DUTCH PUBLIC EV CHARGING INFRASTRUCTURE DESIGN

A MULTI-CRITERIA DECISION ANALYSIS

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Preface

Dear reader,

I proudly present you my thesis report for the MSc Complex Systems Engineering & Management (CoSEM). This graduation project marks the end of two delightful years at TU Delft. When I started this master's program, I would have never imagined that the energy sector would fascinate me so much. Moreover, I certainly not expected that I would get excited about EV chargers. Although it is not the charger itself is that fascinates me, but the potential of a whole intergraded network of chargers. The first steps to an electric mobility system are taken, but I am utterly confident that many will come.

This report is the result of an engaging graduation project. I have experienced all different energy states, but I am proud of what I have accomplished. I could not have done this without the help of several people that supported me through this process.

First and foremost, I want to thank my supervisors. Jan Anne, with whom I had bi-weekly contact. Thank you for helping me structure this thesis, your quick and straightforward feedback, and the pragmatic meetings. I often felt relieved after a meeting with you, which supported me in continuing this thesis. Also, I would like to thank Zofia. Thank you for the helpful advice and for the pleasant feedback sessions. Mylene, thank you for being my advisor. I really appreciated your inspiring insights and new research directions, but also when I felt a little overwhelmed by all the information, you helped me set boundaries. I wish you all the best with your PhD. And of course, Jesse, thank you for being my practical perspective on this thesis topic. You have really welcomed me into your team, were always willing to answer my questions, and pushed me to talk with people in the field.

I also want to thank my family and friends for their unconditional support during my master's. My parents and sister, for always having faith in me and showing your pride. Finally, I would like to thank my fellow CoSEM students Marthe and Sabina. You have made this graduation project a lot more fun.

I hope you enjoy reading it,

Willemijn Hofmans

Delft, August, 2021

Executive summary

Public charging infrastructure serves as essential support in facilitating the sustainable use of EVs. In densely populated areas, such as the Netherlands, EV users do not have access to a private parking spot and thus rely on public charging infrastructure. The charging point operator (CPO) is responsible for the public charging infrastructure's management, maintenance, and operation. The growing demand for EVs brings new challenges around designing and operating the corresponding public infrastructure for the CPO. The form this infrastructure will take is uncertain due to the wide range of charging technologies available (and many more in the pipeline) and varying policy instruments. These influences make it difficult to find consensus for designing a public infrastructure.

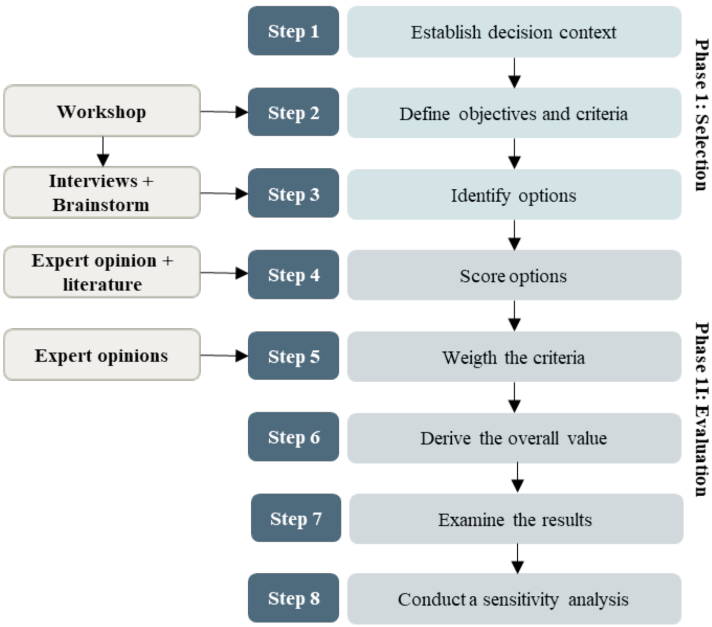
A literature study identified the following two research gaps: (1) insufficient studies investigated combinations of technical innovations and policy instruments to improve the success of public charging infrastructure, and (2) the perspective of the CPO is undervalued in current literature.

From this knowledge gap, the following research question can be derived:

What is the most preferred set of technical innovations and policy instruments to improve the success of public charging infrastructure in Dutch cities from the perspective of the CPO?

A study that combines the aforementioned knowledge gaps has not been conducted before.

In order to answer the identified research question, a multi-criteria decision analysis (MCDA) was chosen as the main research method. This method is applicable to the identified problem because the objective of the MCDA is to provide an overall ordering sets of technical innovations and policy instruments, from the most preferred to the least preferred set. This way, the MCDA supports the CPO in making infrastructure design decisions. The analysis consists of the following sequence of steps:



The methodology of this research can be subdivided in two phases: the selection of the most preferred sets of options (I) and the evaluation of the most preferred sets of options (II).

The first phase consisted of different research methods. First, a definition workshop with six electric mobility experts was executed to derive a comprehensive understanding of the objectives of the CPO.

This understanding led to the identification of assessment criteria on which the identified sets were scored in the evaluation phase. Subsequently, interactive interview sessions with eight stakeholders with different backgrounds were executed to identify a wide variety of technological innovations and policy instruments. This resulted in over hundreds of possible combinations. A data reduction method was developed to funnel the options to four most preferred sets. First, a set of selection criteria was applied that consisted of scope of the research, feasibility of implementation within ten years and clustering similar options. Subsequently, the perspectives of the municipality and EV user were taken into consideration to derive the degree of acceptance on the remaining options. The options with the highest degree of acceptance were included. This resulted in the final sets.

In the evaluation phase, these sets that were selected as having the most potential were scored on the assessment criteria by use of the software program Definite. This program was useful to execute the sensitivity analysis. In the evaluation phase, four experts were asked to rank and prioritize the identified criteria. Based on their selection, weights were allocated to the respective criteria. In order to score the sets on the assessment criteria, a combination of literature, expert options (7) and logical reasoning was used.

This methodology resulted in four possible sets of options, which are: a quantity driven design (set 1), a quality driven design (set 2), a hybrid design (set 3) and a purely institutional design (set 4). The table below exhibits the technical (T), financial (F), institutional (I) and social (S) components of each set.

Table 1 Overview of the components the four most preferred sets consist of.

	Set 1: Quantity-driven design	**Set 2: Quality-driven design**	**Set 3: Hybrid design**	**Set 4: Purely institutional design**
T	Automatic decoupling	More connections per charger	Charging hub Dynamic crossing	No technical adjustments
F	Decreasing tariff	Lower night tariff	Decreasing tariff	None
I	2 spots exclusively for EV	2 spots exclusively for EV	None	Time slot with enforcement
S	None	Push to stop session	Push to stop session	None

The sets displayed above were evaluated on nine assessment criteria. This evaluation was a first attempt to examine if a significant ranking of the sets can be found in order to find one most preferred set. This analysis led to the conclusion that the quantity-driven design seems to be the most preferred set. However, the values of the sets ranged from 0,52 to 0,71 (with 0 being the absolute worst and 1 being the absolute best). The main take-away of the sensitivity analysis on both the weights and scores was the heavy impact of varying weights on the outcome. Also, variations in the following three criteria are perceived as having the most impact on the outcome of the evaluation: number of charge sessions (C1), charged kWh per session (C2) and average charge fee (C3).

Ultimately, it can be concluded that a quantity-driven design (set 1) is perceived to perform the best on the assessment criteria. By performing the sequential steps of the MCDA, different scientific and practical contributions were derived.

The biggest scientific contributions lie in providing deeper knowledge about the objectives of a CPO. A comprehensive objective tree is a valuable contribution to current research. Also, the MCDA is performed in a new creative way, in which more emphasis is given to the option generation process. This research developed a helpful approach to deduce the number of options. In general, the scientific

contribution is the provision of knowledge on available combinations of technical innovations and policy instruments. This academic approach is also valuable in practice since many pilots are conducted based on intuition without an underlying scientific foundation. The evaluation table can be utilized in order to make substantiated infrastructure design decisions.

By conducting this research, several assumptions are made that influence the outcome. The most decisive assumption was to focus on the charged kWh per charging unit. This assumption narrowed down the research scope, which was beneficial for sake of time. Nevertheless, it also led to the exclusion of technical innovation potential, such as using smart charging to sell flexibility. Further research on this potential is therefore recommended. Moreover, limitations in the applied research methods led to recommendations for further research. Further evaluation with larger groups of respondents can be especially meaningful in deriving the degree of acceptance, prioritization of the assessment criteria and scoring the sets on these weighted criteria. Besides including a larger group of respondents, it would be suggested for future analyses to use new research findings as well.

In addition to scientific recommendations, practical recommendations can be derived from this study. It is recommended for the CPO to use this MCDA as a foundation to make charging infrastructure decisions. One plausible implementation scenario according to the researcher's knowledge would be a combination of a quantity-driven design (set 1) and more a quality-driven design (set 2). These sets were ranked first and second, but the deviations are small. Moreover, set 1 is more effective for charging during day, whilst set 2 is more effective for overnight charging. Therefore, it is suggested for the CPO to implement them simultaneously. In order to execute these sets effectively, the CPO should coordinate with different stakeholders. The municipality is important for location determination, strategic set-up enabling, providing standards and communication strategies to EV users. The service providers are needed to implement new billing models and ensure that the prices are transparent for EV users. This suggestion shows that there is a mutual dependence between the municipality and the CPO, indicating an overlap of the public and private domains. Such overlap, complexity, number of stakeholders involved, and combination of technical and institutional aspects, make this thesis a typical CoSEM research.

Keywords: Charging point operator, public charging infrastructure, multi-criteria decision analysis, electric transport

List of abbreviations

EV	Electric Vehicle
ICE	Internal Combustion Engine
CPO	Charging Point Operator
MSP	Mobility Service Provider
CI	Charging Infrastructure
NKL	National Knowledge platform charging infrastructure
NAL	National Agenda charging infrastructure
RAL	Regional Agenda charging infrastructure
QN	Quantity-driven design
QL	Quality-driven design
H	Hybrid-design
I	Purely institutional design

Table of contents

List of Tables

List of Figures

Chapter 1 Introduction

This thesis starts by introducing the challenges regarding public infrastructure design in the Netherlands. Building on these identified challenges, a literature review was conducted. Based on the literature, the two main research gaps addressed in this thesis were identified. Identifying these knowledge gaps led to the research objective, which resulted in the formulation of the leading research question. This chapter concludes by illustrating the outline of the following chapters.

1.1 Problem background

The Climate Agreement states that the Netherlands must reduce CO2 emissions by 49% by 2030 (United Nations, 2015). Several industries need to shift from fossil fuels to alternative energy carriers to reach this target. A vital industry to focus on is the transport sector, as this sector alone contributed to 14% of the global CO2 emissions in 2015 (International Energy Agency, 2016). Electric Vehicles (EVs) have shown great potential to reduce CO2 and local emissions (Wolbertus, 2020). Therefore, the Dutch government decided that by 2030, all new vehicles should be 100% electric (Formula E-team, 2016).

Not only national governments have acknowledged the need for zero-emission kilometers. Urged by the need to improve air quality, municipalities have actively facilitated electric mobility. Municipalities acknowledged the necessity for public charging infrastructure for the sustainable uptake of EVs (Zhang et al., 2020). Especially in densely populated areas, such as the Netherlands, EV users do not have access to private parking spots and thus rely on a public charging infrastructure (Zhang et al., 2020). This necessitates the need for public parking facilities. However, at the initial phase of the development of electric mobility, the so-called chicken-or-egg problem existed (Wolbertus, 2020). The market seemed to fail in creating sufficient infrastructure. Hence, Dutch municipalities decided to take the leading role and invested in infrastructure to stimulate the uptake of EVs. This decision was successful and resulted in the Dutch metropolitans being the frontrunner in the electrification of the mobility sector. Compared to other European metropolitans, the Netherlands has the highest level of available public charges and a low degree of EVs per public charger (Hall & Lutsey, 2020).

