehicles and the accompanying charging networks will, under the current policy, reduce the overall availability of parking spaces in district Binnenstad. The spatial implication of charging location as it is constructed in 2015 creates a reduction of 20,1% in universal parking spaces between 2015 and 2025, when the market share of EVs is 11.4%. Structure visions and ambition documents incorporate electric mobility to reduce GHG emissions and improve spatial quality, but do not address the spatial implications of sufficient accompanying networks. (Gemeente Utrecht, 2012) Constructing sufficient charging locations for the EVs-market development rate conflicts with the spatial visions, which aim to reduce on-street parking locations and limit the presence of vehicles, but create an exception for the electric vehicle. Distilling the results of this research creates the impression that the city of Utrecht is not aware of the spatial implications of a growing EVs-market, or the contradicting goals in spatial policy documents. In a district of such historic value, which already present challenges when parking a vehicle, treating a development with such spatial influence should be treated with a structural and integral approach that benefits residents, EV-users and the district Binnenstad in the next 10 years. EVs are no longer an incident, but a structural change, and should be treated accordingly.

5.4 Recommendations

With the conclusion of this research come recommendations for the city of Utrecht to streamline a future implementation of the EV, accompanied by recommendations for future research in this topic.

From a scientific point of view, this research provides two recommendations on possible future research in the light of the growing EVs-market. Given the use of general figures for vehicle market shares, traffic flows and adaptation towards EVs, it is advantageous to further investigate the actual adaptation towards electric vehicles amongst citizens and visitors in city centres. The higher level of precision and accuracy would create a tool that is able to predict the demand within district accurately, and could help implement the exact demand for charging technology within spatial designs and visions. From a scientific point of view, this tool could improve the accuracy (and with that implementation) of future spatial planning practices.

Spatial and urban planners will need to conduct further research on the spatial implications of mobility technology shifts and their claim on urban living space. As these mobility systems utilize a new method of energy storage and supply, the spatial implications deserve further attention in situations of restricted public space. A spatial component in the form of determining optimal physical locations for charging stations would form a logical addition to this research. With developing charging technologies, relocating the charging networks to fast-charging locations in non-urban settings (comparable to the fossil-fuel distribution network) might prove to be beneficial for the spatial quality of city centres.

A societal impact of a growing EVs-market was indicated in this research. The council of Utrecht would benefit its residents and the city by changing its approach of electric mobility and its demands. Growing market shares and diversification of the market show that the development of electric mobility is not an incident, but a substantial part of future spatial developments and should therefore be treated accordingly. Current and figures indicate a shortage of charging locations and large spatial implications, supporting the need to start acting on an integral level. Improving the projections and further specifying the necessary amounts of charging locations is one, but a structure document aimed at the physical location of charging locations would complete the integral approach for both EV-users and residents. Furthermore, the city of Utrecht has to define the role of the EV in spatial policies. The current vision document '*Utrecht aantrekkelijk en Bereikbaar*' is not aware of the consequences described in this research, and therefore contains contradicting measures for the next 10 years. Spatial implications of a mobility choice include implications for every stakeholder in the city centre of Utrecht.

Act, define and implement, the time of installing symbolic charging locations is over, the age of a mobility shift has arrived.

Bibliography

AgentschapNL. (2015). *De stekker in elektrisch vervoer, maar hoe?* Agentschap NL.

Allego. (2015). *Laadoplossingen in de openbare ruimte.* Opgeroepen op 2015, van https://www.allego.nl/bedrijven/laadoplossingen/laden-in-de-openbare-ruimte/

ANWB. (2015, August 1). *Motorrijtuigenbelasting*. Opgeroepen op September 15, 2015, van ANWB: http://www.anwb.nl/auto/autobelastingen/mrb

BOVAG. (2015). *Het kopen van een elektrische auto*. Opgeroepen op 2015, van http://bovag.nl/thema-s/het-kopen-van-een-elektrische-auto

CBS Statline. (2015, 12 15). *Statline.* Opgeroepen op 1 12, 2016, van http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=71405ned&D1=7%2c13-22&D2=0&D3=10-15&HDR=G1%2cG2&STB=T&VW=D

Chen, K. K. (2013). The electric vehicle charging station location problem: A parking-based assignment method for Seattle. *92nd Annual Meeting of the Transportation Research Board* (p. 20). Washington DC: Transportation Research Board.

De Gennaro, M. (2015, January). Customer-driven design of the recharge infrastructure and Vehicle-to-Grid in urban areas: A large-scale application for electric vehicles deployment. *Energy*, 1-18.

Engbue, L. (2012). Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. *Energy Policy*(48), 717-729.

Frade, G. R. (2011). Optimal Location of Charging Stations for Electric Vehicles in a Neighborhood in Lisbon, Portugal. *Transportation Research Record, 2252*, 91-98.