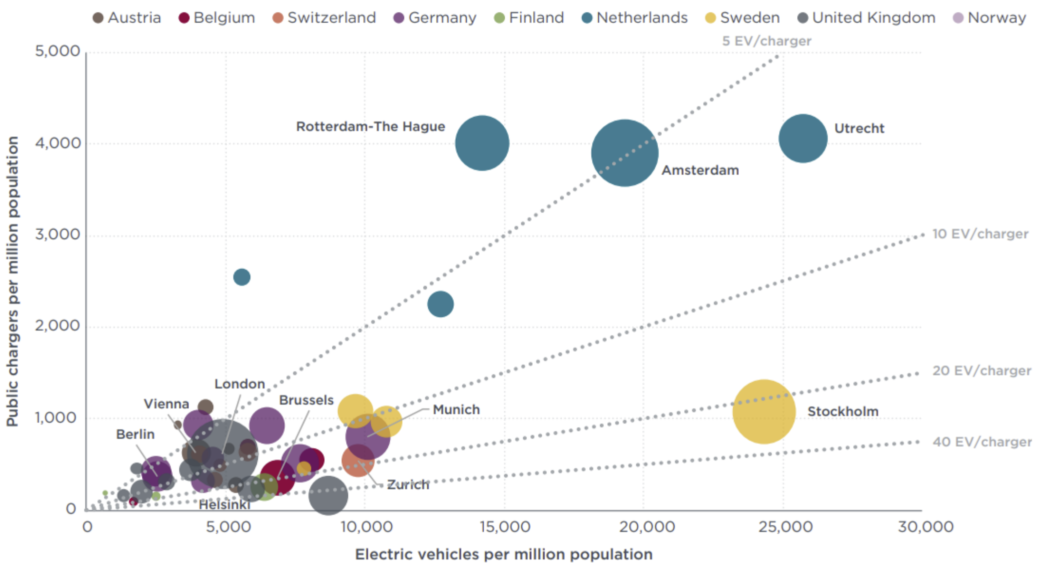


Figure 1 Charging infrastructure and electric vehicle concentration in major metropolitan regions (Hall & Lutsey, 2020)

The numbers of public EV charging points in the Netherlands have increased from 1,250 in January 2012 to 63.185 in November 2020 (Netherlands Enterprise Agency., 2020) and continue to grow (Helmus et al., 2018). The 'Nationale Agenda Laadinfrastructuur' (NAL) even presents measures to have 1.9 million electric vehicles in the Netherlands by 2030. The development of (public) charging infrastructure is expected to follow the growth of EV sales (International Energy Agency, 2016). The NAL predicts that 1.7 million charging points are required to meet future demand. The growing demand for EVs brings new challenges around designing and operating the corresponding public infrastructure.

Now that the market for public charging infrastructure in the Netherlands is evolving, the responsibility for investing in sufficient EV-charging infrastructure has shifted toward the charging point operator (CPO). The CPO is responsible for the charging infrastructure's management, maintenance, and operation (Netherlands Enterprise Agency, 2019). The retreat of the municipalities urges market parties, such as the CPO become self-sufficient. The CPO faces challenges in successfully design and deploy the infrastructure.

The first challenge regards the many ongoing developments in both charging techniques as electric vehicles, making it difficult to predict what infrastructure and policy the future requires. According to Lee and Clark (2018), the many possible charging techniques make it complex to find consensus regarding the set-up of a successful infrastructure in the future. Although the precise design of the infrastructure is uncertain, one thing is for sure: there will be charged more in the future. This makes it difficult for the CPO to make the right investment decisions. The second challenge refers to optimize the success of the infrastructure. Van Montfort et al. (2016) defines the success of public charging units as the average charged kilowatt-hours per day. Initially, the focus predominantly lay on expanding the existing EV-charging infrastructure to deliver more power. Nevertheless, seeing that sufficient infrastructure is realised at a certain point in time, a new strategy should be implemented to become self-sufficient.

1.2 Literature review

Building on the identified challenges, a literature review was conducted regarding the design of public infrastructure. The aim was to investigate what research is conducted on infrastructure design and the CPO's role. This review resulted in the identification of two knowledge gaps: (1) insufficient studies investigated combinations of technical innovations and policy instruments to improve the success of public charging infrastructure, and (2) the perspective of the CPO is undervalued in current literature.

1.2.1. Perspective of the CPO in current research

The CPO has different objectives for facilitating charging infrastructure than the municipality. The municipality focuses on providing sufficient infrastructure while managing scarce parking resources (Wolbertus, 2020), while the CPO prioritizes a positive business case (Helmus 2016).

In the initial development phase, when the municipalities were the key players on the market, research focused on infrastructure roll-out strategies from the municipality's perspective. The research focused on reducing (local) air pollution and increasing the adoption of electric vehicles (Wolbertus, 2020). The scope has shifted towards providing sufficient infrastructure while managing scarce parking resources (Wolbertus, 2020). This line of research focuses on planning and location determination.

Extensive research on roll-out strategies is conducted by Helmus et al. (2018). In this study, the researchers compare demand-driven and strategic roll-out strategies. Demand-driven roll-out entails that an EV user requests a charging unit for a selected location. The strategic roll-out entails that local and regional governments decide where to place chargers near public facilities strategically. It was found that demand-driven roll-out was effective for immature infrastructures, thus in the first phase of infrastructure development. Strategic roll-out is preferred at places with high network densities, such as Dutch cities, as EV adoption is high and the response time of demand-driven roll-out is too low. The two roll-out strategies that were compared predominantly focus on infrastructure planning, an essential objective for the municipalities. Frade et al. (2011) identified that municipal policy focuses on efficient planning of charging infrastructure to meet the demand of EV users. Their research focused on the location aspect of planning charging infrastructure.

In this line of research, various studies developed models to optimize the location of EV infrastructure (Xi et al., 2013)(He et al., 2013). Moreover, Askrof et al. (2019) found that technical charging characteristics, such as the availability of fast charges and charging duration, influence the route choice of EV drivers significantly, which can be taken into account for the location determination of chargers.

However, only this line of research is not sufficient anymore due to the shifted key player role from the municipality to the CPO, which has different objectives than a municipality.

The CPO prioritizes a positive business care (Helmus 2016). The business case is predominantly based on energy sales, not on incentivizing the driver to improve their charging behaviour (Wolbertus, 2020). Currently, CPOs are investigating possibilities to improve the efficiency of their operations without interfering with the user experience (Wolbertus, 2020). Thus, the CPO has a more practical research objective than the municipality. The CPO is interested in what technical innovations are best to invest in and which policy instruments can incentivize optimal use. This led to identifying a second knowledge gap, namely the lack of research that combines these two aspects.

1.2.2. Combination of technical innovations and policy instruments

The majority of literature investigates either technical innovations or policy instruments to improve (public) EV-charging infrastructure. However, a combination is lacking. This section describes what current research has investigated on technical innovations and policy instruments.

Technical innovations

A substantial number of studies have investigated different charging techniques. The Amsterdam University of Applied Sciences research projects have gathered and analysed data of Dutch public charging infrastructure (van den Hoed et al., 2019). They have investigated various charging techniques over the years, such as AC and DC charging stand-alone sockets with two outputs and charging clusters (van den Hoed et al., 2019). More futuristic studies have reviewed wireless charging techniques (Ahmad et al., 2017). Moreover, researchers have investigated smart charging techniques such as flex power (van den Hoed et al., 2019).

However, no research was found that compared alternative charging techniques for public applications. Only a report of the National Knowledge Platform for Public Charging Infrastructure (NKL) researched alternatives for regular public charging points. With this research, they aim to exchange knowledge between different municipalities. This research conducted a small factor analysis (technical, financial, organizational, and spatial). Trends in charging techniques stated in this report are multifunctional objects, clustered charging, underground charging, inductive charging, and different grid connections (NKL, 2019).

Policy instruments

CPOs seek instruments that stimulate the practical usage of charging units (Wolbertus et al., 2018). In the literature was found that the majority of the studies focus on financial incentives to influence EV user behaviour. Extensive research was conducted in the PhD study of Wolbertus (2019). In this study, he analysed how price incentives play a role in charging behaviour (Wolbertus & Gerzon, 2018). They found that a time-based fee can result in a higher effectiveness of charging stations. This shows that the efficiency of a charging point can also be increased by behaviour change of EV drivers. Similarly, the study of Globisch et al. (2019) found that EV drivers are unwilling to pay a fee for a public-charging spot.

Social incentives are expected to improve the charging behaviour. Limited research is executed that explores social incentives to improve the charging behaviour of EV users. However, research on this social charging behaviour showed that 57% of EV users are willing to share charging points with other EV users (Helmus et al., 2020). These researchers even expect that a 20-50 percent increase in charging point utilization can be reached. This shows that the potential of social incentives is considerable.

1.3 Research objective

From the literature review can be derived that the shift of responsibility from the municipality to the CPO resulted in a mismatch of scientific studies available and practical recommendations required. The CPO desires an academic foundation that supports them in making investments decisions. Currently, literature is behind on these needs. It is concluded that a fast-growing demand for electric charging infrastructure necessitates the need for a scientific framework to base investment decisions. This framework should combine technical innovations with policy instruments.

Therefore, this research aims to explore different sets of combinations of technical innovations with policy instruments to increase the success of public charging infrastructure from the perspective of a CPO and conceptualize how these combinations of options score on assessment criteria. This way, the aforementioned research gaps can be addressed. In order to fill these gaps, it is chosen to apply a multi-criteria decision analysis as the primary research method (see section 2.1). By applying this method, it is aimed to support the CPO in making charging infrastructure decisions.

1.4 Resulting research question and sub-questions

These research objectives resulted in the following main research question:

What combination of technical innovations and policy instruments is preferred to improve the success of the public EV-charging infrastructure in Dutch cities from the perspective of the charging point operator?

The following sub-questions are derived in order to answer the main research question.

1. What is the decision context for the CPO with regards to public EV-charging infrastructure?
2. What are the critical objectives for the CPO, and how can performance on these objectives be measured?
3. Which combinations of technical innovations and institutional instruments are suitable for improving the success of EV-charging infrastructure?
4. How do the combinations of options score on the predefined assessment criteria?

Although the perspective of the CPO will be central in this research, other stakeholders' perspectives will be acknowledged as well. Section 3.2 identifies the other key stakeholders that are apparent in this research.

1.5 Outline of this thesis

This thesis consists of seven chapters, of which the first chapter is this introduction. The following chapter is a comprehensive methodology description. Scientists can consult this chapter by interest in repeating or evaluating (parts) of this thesis. This methodology is also applicable for practitioners interested in conducting a multi-criteria decision analysis (MCDA). Chapter 3 starts by describing the Dutch system context around e-mobility and determines the scope of this thesis. Chapter 4 derives the objectives of the CPO. Here, the definition for a successful charging infrastructure from the perspective of the CPO is derived. Ultimately, from these definitions, assessment criteria to evaluate the success are derived. In chapter 5, the option creation process is described. The conclusions of this chapter are especially interesting to consult for practitioners. Subsequently, chapter 6 performs the first attempt to evaluate the options that were found in chapter 5. This thesis ends with a conclusion, discussion, and recommendations in chapter 7. Readers that desire a direct answer to the research question are directed to this chapter. Subsection 7.3 contains interesting recommendations for both scientists and practitioners.

Chapter 2 Methodology

This chapter describes the methodologies applied in this research. In this chapter explains what research methods were applied, why these methods were chosen, and how these methods were executed. The methodology starts with the overarching research approach, which was the multi-criteria decision analysis (MCDA). Subsequently, the various research methods applied to execute the steps in an MCDA are described in separate sections.

2.1 Multi-Criteria Decision Analysis (MCDA)

The objective of the MDCA is to provide an overall ordering of the sets of technical innovations and policy instruments, from the most preferred to the least preferred set (Dodgson et al., 2009). The MCDA is a formal model to make decisions by an analytical approach (Belton & Stewart., 2002). This analysis applies to decision problems that contain a high degree of complexity. The method is useful for decisions that have long-term impact and therefore require reasonable consideration (Belton & Stewart., 2002). The context in which the CPO should make charging infrastructure decisions is complex. The consequences of their investment decisions define the future infrastructure design. Once infrastructure decisions are made, it is not easy to change them. This makes it difficult for the CPO to make the right charging infrastructure decisions. The many innovations in the pipeline and policy instruments available complicate these kinds of infrastructure decisions even more (Lee & Clark, 2018). The advantage of an MCDA is that it can structure a wide variety of combinations and provide focus. Another aim of an MCDA approach is to minimize the post-decision regret (Belton & Stewart., 2002). However, it is essential to understand that an optimum does not exist in a multi-criteria analysis (Belton & Stewart., 2002). As Keeney et al. (1979) summarize: MCA is a formal analysis to promote good decision making.

Ultimately, this thesis aims to determine the most preferred set of technical innovation and policy instruments for the CPO to implement. Therefore, an outranking method is applied. In such a method, the options are ranked to find the preference of one option over another, based on predefined selection criteria (Belton & Stewart., 2002). An MCDA consists of the following eight steps (Dodgson et al., 2009). The figure below represents these steps. Subsequently is described what the subsequential steps entail.

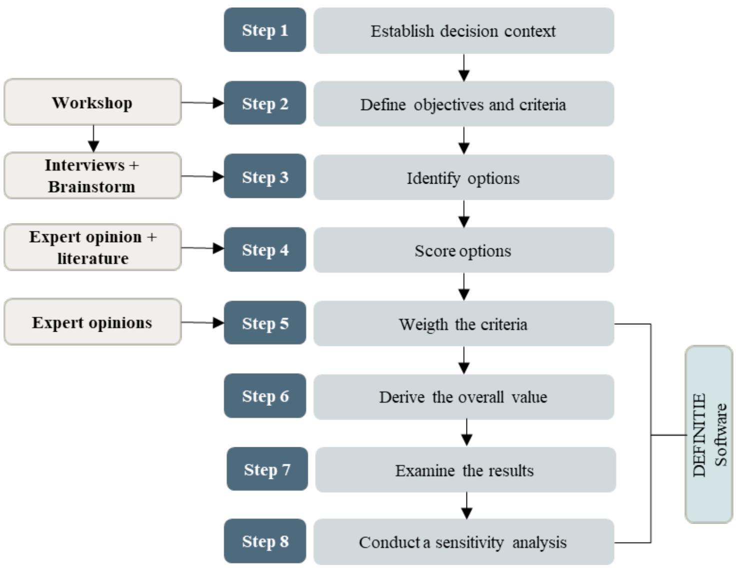


Figure 2 The applied MCDA process. Adapted from Dodgson et al (2009)

1. Establish the decision context

The first step of the MCDA was to establish the decision context. Before exploring possible options to increase the success of EV charging infrastructure, it was deemed essential to understand the current system characteristics. Since the focus is on public charging infrastructure in Dutch cities, the socio-technical aspects of this system are defined. However, Dutch cities are not homogenous. Therefore, was chosen to take Amsterdam and Rotterdam, leaders concerning charging infrastructure, as a reference. Chapter 3 describes the results of this analysis.

2. Objectives and assessment criteria

In the second step, the critical objectives of the CPO were defined. The identification of these objectives resulted in the focus for further steps in the MCDA. The process to find the focus and definition is illustrated in the figure below. The workshop methodology is explained in section 2.2.

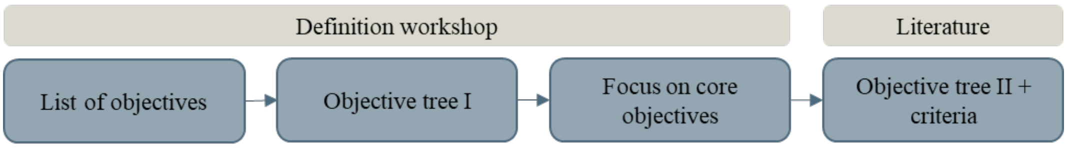


Figure 3 Process to find the objectives and assessment criteria.

As illustrated in figure 3, the workshop's output is used for the first three steps in the process. The criteria are derived after determination on what core objectives the focus lies. From these end-objectives, corresponding criteria were derived based on the literature.

3. Identify and describe the sets of options

The third step was to identify sets of technical innovations and policy instruments to increase the success of public EV charging infrastructure. For this purpose, interviews were conducted. These interviews are supplemented with output from the workshop. Section 2.3 describes the interview process.

The interviews resulted in more than a thousand combinations of options. Selection criteria were applied to deduce the number of options. This resulted in four technical options, but still over 100 options to effectively execute these technical innovations. The remaining options have been subjected to the objectives of the E-driver and the municipality. This second deducing method aimed to find the most relevant sets. Finally, four sets were constructed. Section 2.3 describes this process in more detail. The results can be found in chapter 5.

4. Score each option against the criteria

In this step, the four final sets are scored against the criteria. The criteria are scored on a plus and minus scale that varied from -- to ++. It was chosen to score these effects on a scale because there was no data available to score it on a more detailed level. Therefore, it was chosen that indicating the changes (performance increase or decrease) would be more insightful. The method used to obtain these scores is explained in sections 2.4 and 2.5. The results can be found in chapter 6.

5. Weight the criteria

The criteria are prioritized based on the opinion of four E-mobility experts. The expected value method is applied to obtain the weights. Section 2.5 explains this method in more detail. The final weights are displayed in chapter 6.

6. Derive the overall value

In this step, the outcomes of step 4 and step 5 are combined by multiplying the scores by the weights. In this way, the overall value of each set of options is derived. This analysis is conducted in the Definite software program by applying the Weighted Summation Method (Janssen & van Herwijnen, 2011). Section 2.5 explains why and how this software is used to examine the results.

7. Conduct a sensitivity analysis

The final activity was to conduct a sensitivity analysis to find the effect of other preferences or weights on the overall ordering of the options. The ranking is dependent on the scores and weights. Therefore, changes in scores or weights may influence the ranking (Janssen & Herwijnen., 2011). This analysis is conducted in the Definite software program. Section 2.5 explains how this software is used to examine the results.

8. Examine the results

In this step, the rank of sets of options is examined. This examination can be found in chapter 6. This also served as input for the conclusion and discussion in chapter 7.

2.2 Workshop methodology

To find the objectives of a CPO, a workshop was conducted with six participants.

Table 2 List of workshop participants (WSP) and their expertise

Interview ID	Company	Function	Background/expertise
WSP1	ENGIE	E-mobility consultant	Management of Technology
WSP2	ENGIE	New business developer	Complex Systems Engineering & Management
WSP3	ENGIE	Project Lead E-mobility	Strategic Innovation Management
WSP4	ENGIE	Management Trainee	Engineering Policy Analysis
WSP5	ENGIE	Management Trainee	Sustainable Energy Technology
WSP6	ENGIE	Data scientist	Industrial Design

The goal of the workshop was to construct an objective tree and to define assessment criteria. This approach supports discussion and collaboration of objectives (Borysowich, 2016). A workshop is better to find overlapping objectives and combine them. For this purpose, a workshop is preferred over interviews.

A three-step process was performed to find the critical objective and corresponding criteria. The first step was to identify a list of objectives. Subsequently, a hierarchical model (objective tree) was constructed. Finally, the criteria to measure the performance on the objectives were derived.

The initial list of objectives was created by brainwriting. Brainwriting is a relatively simple technique but very effective. The idea of brainwriting is to give the participants five minutes to write down their ideas in silence. After five minutes, every participant explains the ideas they wrote down. This technique has two benefits. It ensures that all participants think about the subject, and it reduces hierarchy influences between participants. Additionally, many ideas are generated to start with (Mansfield, 2019).

In the second step, a hierarchical model of the objectives was derived. This hierarchical model is also known as an objective three. The notes were categorized and moved around to find different hierarchy levels. The idea is that the overall objective is the end goal. The most critical trade-off between the objectives formed the first level objective (Dodgson et al., 2009). These objectives serve as separate objectives and can be broken down into sub-objectives. This process continues until fundamental objectives are found at the bottom of the hierarchy (Dodgson et al., 2009). For these objectives, criteria are derived.

Not only objectives were found during the workshop. The participants already mention different means to reach the objectives. These means, or options, are captured in a separate table in the workshop report. These options can already serve as input for the interviews and the next step in the MCA. This process is indicated with an arrow from the workshop to the interviews in figure 1.

The goal of the workshop was to construct an objective tree and to define assessment criteria. It was chosen to conduct a workshop because this approach supports discussion and collaboration of objectives (Borysowich, 2016). A workshop is better to find overlapping objectives and combine them. For this purpose, a workshop is preferred over interviews.

2.3 Interview methodology

A major part of the options was found during interactive interview sessions with stakeholders from different backgrounds.

Table 3 List of participants (PO) and their role and expertise.

ID	Company	Role	Experience in E-mobility sector (years)
PO1	Joulz	Service Provider	4
PO2	Municipality of Rotterdam	Policy maker (regional)	15
PO3	Ministry of Infrastructure and Water Management	Policy maker (national)	2 (infra since 1992)
PO4	VVE – association for E-drivers	EV interest representative	6
PO5	Royal Haskoning	Consultant	12
PO6	SlimLaden	Service provider	30
PO7	Draka	Marketing developer	2
PO8	Vattenfall UX-designer	Flexibility developer	3

The goal of the interviews was to find suitable options to increase the charged kWh per charger. This section explains why this methodology was chosen and what the interview process was. The interview report can be found in Appendix II. The results are described in chapter 5.

Interviewing is a useful method to gather empirical data in an exploratory stage of research (Sekaran & Bougie, 2016). Interviewing is a suitable method for this research as the goal was to find new combinations of options. There are different types of interviews, for example, structured, semi-structured, and unstructured interviews. The latter is chosen as the approach for the interview sessions. This method is the most flexible in which a conversational approach is applied to gather empirical data. In this approach, the interviewer leads the conversation but can change directions during the interview process. A benefit of such an approach is that it is not limited to a format and can therefore develop new ideas.

The interview process consists of three phases: preparation, execution, and data analysis. Per phase is explained what the subsequent steps in the process were. Figure 4 provides an overview of the whole process.

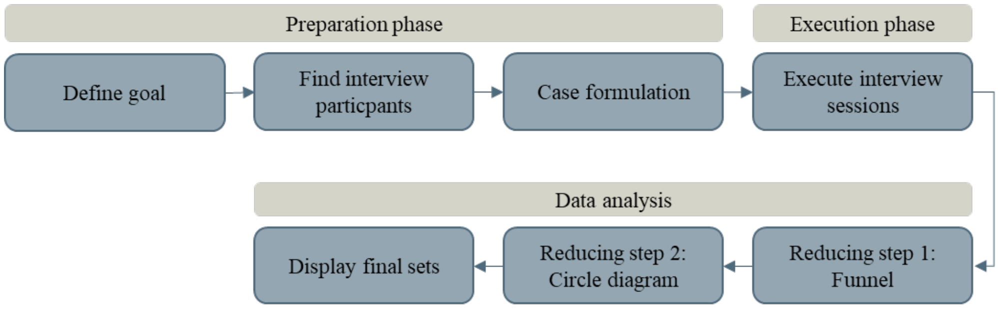


Figure 4 The interview process

The first step was to define the goal of the interview. This goal was defined as finding technical innovations and policy instruments that stimulate better use of the current infrastructure, thus increasing the kWh per charger. Subsequently, a list of interesting participants was created. Since the focus is to find combinations of technical innovations and policy instruments, it was chosen to look for interviewees with different backgrounds. The list of participants consisted of: policymakers, charging point operators, service providers, industry experts, technical experts, grid operators, and consultants. The choice for such a diverse group of interviewees was made to obtain options from different perspectives and to foster discussion and collaboration. It was assumed that combining a policymaker with a technical could lead to new insights. A flyer was made to attract interviewees. This flyer was posted on LinkedIn and can be found in Appendix II. Also, a short presentation in the Future Energy meeting of the consortium was given to create enthusiasm to participate in this research. In this way, eight participants with different backgrounds were found. These participants were divided over different time slots.