Gemeente Utrecht. (2012, January). *Utrecht Aantrekkelijk en Bereikbaar.* Opgeroepen op September 2015, van Gemeente Utrecht: http://www.utrecht.nl/fileadmin/fileshare/images/DSO/verkeer/AantrekkelijkBereikbaar/Ambitiedocument/2012_01.pdf

Gemeente Utrecht. (2013). *Nota Stallen en Parkeren 2013.* Opgeroepen op 2015, van Gemeente Utrecht: http://www.utrecht.nl/images/DSO/verkeer/Verkeerenvervoerbeleid/pdf/Nota_Stallen_en_Parkeren_2013.pdf

Gemeente Utrecht. (2015). *Dit is Utrecht.* Opgehaald van http://www.utrecht.nl/fileadmin/uploads/documenten/2.concern-bestuur-uitvoering/Onderzoek_en_cijfers/Dit-is-Utrecht-2015.pdf

Gemeente Utrecht. (2015). *Parkeren in Utrecht*. Opgeroepen op July 2015, van Website van Gemeente Utrecht: www.utrecht.nl/parkeren/

Gemeente Utrecht. (2015, July 1). *Utrecht elektrisch, elektrisch rijden in Utrecht*. Opgeroepen op July 30, 2015, van Website van de Gemeente Utrecht: http://www.utrecht.nl/utrecht-elektrisch

Gemeente Utrecht, Utrecht Monitor. (2015). *Utrecht Monitor 2015.* Opgeroepen op 2016, van Utrecht Monitor.

Gennaro. (2015). Customer-driven design of the recharge infrastructure and vehicle-to-grid in Urban area's: A large scale application for electric vehicles deployment. *Energy*, 1-18.

Gnann, P. &. (2015). How to address the chicken-egg-problem of electric vehicles? Introducing an interaction market diffusion model for EVs and charging infrastructure. *ECEEE Summer proceedings - First Fuel Now* (pp. 873-884). Researchgate.

Hatton, C. (2009). Charging Stations for Urban Settings the design of a product platform for electric vehicle infrastructure in Dutch cities. (p. 13). Stavanger: EVS24.

ING Bank. (2015). *"Vergrijzing stuwt wagenpark".* Opgehaald van https://www.ing.nl/media/ING_Vergrijzing-stuwt-wagenpark-november-2015_tcm162-93116.pdf

National Resources Defence Council. (2007). *The Next Generation of Hybrid Cars: Plug-in Hybrids Can Help Reduce Global Warming and Slash Oil Dependency.* Opgeroepen op 2015, van https://www.nrdc.org/energy/plugin.pdf

Oplaadpalen.nl. (2015). *Laadmethodes*. Opgeroepen op 2015, van Oplaadpalen.nl: www.oplaadpalen.nl/w/laadmethode

Parkeerwet Utrecht. (2015). *Beleidsregels uitgifte parkeervergunningen en garageplaatsen 2015.* Opgeroepen op 2015, van Ontwerp collegebesluit gemeente Utrecht (Kenmerk: MM14.502163): https://zoek.officielebekendmakingen.nl/gmb-2014-74295.html

Pierre, J. L. (2009). Driving an electric vehicle. A sociological analysis on pioneer users. *ECEEE Summer Study: Act, Innovate, Deliver, Reducing energy demand sustainably* (pp. 1437-1444). ECEEE.

Regiocanons. (2015). *Regiocanon Utrecht*. Opgeroepen op September 15, 2015, van http://www.regiocanons.nl/utrecht

Rijksdienst voor Ondernemend Nederland. (2011). *Elektrisch Rijden in de versnelling.* Opgeroepen op 2016, van http://www.rvo.nl/sites/default/files/bijlagen/Plan%20van%20aanpak%20-elektrisch%20rijden%20in%20de%20versnelling-.pdf

Rijksdient voor Ondernemend Nederland. (2015, July 1). *Cijfers Elektrisch vervoer*. Opgeroepen op August 1, 2015, van Rijksdienst voor Ondernemend Nederland: http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/...

Siemens. (2015). *Charging modes for electric vehicles by Siemens*. Opgeroepen op 2015, van http://w3.siemens.com/powerdistribution/global/en/lv/green-applications/electromobility/pages/charging-modes-for-electric-vehicles.aspx

Times Higher Education. (2014). *Times Higher Education Ranking 2014*. Opgeroepen op 2015, van https://www.timeshighereducation.co.uk/world-university-rankings/2014/reputation-ranking#!/page/3/length/25

Van Dijken, K. (2002). *Parkeren in Nederland.* Zoetermeer: IOO B.V.

Van Vliet, B. K. (2010, January). Energy use, cost and CO2 emissions of electric vehicles. *Journal of Power Sources, 196*(2011), 2298-2310.

Visiedocument Utrecht. (2012). *Utrecht: Aantrekkelijk en Bereikbaar.* Utrecht: Gemeente Utrecht.

Wistudata. (2015). Utrecht in Cijfers. Opgeroepen op 2016, van Utrecht in Cijfers.