Subsequently, a draft interview set-up was made. This draft set-up was prepared with three research experts, that have conducted an immense number of interviews before. Their feedback was to make the question more specific. For what problem are these options important. Therefore, it was chosen to construct a specific case. This case served as a starting point for the discussion. It was chosen to apply the same structure as in the definition workshop, starting with five minutes of brainwriting and opening the discussion afterward. Finally, an informed consent was constructed that can be found in Appendix II.

The tools used for conducting the interviews were Microsoft Teams and Microsoft Whiteboard. In contrast to the workshop, the participants did not have access to this whiteboard. This choice was made to save time. It was difficult to predict the knowledge level and familiarity with the use of Microsoft Whiteboard. Therefore, the participants wrote down the options themselves and communicated them orally. The interviews were recorded to write the interview reports and to derive citations.

During the interview, a presentation explained the goal of the session and the participants' role in it. The researcher also explained the importance of combining technical innovations and policy instruments. At the end of the presentation, the case as illustrated below was introduced. This case served as a starting point for a discussion in Microsoft Whiteboard. The questions served to guide the discussion. It was meant to steer the participants in a particular thinking direction. However, it was important not to limit the participants in their creativity to think of other options. The table describes the type of options for which was sought. Chapter 5 describes the policy framework these definitions are based on.

Situation
The charging point operator is responsible for managing, maintenance and operation of the charging infrastructure. This role is complex since different trends makes it difficult to predict the design of future infrastructure and thus which investment choices should be made.

Problem
Find an optimum between convenience E-driver and the placement of excessively many chargers. Thus optimize the use of a charger.

Interventions
- Behavior: How can we stimulate users to charge more kWh at once? How can we stimulate users to move their car? How can we stimulate a the feeling that we have to share the infrastructure? How can charging moments better aligned
- Technical: How can we ensure a charger is more often available? How can we decrease the duration a car should be connected to a charger? How can we ensure charging security?

Option	Description
Technical	Adjustments in hardware/back office or software
Institutional	Laws and regulations that improve the use of chargers
Financial	Financial incentives to improve use of chargers
Social	Instruments to encourage socially desirable behavior E-drivers
Organizational	Adjustments in governance and interoperability to improve the infrastructure

The interview sessions resulted in an extensive list of options. The recordings were used to write the interview reports that can be found in Appendix II. The number of sets of options to be considered was too large. Therefore, the number of options was reduced by a reduction process.

A so-called short-list of options was created. For creating this short-list, two reducing approaches were applied. The first approach was to apply a set of selection criteria to the options. By applying these criteria, a funnel was created. The second approach was to include the municipality's objectives and the EV users to find the highest degree of acceptance for the remaining options. At the beginning of the reducing process, over a thousand combinations were possible. At the end of the funnel, four technical innovations were left. However, these innovations could be combined with a substantial number of policy instruments. These intermediate results can be found in section 5.3. The two reducing methods are described in more detail below.

Appling selection criteria to the set of options

The first reduction method consists of a funnel in which different selection criteria were applied the reduce the number of options. The first set of selection criteria applied to the scope of the research. Due to the interview process's unstructured nature, not all interviewees' options were applicable for this research. All options that did not apply to the public domain were excluded. Also, options that do not increase the number of transactions or the kWh per transaction were excluded. Chapter 3 explains the reasoning for including these criteria. The second set of selection criteria was the feasibility of implementation within ten years. Finally, the options were clustered based on similarities and differences. This is not a selection criterion, but it did reduce the number of options. Figure 3 illustrates this process. Per phase, the corresponding selection criteria are indicated. The majority of the options were found during interviews; therefore, it has a bigger font size.

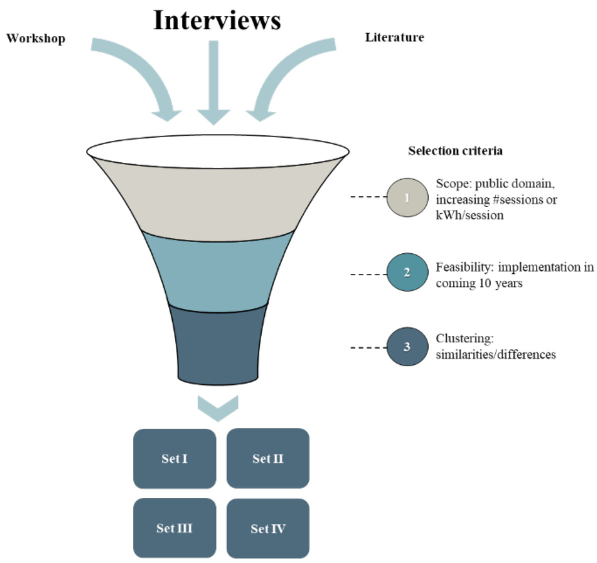


Figure 5 Funnel to reduce number of options based on selection criteria

Circle diagram to find the highest degree of acceptance

Subsequently, a second reduction round was applied based on the degree of acceptance. Here, the objectives of the municipality and the EV user were taken into account as well. A table indicated the degree of acceptance (low, medium, high) per option. The degree of acceptance was defined as the level to which the options met their objectives. The levels were assigned based on interview statements of different stakeholders, a brainstorm session with an E-mobility expert [WSP2], and the researcher's intuition. The options in the core of the circles were selected for combinations with the technical instruments. Figure 6 illustrates this method. Section 5.3 illustrates the completed version of this circle method.

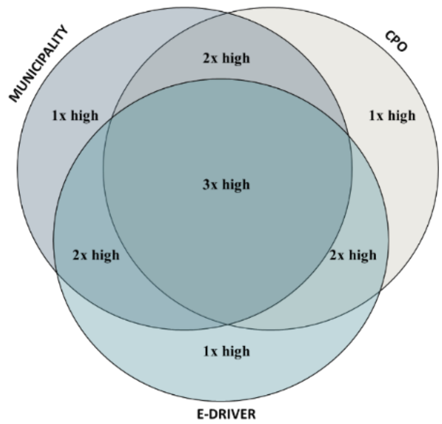


Figure 6 Circle method to find overlapping objectives

2.4 Brainstorm & Expert opinions

A frequently used method throughout this thesis were short brainstorm sessions and expert opinions. For different purposes, this method was applied. The most common purpose was to validate if the statements made were factual or if the expert agreed with the statement. It was also applied to check if certain decisions could be made. For example, in consideration with a researcher, it was chosen not to conduct a specific case study on one Dutch city but generalize it to Dutch cities based on a sample of two progressive cities in the field of charging infrastructure. Experts were consulted in the preparing phase and data reducing phase of the interviews, as explained in section 2.3. Also, in the evaluation phase, expert options were gathered. The following section explains for what purposes experts were contacted.

2. 5 Evaluation methodology

A suitable software program is recommended to perform an effective multi-criteria analysis. The software program can apply weighting methods and standardize the results. In this way, it is relatively simple to generate the results. The advantage of using software is the ease of testing for the robustness of the results by conducting a sensitivity analysis. The software program used for this research is the Definite software from the VU Amsterdam (Janssen & Herwijnen., 2011). This software program was especially chosen because of its simplicity in conducting an effective results analysis. Once the required data is gathered, it is relatively simple to obtain the rank for the different alternatives and perform a sensitivity analysis. Another practical reason that Definite was chosen is that the program developer granted permission to use it.

Step 1: Problem definition

In the first step, the alternatives (sets of options) are entered. Subsequently, the criteria were entered. For each criterion can be indicated what the measurement scale of the criteria is. It was chosen to apply the same measurement scale to all the criteria, namely a --/++ scale.

Step 2: Multicriteria analysis

Definite uses the Weighted Summation to conduct the multicriteria analysis. Weighted summation is modest method a frequently used for evaluations. To perform this method, it is essential that the scores are standardized, and the criteria are weighted. Subsequently, the software program (Definite) multiplies the standardized scores by the weights, followed by summing the weighted scores of all criteria (Janssen& Herwijnen., 2011).

First, the standardization method is chosen. A standardization method is essential when using different measurements of scale. For this research, an interval was chosen. The scores are normalized with a linear function between the absolute lowest score and the highest score. The absolute highest score is indicated with a 1, and the absolute lowest with a 0 (Janssen& Herwijnen., 2011).

Subsequently, the criteria are weighted. The expected value method is chosen to assign weights to the criteria. This choice was made because it is a less demanding method than a pairwise comparison. Therefore, more time can be spent on interpreting the results instead of the exact value of the criteria. For this method, four workshop participants were asked to rank the criteria according to their performance. The most critical criteria formed the first level. Less important criteria are assigned to lower levels. Criteria can be selected as equally important and receive the same level. After entering the levels, the program calculates the weights for each criterion. When completing this step, the definite program ranks the sets by multiplying the scores by the weights. In this way, the overall value per set is derived.

Step 3: Sensitivity analysis

The robustness of the results can be evaluated by performing a sensitivity analysis. The uncertainty in the weights and in the scores can be entered in the software program.

2.6 Research flow overview

A comprehensive overview of the research is provided below in the form of a research flow diagram. This diagram shows the different research phases. Per phase is indicated what chapters it entails. Per chapter is indicated what steps were taken. Every step identifies what the corresponding research method was, what the output was, and what sub-question it answers.

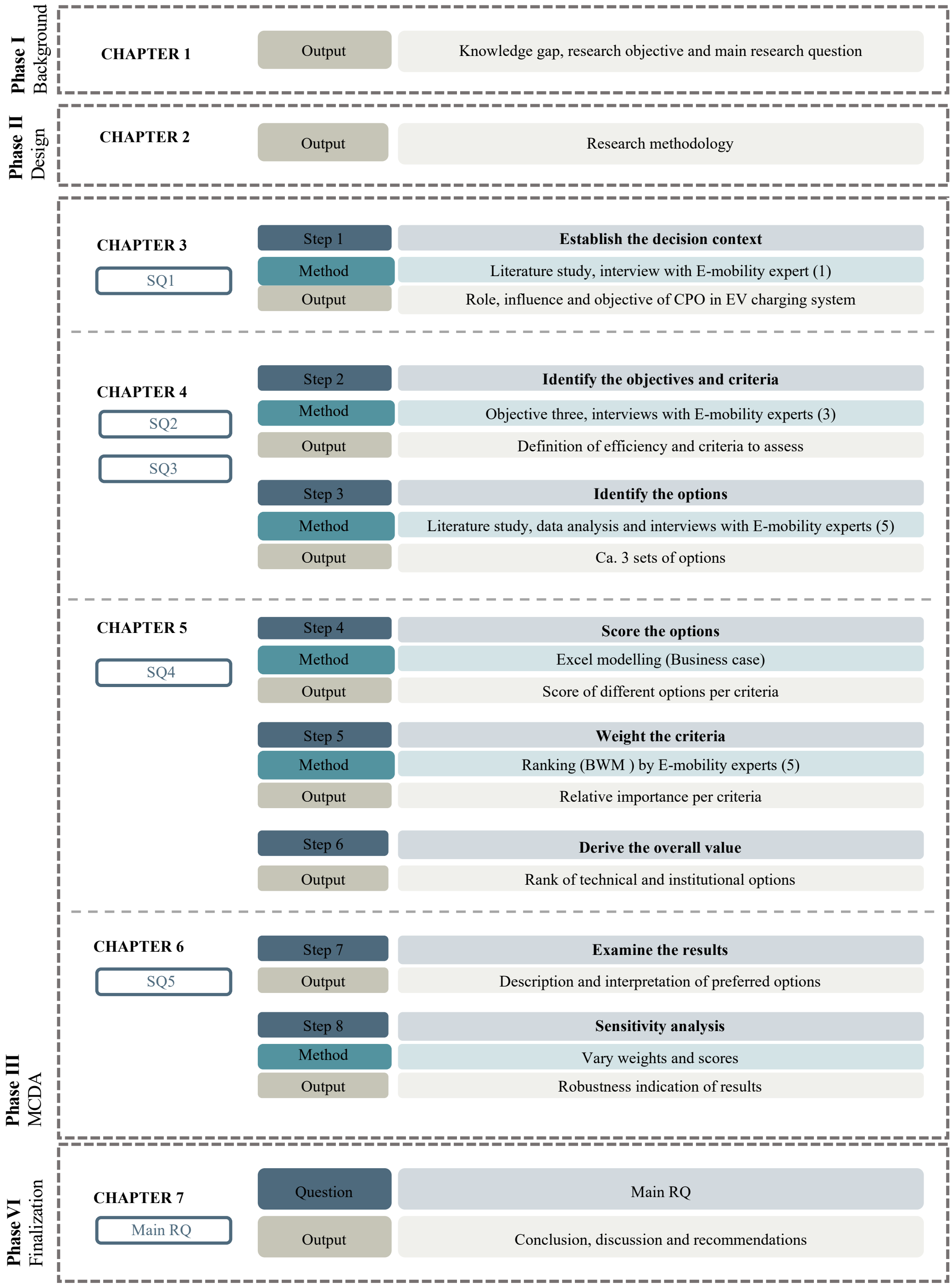


Figure 7 Research flow diagram

Chapter 3 System analysis and decision context

This chapter serves as a foundation for the further steps of the MCDA. It is important to understand the context in which the decision for the appropriate technical innovations and policy instruments are made. For this research, it is essential to understand the current situation first to facilitate the generation of new and better options in the following steps (Dodgson et al., 2009). Therefore, this chapter describes how the current EV charging infrastructure in Dutch cities is designed and operated. In order to understand this, the system is analysed from both a technical and institutional perspective. With this, the main focus is on the role of the CPO within the system. This way, it is deemed to answer the first sub-question:

SQ1 What is the decision context for the CPO with regards to public EV-charging infrastructure?

First, a short overview of the important stakeholders in the system is given, and the CPO's role is further described. After that, the technical and institutional context around EV charging infrastructure is described in more detail. This entails a description of the regional and national policy agendas for urban mobility and the technical configurations that are currently dominant in the public domain. Hence, a sufficient foundation is laid to understand the dynamics and explore options to improve this current system.

3.1 System context and scope

The context around charging infrastructure influences design and policy choices made to improve the EV charging infrastructure. These contexts differ. Hence it is vital to understand for whom the infrastructure should be designed and what essential conditions are. Therefore, it is characterized what public infrastructure in Dutch cities entails.

For this research, two leading choices are made regarding the scope. These are the focus on public infrastructure and the focus on Dutch cities. These two choices influence the preferred infrastructure design.

3.1.1 Public charging infrastructure definitions

The focus of this study is on public charging stations. Charging infrastructure can be defined as public if it provides twenty-four-seven and non-discriminatory access to users (Netherlands Enterprise Agency, 2019). Other groups are private infrastructure (households) and semi-public infrastructure (i.e., offices/theatres/stations), but these are outside this context. The Netherlands knows a ratio of 4 EV drivers per public charger. This is the highest number of EV drivers per charger in Europe (Transport & Environment, 2020). This can is explained by the fact that Dutch EV drives rely more on public charging infrastructure. In other countries, EV drives more often have their own driveway.

A distinction should be made between slow-, regular- and high-power charging points within the public domain. The difference between them is the level of power of electricity transfer that is delivered. Slow charging points have a maximum power output of 11kW, regular charging points have a maximum power output of 22 kW, while high power points (commonly referred to as fast chargers) have a power output around 50 Kw (Netherlands Enterprise Agency, 2019). Developments are ongoing to deliver power outputs above 175 kW (Netherlands Enterprise Agency, 2019). This research focuses on public charging infrastructure in the Netherlands, which are predominantly regular charging points. Section 3.3 further elaborates on the technical configurations of public chargers in Dutch cities.

3.1.2. City characteristics

Cities have two main characteristics: parking and refuelling behaviour of vehicles and many different user types.

The subject area is Dutch cities, primarily focusing on Rotterdam and Amsterdam as frontrunners in the rollout of charging infrastructure. In cities, the facilitation of public charging infrastructure is more critical because most residents do not have their own driveway. This makes them dependent on public spaces to charge their cars. 70% of the Dutch rely on on-street parking (Wolbertus et al., 2020)

What characterizes cities is the combination of charging and parking behaviour of electric cars. This requires a different type of charger units and policy measures. What makes analysis of charging duration particularly difficult in an urban context is that charging units are not solely used for refuelling, but for a combination of parking and refuelling. This interplay between parking and refuelling makes it hard to predict the charging duration. The parking behaviour results in EV users sticking at a charging station, even when fully charged. This makes it hard to predict the time a charger will be occupied and makes demand planning more difficult.

What further complicates the public charging infrastructure design is that EV drivers are not homogenous, but significant differences in charging behaviour exist. Therefore, it is essential to distinguish the most important user types, called E-types, that use the public charging infrastructure. Extensive analysis to identify different user types of EV is conducted by Helmus & van den Hoed (2015). They found five different user types: residents, commuters, visitors, taxis, car-sharing, and logistics. They identified different user patterns in terms of timing, charging amount, and location preferences (Helmus & van den Hoed, 2015). This implies that customized solutions are needed to design public charging infrastructure per city because the user types may differ between cities. It is important to understand the heterogeneity among EV drivers. Section 3.3 describes what E-types are found in Dutch cities.

3.2 Key players and their role

The key players in the multi-criteria decision analysis should be defined first. The key players can make a significant contribution to the MCDA and represent critical perspectives on improving public charging infrastructure (Dodgson et al., 2009). The key players identified are the CPOs, municipalities, charging technique developers (manufacturers), grid operators, service providers, EV drivers, and non EV drivers. This research primarily focuses on the interplay between the CPO and the municipality and the EV users. Those two stakeholders are chosen to focus on as they predominantly influence the choices of the CPO. Figure 8 illustrates the relations between the CPO and the two stakeholders.

Figure 8 Roles of the main stakeholders in this research.

The CPO is the problem owner in this research and the main party for this analysis, as they make investment decisions. The role of a CPO consists of the management, maintenance, and operation of the charging infrastructure for EV users (Netherlands Enterprise Agency, 2019). However, they cannot operate entirely on their own. They can operate within the boundaries that (local) governments set. In the Netherlands, the CPO must tender for a concession for the exclusive right to supply, place and manage stations within an area for a certain period of time. Thus, the municipality determines which party has the permission to roll out and design the infrastructure. In such a concession, the municipality still has an enabling and facilitating role. Vice versa has the CPO an advising role in policymaking for municipalities. As derived from the literature review in section 1.2, the municipality's role in investing in infrastructure is fading as market parties are taking over. This results in more traditional roles of the public and private domain.

The CPO's goal is to improve its operations (providing charging infrastructure and service) without interfering with the user experience (Wolbertus & Gerzon, 2018). Hence, the EV users are important stakeholders because their behaviour influences the decisions of the CPO.

3.2.1 The business case of the CPO

This paragraph roughly describes the business case of the CPO. However, a more nuanced analysis of the objectives is conducted in chapter 4. In chapter 5, the objectives of the municipality and the EV user are described in more detail.

Thus, the CPO is responsible for the facilitation of infrastructure. The main objective of the CPO is to facilitate a viable business case. The business case of charging infrastructure for the CPO consists of the costs and revenues of a charger. The return on investment can be calculated by developing a model to compare the cost with the revenues. In this business model, the sales of the energy transferred determines the outcome. The price that is paid for this energy should be attractive for the e-driver to make the switch to electric driving attractive, but at the same time, it should offer enough margin for the CPO to recover its investment (Blok, 2018).

The NKL states that the costs for public charging infrastructure have significantly decreased compared to 2013. Appendix V can be consulted for a detailed description of these costs. It is expected that the trend of charger cost reduction will continue. This is due to standardization of the charger and the back-office system, the economies of scale, integration with smart kWh meters, optimalisation of the application process, further development of smart charging applications, and optimalisation of the capacity utilization (The Ministry of Economic Affairs, 2017).

The combination of technical innovations and policy instruments influences the outcome of the business case. Therefore, it is described what technical innovations and policy instruments play a role in the current and future charging system in the following section.

3.3 Public chargers in the Netherlands: the current situation

In this section, the Dutch EV charging infrastructure system is described from both a technical as an institutional perspective.

3.3.1 Technical system

The technical side of the system regards to infrastructure and components it consists of. The most important decision that should be made are the type of charger, the connector type, the grid connection, and the charging mode. The table below shows what the most commonly used set of options for public chargers is.

Table 4 Technical configuration of a regular charger in the Netherlands.

Public chargers	
Capacity	Regular charging with a maximum power output of 22kW
Connector type/socket	Two sockets of type 2 (IEC 62196-2), which is the European standard for regular charging
Grid connection	Most commonly one grid connection per charger. Pilots with parking clusters, in which more chargers are connected to one grid connection.
Mode	Mode 3 in which the AC is determined by communication between the charger and vehicle

The difference between a regular charger and a fast charger is the current it delivers. The current in the socket is alternating current (AC), while the batteries in the car work in direct current (DC). At regular chargers, an inverter in the car converts AC to DC. The capacity in this converter determines how much energy is utilized (Netherlands Enterprise Agency, 2019).

Capacity (kWh) is the amount of energy that can be stored in a battery. Power (kW) is the amount of energy a charging station can deliver per unit of time. The average capacity of the eight best sold electric vehicle types in the Netherlands is 60 kWh (Appendix IV). The regular charger has a power of 11 kW. This means that theoretically, it takes 5,5 hours to charge an electric vehicle fully. However, not all electric vehicles can charge at 11 kW, which results in a longer charging time.

What complicates the choice for the required infrastructure are the battery developments. The innovations in battery capacity and switch to BEVs are significantly increasing. The improvements in battery technologies over the past ten years are impressive. The energy densities in batteries are more extensive, while the cost per kW is dropping. Especially Lithium-ion cells have experienced a 70% manufacturing cost decrease due to economies of scale.

For the CPO, monitoring and data analysis to optimize the infrastructure are relevant. Therefore, the charging point communicates with the server of the CPO. By enabling data-sharing, the CPO has the opportunity to analyse the charging behaviour of EV drivers. The figure below illustrates how this works. The OCPP is the so-called Open Charge Point Protocol that provides EV users to access public charging stations with a single charging card (Wolbertus et al., 2018). This stimulates the interoperability of public charging stations and reduces barriers to Electric vehicle uptake. The necessity for such standards is further explained in paragraph 3.3.2.

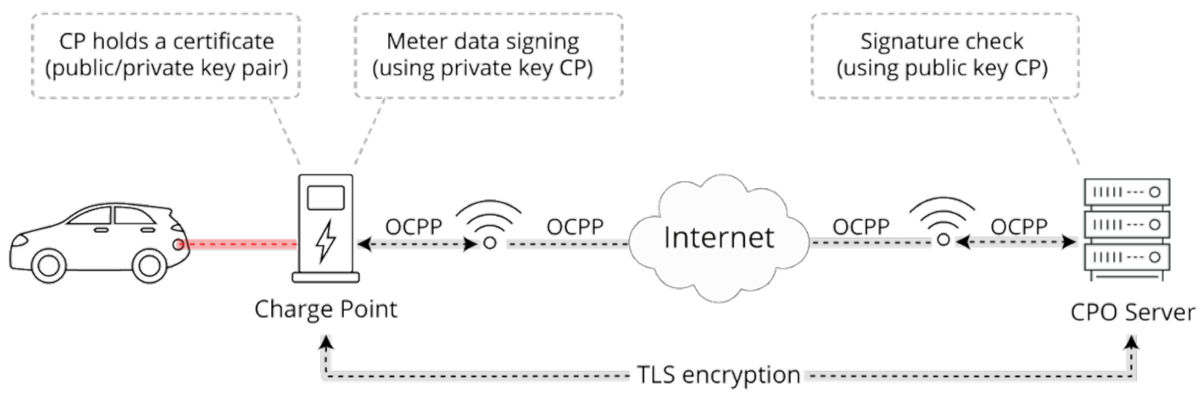


Figure 9 Communication system between charging unit and CPO server

3.3.2 Institutional design

Policies for electric mobility are constantly being developed at the European-, national-, regional- and municipal levels. For example, the municipality of Amsterdam is working on a vision around region hubs, while Dutch national policy is focusing on flexibility of the grid and transparency of charging prices. Simultaneously European standards for charging infrastructures are being developed at the European level.

Local and national governments have been proactive in the facilitation of infrastructure in the Netherlands. In this section, the national and local policies of two different regions in the Netherlands are described.

Dutch national policy

In the Electric transport Green Deal was agreed that a shared vision on the charging infrastructure in the Netherlands would be developed. This vision should address new technical developments, regulations, interoperability and ensure a viable business case (Ministry of Economic Affairs, 2017). In the vision on the charging infrastructure for electric transport by the Dutch Ministry of Economic Affairs, two basic principles for the charging infrastructure are described.

The basic principles for the Dutch policy for infrastructure charging consist of a charging tree and a market model. This market model standardized the payment for making use of the infrastructure. This enabled the interoperability, as a single card can be used to charge at all public chargers (Ministry of Economic Affairs, 2017). Also, this enabled charging an EV driver for consuming electricity, which is at the core of a CPO's business case. The role of the CPO within this market model is to ensure that a charging point is accessible and delivers electricity to an EV user (Ministry of Economic Affairs, 2017).

The charging tray entails that, in principle, EV drivers park and charge on their premises (private infrastructure). If private charging is not possible, cars can be charged at semi-public locations. If a combination of those two is still not sufficient, as is often the case in urban contexts, public charging infrastructure should be accessible to meet the charging demand. In this way, the public space is not overrun by chargers. Also, a basic principle is that the distance between charging points should be 250-300 meters.

Standards are implemented to ensure interoperability and efficiency in the process. The NKL developed a set of fundamental principles regarding public charging infrastructure. This set consists of the requirements of the Netherlands for its infrastructure. This set provides a clear overview of all agreements concerning EV charging infrastructure to which the parties involved should conform.

The most important agreement that influences the development of EVs is the Energy Agreement for electric mobility and transport of the Social and Economic Council of the Netherlands (SER). This agreement states, among other things, that all passenger vehicles sold in 2030 should be electric. This led to significant technology improvement and new EV models. The market is evolving to mass adoption. With the expected growth of charging demand, the business case of public charging is likely to improve.

Local policy

The municipalities have a facilitating and enabling role in the roll-out of charging infrastructure. The municipality has authority that grants a concession for public charging infrastructure. The vision on infrastructure design can slightly differ amongst the municipalities. This is due to slightly different ambitions the municipalities have, i.e., reducing air pollution or grid balancing. Therefore, the 'laadkaders' of Amsterdam and Rotterdam are consulted to extract the main policy choices. The choice for these two cities is made because they are the two leading cities in the Netherlands and serve as an example for other cities.

Table 5 'Laadkader' Amsterdam and Rotterdam. Adapted from Gemeente Amsterdam (2020) and (Gemeente Rotterdam (2020).

	Amsterdam	**Rotterdam**
User types of public charging infrastructure (regular chargers up till 22kW)	Passenger cars, taxis, delivery cars, trucks	Inhabitants, workers, visitors, shared cars, business frequent drivers
Placing strategy (request/strategic/data-driven)	Focus on data driven. Strategic placement on basis of charging need and charging behavior.	Focus on data driven. Also, on request (by e-driver or commissioned by a municipality)
Realization strategy	*'Charging tray'* principle	*'Charging tray'* principle
Financial	Tender based quantity. No price cap. Risk of changing policies for CPO.	Focus on both quantity as quality. Price cap. More focus on service.
Type chargers	Predominantly regular chargers (22 kW). Focus on smart charging and charging clusters (10 charges connected to 1 grid connection)	Predominantly regular chargers (22 kW). Focus on smart charging.

The most significant difference for the CPO is that Amsterdam focuses on quantity, i.e., volume, of charging points. They have not introduced a price cap in their concession. The CPO has to offer the municipality a fixed price per charger that is placed. The price they are willing to offer depends on the business case. This shows that a positive business case is valuable for a municipality as well. Contractionary to Amsterdam, focusses Rotterdam also on quality, i.e., service provision. A price cap stimulates CPOs to compete more on service.

In general, one could state that the user groups that should be focused on in urban contexts are inhabitants, workers, visitors, and taxis. This corresponds to the E-types Helmus & van den Hoed (2015) have indicated. Biros and Light Electric Vehicles (LEVs) are not allowed to charge at public places and, therefore, are not part of public infrastructure users. Moreover, trucks and delivery cars will primarily use charging infrastructure at depots and are not the focus of this research. These user groups make predominantly use of regular chargers.

3.3.3 Financial design

Four different kinds of billing models can be distinguished. The most commonly applied billing model in the Netherlands is currently the flat rate. This means that a fixed price is paid at the charger. This is the simplest model for the CPO since costly connections to IT systems are unnecessary (Günther & Fallahnejad, 2021). However, a flat rate leads to charging station hogging. When more EVs are on the road, this billing model becomes unsuitable. Alternatives to a flat rate are lump-sum payment per usage, billing on used kWh, and on parking time (Günther & Fallahnejad, 2021). Lump-sum payment per user is a method in which every EV user pays a fixed amount for a charging process, regardless of the charger kWh or duration. This method prevents users from charging their battery when it is almost full. However, the CPO needs to prevent users from parking without charging. This method can be misused by using it as a parking solution. A second variation for the CPO is to implement billing on used kWh. This billing method is already much more complex as many additional data and legal requirements should be met (Günther & Fallahnejad, 2021). However, it should be effective to avoid unnecessary charging. The final billing solution is on parking time. For this alternative, the CPO charges higher parking fees for parking spots that have a charger available (Günther & Fallahnejad, 2021).

3.4 Conclusion

This chapter aimed to understand the context in which the CPO should make infrastructure design decisions. Hence, it was deemed to answer the first sub-question. From this analysis can be derived that public charging in urban cities is characterized by a parking and refuelling behaviour. Moreover, various E-types with different charging patterns utilize the public charging infrastructure. In the public domain, primarily type 2 chargers are implemented. These have lower charging rates in general.

The role of the CPO in this context is facilitating and operating the charging infrastructure. The CPO decides in what charging techniques to invest. However, the rules and regulations of the municipality determine the boundaries in which the CPOs can operate. Nonetheless, the boundaries are not that rigid. The CPO can have an advising role for policymakers. This shows that cooperation and coordination between the CPO and municipality are essential.

Chapter 4 Objectives and assessment criteria

This chapter deems to answer the following sub-question:

SQ2 What are the critical objectives for the CPO, and how can performance on these objectives be measured?

In order to derive the assessment criteria, the following process is completed. First, a comprehensive study is executed to identify the objectives of the CPO. These objectives are structured in an objective tree. From this objective tree, the focus on a set of key objectives is chosen. These key objectives served as the foundation to define the required assessment criteria. The criteria defined at the end of this chapter are used to score the options against in chapter 6.

4.1 Identification of the objectives

The choice to write this thesis from the perspective of the CPO has implications on the definition of successful charging infrastructure. Current literature does not explore the objectives of the CPO in great detail. Glombek et al. (2018) define a successful infrastructure rollout such that user convenience is balanced with the investment costs. The main objective of the CPO is defined by Helmus & van den Hoed (2016) as 'facilitate a positive business case.' In both definitions, the focus is primarily on balancing the benefits with the costs. However, this definition could apply to any private company. Therefore, a more sophisticated definition is preferred in this research. Hence, a workshop to find objectives for successful public charging infrastructure is performed to give more dimension to this definition.

4.1.1 The list of objectives

As explained in section 2.2, a workshop was executed to find the objectives of the CPO. The following list of objectives is derived from the definition workshop. See Appendix I for the full report.

Table 6 List of objectives derived from the definition workshop

List of objectives from CPO
The following list of objectives is retrieved from the definition workshop.
Improve convenience for all E-drivers
Ensure that E-drivers can always charge
Create feeling of sufficient chargers available
Minimize failures
Create a viable business case for public charging infrastructure
Increase the kWh/charger
Increase number of transactions
Increase kWh/charger
Minimize failures
Make optimal use of flex power
Find optimum between staying at charger and use of flexible power
Sell HBEs
Increase the predictability
Better forecast the amount of EVs
Better forecast the share of renewables
Create a simple process
Good relation with client and customers
Uniform working principle for chargers
Align different user groups of infrastructure
Good information provision for E-driver
Minimal burden on grid operator

From the list of objectives, different clusters can be derived. Indeed, a significant part of the objectives is directly related to generating a positive business case. Such as: increase the kWh per charger and the sales of HBEs (green certificates for E-mobility). However, there are also clusters found that relate to the soft side of the charging point operator. These clusters relate to improving the convenience for all E-drivers. Objectives as enough charging spots available and good information provision on where and when to charge are part of this cluster. Another interesting cluster relates to the creation of a simple process. WSP4 mentioned:

Easy coordination with municipalities ensures quick response to new situations or demands. Also, the placement process is more straightforward when the relationship with the client is good [WSP4]

From this initial list, three main clusters were derived. These consist of the revenues, the costs, and the EV convenience. Sub-clusters that can be derived were: energy sales, HBE sales, flexibility sales, predictability, process, EV convenience, fixed costs, and variable costs. These identified clusters formed the foundation for deriving the objective tree.

4.1.2. The objective tree

In this paragraph, the list of objectives is converted into an objective tree, as showed in figure 9. An objective tree consists of several levels, starting with the high-level objective (Dodgson et al., 2009). The high-level objective represents the main trade-off. In this research, the main trade-off consists of maximizing revenue and user convenience while minimizing costs. The EV convenience, revenue, and costs are shown as separate objectives in the next level down. These objectives are further broken down into lower-level categories. At the bottom of the objective three, the right in this figure, end objectives are reached (Dodgson et al., 2009). For these objectives, assessment criteria are derived.

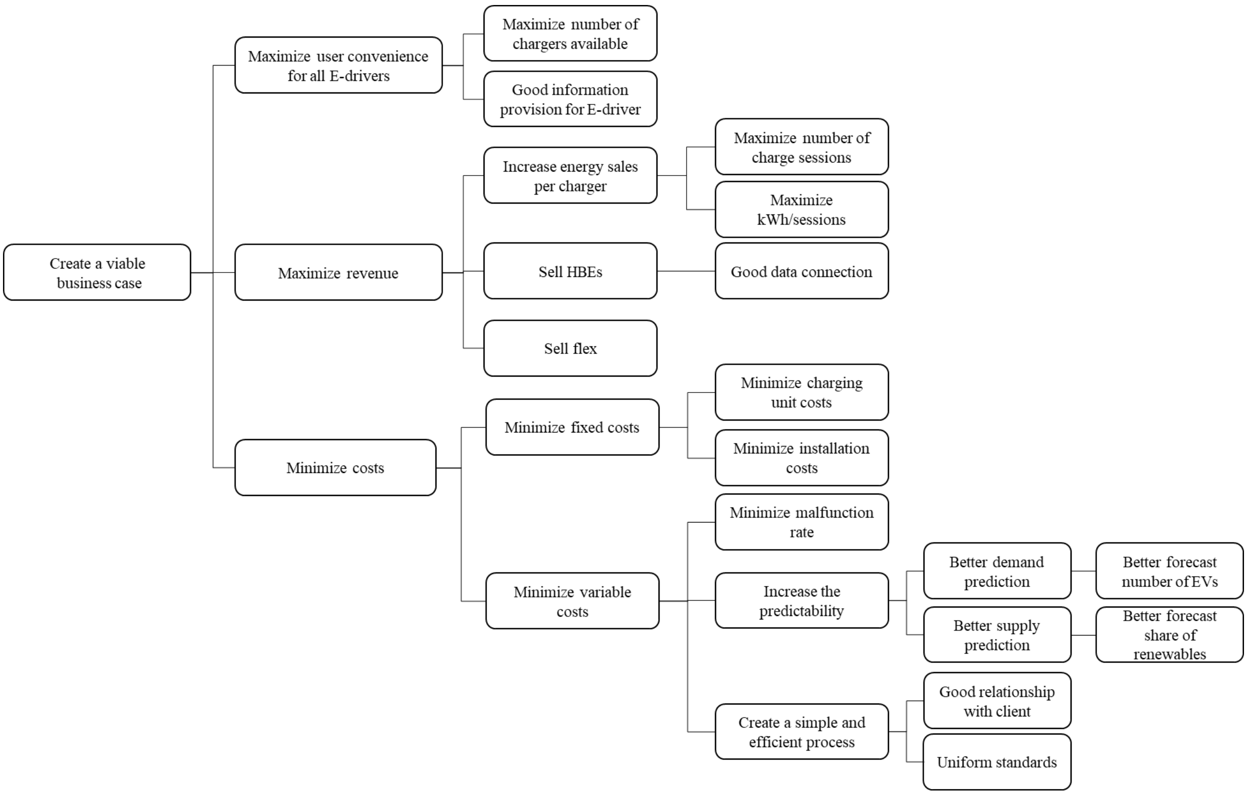


Figure 10 Hierarchical representation of objectives.

Figure 10 shows that the overall objective of this study is to facilitate a positive business case. This objective can be divided into three high-level objectives that form the main trade-off: maximizing revenues and EV convenience while minimizing costs.

Thus, the aim is to maximize the revenue. There are three ways for Dutch CPOs to generate money. The first one is to sell HBE's. These are green certificates for mobility. The Dutch Government allows certificate trading for Energy and Transport. By delivering renewable energy, the CPO can sell HBEs to other companies using fossil fuels (Dutch Emissions Authority, n.d.). Secondly, the CPO can indirectly earn money from the DSO or TSO for flexibility services. The EVs provide demand response in case smart charging is applied. This means that the charging time and speed are adjusted to respond to low market prices (TenneT, 2019). Thirdly, the energy sales per charger can be increased. The energy sales per charger depend on the number of sessions and the amount of kWh charged per session. Thus, it can be calculated by the following formula:

$$kWh/charger = \#\, sessions/\, charger\ * kWh/session$$

It is deliberately chosen to increase the energy sales per charger instead of energy sales in total. This is chosen to avoid the scenario in which excessive placement of chargers would be the best solution to increase energy sales. This scenario is not desired for the CPO because it requires enormous investment costs. Also, the municipality will not allow the CPO to place an excessive number of chargers because of spatial planning objectives and complaints of non EV drivers. Section 4.2 further elaborates on these conflicting objectives.

Next to monetary revenues are the social benefits also important to take into account. This is the objective of the CPO to improve the EV convenience for all E-drivers. All EV drivers involve all the various types of E-drivers that make use of public charging infrastructure. This user experience can be increased by creating a feeling of sufficient chargers available and by good information provision. It is chosen to separate the social benefits from the monetary benefits. Therefore, EV convenience is a separate objective.

On the other hand, it is essential to minimize the costs to create a viable business case. The costs can be subdivided into fixed and variable costs. The fixed costs are the costs of the charging solution and the installation costs. The total costs for installation consist of grid connections, location determination, and parking space design. The grid connection costs largely depend on the grid connection capacity. Municipalities can decide to lower the grid capacity, thus reducing the charging power to save on connection costs. The variable costs are maintenance and service costs. Therefore, a frequently mentioned objective was that the malfunction rates should be decreased.

In an ideal theoretical scenario, we have a 100% uptime, in which we have 100% charge occupancy. Therefore, it is vital to ensure that the charger is always working. When malfunction does occur, it should be able to fix it more remotely [WSP 6]

Other objectives that contribute to the minimization of costs are creating a simple process and increasing predictability. Since the Netherlands uses concession contracts to roll-out public infrastructure, there is close cooperation between the CPO and municipality (client). The CPO acknowledges that a good relation improves the efficiency of the decision-making and placement process. To conclude, increasing the predictability was also a repeated objective.

Energy is purchased ten years ahead, while the market is on 15 min or even seconds. Therefore, we should obtain more information (#EVs, sun/wind, unform rules) to predict energy consumption more precisely [WSP5]

By better forecasting the number of EVs or share of renewables, the energy consumption can be better predicted or shifted.

4.2 Critical objectives and focus of the research

From this objective tree can be derived that the CPO has various objectives to adhere. However, it is not possible to optimize all objectives. Thus, certain choices should be made. As aforementioned, a trade-off exists between the three high-level objectives. It is not possible to maximize the EV convenience, maximize the revenue and minimize the cost simultaneously. For example, the EV-driver would prefer an excess of chargers to ensure a charger is always available. Contradictory, the CPO would prefer to create a shortage to ensure that their chargers are always charging. This stresses the need to find the right balance between different objectives. Also, some objectives have more priority than others. The priority is indicated as the level to which the objective influences the outcome of the business case. Since a viable business case is an overall objective, it is chosen to depict the critical objectives of the CPO based on the influence on the business case.

In section 4.1 are three revenue streams for the CPO described. Increasing the charged kWh per charger is chosen as the focus for this research. All participants acknowledged that this is the dominant revenue stream for the CPO.

The kWh per charger can be seen as a one-on-one business case [WSP2]

The main aim of the CPO is to sell as much energy as possible. If you can maximize that, that is inherently super important for the business case [WSP1]

Although smart charging is increasingly important, the participants estimate the probability that earnings from flexibility would be higher than from selling energy minimal. Thus, it is chosen to focus on increasing the energy sales per charger. However, this should be balanced with EV convenience. EV convenience consists of maximizing the spots available and ensuring good information provision. However, it was noted during the workshop that user complaints do not always match the number of available chargers.

The cohesive feeling amongst EV-driver should be increased. In the beginning, the early adopters believed that electrics driving is fascinating. Now, EVs are becoming cheaper and more widely available. A new type of users that er not necessarily pro electric. The solidarity decreases. Tend to stay longer at a charger, less urge to move vehicle. This behaviour is challenging. Should create a new feeling that we should share the infrastructure [WSP1]

Another core objective is to minimize the costs. It is chosen to focus on fixed and variable costs. However, increasing the predictability and create a simple and easy process are left out of scope. Both objectives are very interesting for further research, but it is chosen not to include these research directions for the sake of time. These objectives require a whole different set of options than increasing the charged kWh per charger do.

These choices lead to the following objective tree as the focus of this research. Thus, the goal of the CPO is to maximize the kWh per charger, maximize the EV convenience and minimize the costs. These are the pillars for a successful charging infrastructure from the perspective of the CPO.

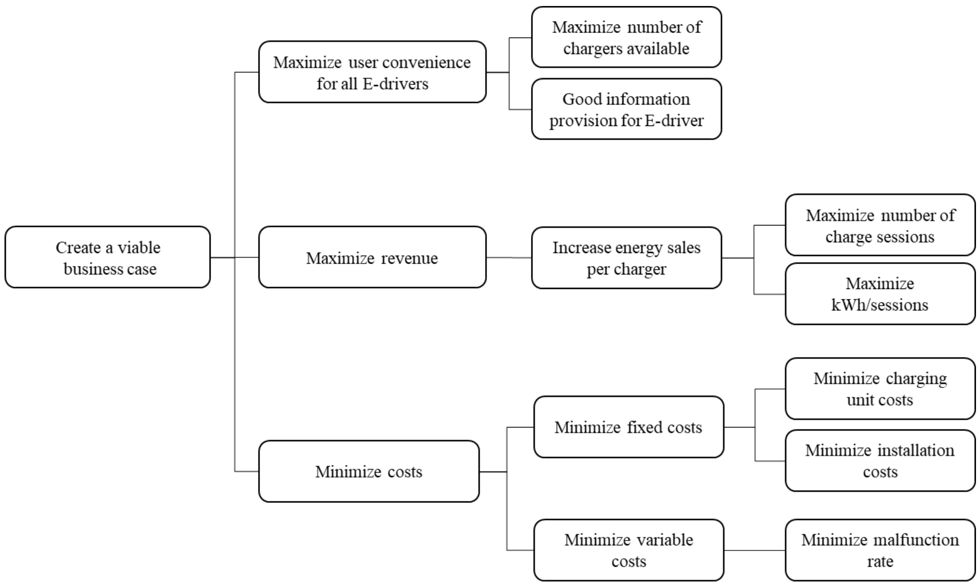


Figure 11 Final objective tree

4.3 From objectives to assessment criteria

Assessment criteria are derived to evaluate the performance of the sets that will be identified in the following chapter. Criteria are specific and measurable objectives (Dodgson et al., 2009). A criterion is a tool for evaluating and comparing different alternatives to a point of view. The criterion should be well-defined (Greco et al., 2016).

The performance evaluation index system of Zhang et al. (2011) is taken as an example and adapted for this research. Their evaluation system started with the goal of the system. This goal led to the identification of five overarching criteria, which subsequently led to the identification of sub-criteria. These sub-criteria were used to assess the performance. The same structure is applied to this research and results in the figure below.

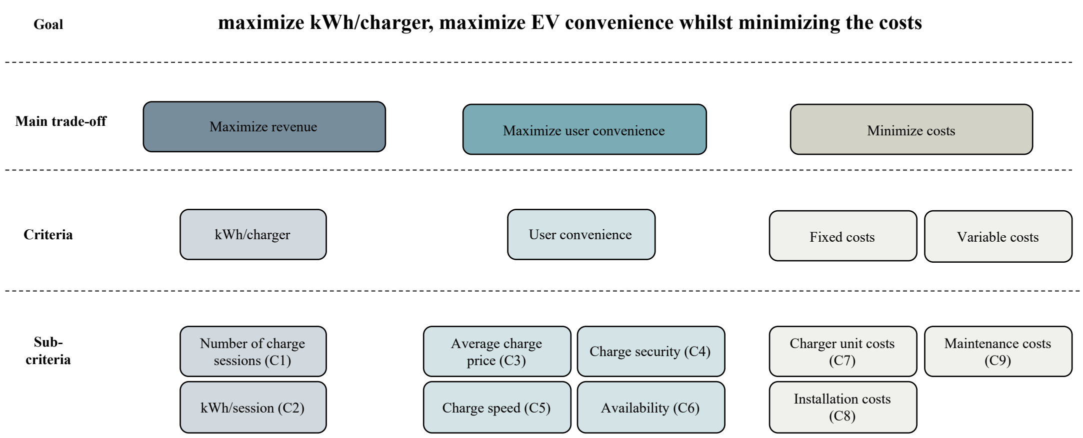


Figure 12 Representation of main objectives and their assessment criteria.

For this research, the goal for the CPO was identified as maximizing the kWh per charger and EV convenience whilst minimizing the costs. This led to the main trade-off of maximizing revenue, maximizing EV convenience, and minimizing costs. The criteria for the revenue solely depend on the charged kWh per charging unit, as chosen in section 4.2. User convenience can serve as a criterion in itself. The cost depends on the fixed cost and variable cost.

Of course, this is only a selection of the criteria. For the sake of time, it was chosen to focus on a small set of criteria. The selection for appropriate sub-criteria was made on the link to the main trade-off, the possibilities to assess them, and logic. For example, in other studies, walking distance is an essential criterion for user convenience as well. This criterion is not included in this research because walking distance refers to the location and strategic planning of infrastructure, which is out of the scope of this research. The included selection criteria, the description, and unit for observation can be found in table 7.

Table 7 Description of assessment criteria.

Criteria	Description	Unit
C1	Number of charge sessions per charger per year	--/-/0/+/++
C2	kWh charged per session per charger per year	--/-/0/+/++
C3	The average charge fee the consumer has to pay for a charge session	--/-/0/+/++
C4	The assurance that the EV is charged until a desired level within a desired timeframe	--/-/0/+/++
C5	The time needed to charge an electric vehicle until the desired level at a charging point	--/-/0/+/++
C6	The number of charging points available	--/-/0/+/++
C7	The purchase price of the charger (hard- and software)	--/-/0/+/++
C8	The total costs for grid connections, location determination and the design of the parking space	--/-/0/+/++
C9	The costs for reparations as a consequence of malfunctions, which means that chargers are not in operation	--/-/0/+/++

Revenue
The two criteria that predominantly determine the revenue are the number of sessions per charger (C1) and the kWh charged per session (C2). These two criteria are directly derived from the formula to calculate the kWh per charger. It is chosen to assess them on a yearly basis since EVdata provides these numbers on a year scale.

EV convenience
The third criterion that is included is the average charge fee. The average charge fee influences the user's enthusiasm for using the electric charging infrastructure and is therefore considered a criterion influencing EV convenience (Zhang et al., 2020). Another essential criterion for service quality, according to the study of Zhang et al. (2020), is the reliability of charging. This criterion is included as charging security (C4).

For the remaining criteria, it was chosen to look at the objectives found during the workshop and the options found during the interview sessions. Many options stated influenced the charging speed. Therefore, charging speed (C5) is included as a criterion for EV convenience.

The objective tree illustrates that maximizing the number of chargers available and good information provisions are two objectives for the CPO to increase EV convenience. Availability is included as a sub-criterion to adhere to the first objective. The availability is defined as the number of charging points available per acre in a given time period.

Costs
The last criteria all refer to the investment and maintenance cost of the CPO. The choice for these criteria was logical since the business case distinguishes three costs streams. Therefore, the sub-criteria consist of the charger unit costs (C7), the installation costs (C8), and the maintenance costs (C9).

4.4 conclusion

This chapter aimed to answer the second sub-question. Nine criteria are identified that will be used in chapter 6 to score the sets of technical innovations and policy instruments.

In addition, is a comprehensive objective tree derived that gives more dimension to definition of the objectives of a CPO. Also, key choices are made to improve the focus of the research. The focus is on increasing the charged kWh. This serves as input for the interview methodology and the results of the following chapter, i.e., options are sought for that increase the charged kWh.

Chapter 5 Options identification

This chapter develops different sets of technological innovations and policy instruments the CPO can implement to increase the kWh per public charger while securing the convenience for E-drivers. The central methodology to develop these options was by conducting interviews, as described in section 2.3. This resulted in over a thousand possible combinations. These options are first reduced by applying selection criteria. This resulted in four different technical set the CPO could implement. However, still, a tiny hundred options remained to deploy these sets effectively. Therefore, the perspectives of the municipality and E-drivers are included as well to find overlapping objectives. In this way, it was deemed to answer the following sub-question.

SQ3 Which combinations of technical innovations and institutional instruments are suitable for improving the success of EV-charging infrastructure?

5.1 Introducing the option categories

In chapter 4 is determined that the focus of this study is to increase the kWh charged per charging unit. The following formula was determined:

$$kWh/charger = \#\, sessions/charger * kWh/sesion$$

This formula explains that options that increase the number of sessions per charger or the kWh charged per session are relevant. There are areas of interventions that can be distinguished to increase (one of) the variables (# sessions or kWh/session), but the CPO cannot influence all of them directly.

Table 8 Area of interventions to increase the kWh/charger.

# sessions/charger	kWh/session
Charging time	Availability
Number of chargers	Battery developments
Charge moment	

The areas of interventions are illustrated in table 8. The charging time is the duration that an EV should be connected to fully charge. The CPO can directly influence this through adjustments in the hardware of the charger or different grid connections. The number of chargers can also be adjusted directly by the CPO. The charge moment deals with the time the car is charging, for example, day or night. The CPO can directly influence this. The second category focuses on means to increase the kWh per transaction. This is predominantly related to charging security. Availability is defined as the perception of E-drivers that enough chargers are available to charge their car when they need it. Thus, they are confident enough to charge their vehicles when the battery is low, instead of already at 50%. The CPO can influence this. Charging security is related to battery developments as well. The CPO cannot influence these developments directly because manufacturers play the most prominent role here. Nonetheless, seeing the trend that batteries are increasing, it is suggested that the kWh per transaction will increase as well. The increase in drive range will positively influence the perception of availability.

Thus, the CPO can influence these areas either directly or indirectly. The means, or options, the CPO can implement can be distinguished into different categories. This thesis focuses on technical innovations and policy instruments. Technical innovations refer to hardware or software changes to increase the charger's efficiency, while policy instruments can be divided into different categories. The policy instruments can be further subdivided. The framework for policy analysis distinguishes five categories of policy instruments. These are financial instruments, information instruments, regulation, procedural instruments, and voluntary instruments (Chappin et al., 2021). Financial instruments are deployed to overcome financial barriers, such as the Dutch government's tax benefits to buyers of electric cars. Information instruments aim to increase awareness amongst customers, and the primary function is to tackle behaviour barriers (Chappin et al., 2021). The regulations consist of standards and requirements. An example of such a regulation is the ban on fossil fuel car sales by 2030. Procedural instruments refer to protocols and audits (Chappin et al., 2021). The last category is voluntary instruments, that consist of self-regulation and guidelines (Chappin et al., 2021).

This framework is slightly adjusted for this research. Table 9 shows the categories and descriptions used for this research. This research predominantly focused on the financial instruments, the voluntary, i.e., social instruments, and the regulations, i.e., institutional instruments. A fourth category was included during the interviews. This was the organizational category and can be interpreted as the combination of the information instrument and procedural instruments.

Table 9 Descriptions of option categories. Adjusted from Chappin et al. (2021).

Option	Description
Technical	Adjustments in hardware/back office or software
Institutional	Laws and regulations that improve the desired use of chargers
Financial	Financial incentives that improve the use of chargers
Social	Instruments to encourage socially desirable behaviour E-drivers
Organizational	Adjustments in governance and interoperability to improve the infrastructure

5.2 Main take-aways of the interviews

The interviews resulted in a substantial list of options. The complete list can be found in Appendix III. The two main takeaways of these interviews are described first.

The main finding is that many options are apparent, which underscores the complexity of making design decisions. The options can be combined in various ways. It is not that much an either, or situation. Moreover, the organizational category mainly serves as input for system conditions and recommendations instead of a separate option category. The options that were mentioned in this category indirectly influence the kWh per charging unit, instead of directly. Examples of excluded organizational options were: standardization between policy and technical components, increase facilitating behaviour of the municipality, open standards for data, more data transparency, more price transparency, and better information provision for EV users where and when to charge. These examples serve more as system objectives or conditions than options to improve the kWh per charger. Therefore, it is chosen to include them as system conditions in the corresponding final sets.

An approach is needed to reduce the number of options systematically. Therefore, a deducing method was developed. This method consists of two phases. The first phase of the process is described in section 5.3, and the second phase in section 5.4.

5.3 Deducing process (phase 1)

The first part of the reducing method consists of a funnel, as illustrated in section 2.3. This funnel consists of three steps to narrow down the number of options systematically. The first two steps apply a set of selection criteria to the list of options. The first selection criteria refer to the scope of the research, and the second selection criterion is the feasibility of implementation in the coming ten years. In the third step, the remaining options are clustered based on similarities and differences. The following paragraphs describe those steps in more detail. The main decisions are highlighted per step.

5.3.1 Scope of the research

The selection criteria for the scope of this research were obtained by answering the following questions: is this option applicable in the public domain? Does this option influence the number of sessions? Does this option influence the charged kWh per charging unit? If the answer was no, the options were excluded. From these questions, the following selection criteria could be derived: (1) focus on public domain, (2) influence number of sessions, and (3) influence the charger kWh per charger.

The first criterium was very effective in reducing the bulk of, primarily technical, options. Several options focused on the semi-public or even private domain. For example, the option to place more chargers in paid parking lots or at offices is out of this research's scope. Also, fast-charging stations at the in- and exit of cities are outside the scope of this research. The focus is on AC charging, and the business case for DC charging is very different.

Criteria number 2 and 3 predominately excluded options that influence grid stability but do not necessarily lead to more kWh per charger. Therefore, smart charging was considered out of scope, although mentioned in all the interview sessions. Nevertheless, from the objective tree in chapter 4 was concluded that smart charging does not lead to more kWh per charger, and is thus out of the scope of this research. The same reasoning applies to Vehicle-to-Grid (V2G) applications. Also, financial options such as lower tariffs in combination with solar energy and lower tariffs when renewables are used [PO8] are excluded for this reason.

This criterion also led to the choice not to include the organizational category as separate options, as explained already in section 5.2.

5.3.2 Feasibility of the options

The remaining options were evaluated on feasibility. Feasibility is defined as the probability that this option will be implemented in the public domain in the coming ten years. Based on this criterion, options as inductive charging (without a cable) and charging robots are considered out of scope. Also, the snake modus for automatic decoupling was rejected based on this criterion. Snake modus entails that the charger rewinds the cable automatically when the charge session is over. The probability that these options will be cost-effective for the public domain is too low. The financial options differ in positive and negative price incentives. Examples of pricing incentives that negatively influence EV users were a starting tariff or a fee after 24 hours. In the Netherlands, it is currently not allowed for the CPO to give such negative incentives. Nonetheless, these options are not rejected yet, because there is a probability that these regulations will be adjusted.

5.3.4 Clustering

The remaining technical options were clustered based on similarities and differences. The remaining technical options can be categorized into four clusters: automatic decoupling (T1), more connections per charger (T2), charging clusters (T3), and no technical adjustments (T4).

Automatic decoupling was suggested both with and without the need for a fixed cable. Nonetheless, the core idea of this technical innovation is similar. Therefore, both variants are clustered to the option of automatic decoupling. Section 5.5 describes what exactly automatic decoupling entails. A second cluster was more connections per charger. This cluster consists of technical options defined as more vehicles to one charger [PO2] and literally more connections to one charger [PO4]. All technical options that regard to charging clusters were: charging square to serve up to 6 vehicles [PO2], charging square [PO5], and a dynamic system (both EV as non-EV can utilize) [PO6]. These options were combined and defined as charging clusters. It is chosen to continue with the dynamic charging cluster, as this option is the most innovative, yet feasible. This makes it technically interesting to further analyse. Finally, an institutional cluster can be derived that does not contain any technical adjustments. These four clusters are four fixed technical (T) clusters.

5.3.5 Output first reducing round

This first reduction round resulted in four fixed technical options that were suitable for public charging infrastructure. However, the institutional (I), financial (F), and social (S) instruments that can be combined to deploy the technical options best are still variable, i.e., the technical options can be combined with multiple policy instruments. In Appendix III, the descriptions of these remaining policy instruments can be found. Figure 13 illustrates the abovementioned situation. A second reducing round is required to determine which policy instruments should be coupled to deploy the technical innovation best.

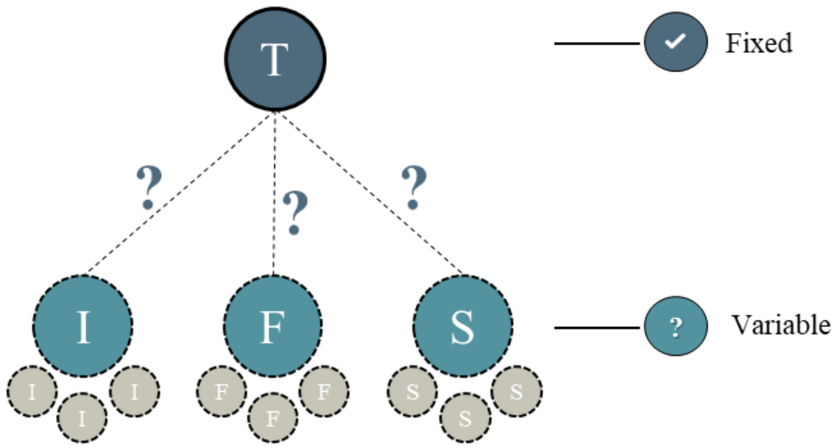


Figure 13 Situation sketch to show variety of combinations still available

The figures below illustrate the possible combinations per technical option. The light grey boxes indicate the policy instruments that can be combined with the technical innovation. Per set is roughly described as why specific policy instruments are perceived to be suitable and not. Section 5.5 describes the final sets in more detail.

T1: Automatic decoupling

This is a technical solution where the charger automatically decouples when a charging session is over. The policy instruments that can be combined with this solution are light grey. Starting with the institutional options, it is chosen not to combine it with municipality co-invest and time slots with enforcement. This solution does not require immense investment costs for the CPO. Time slots with enforcement are a separate set and therefore not included in this set. This set can be combined with almost all financial incentives, except a night tariff. Theoretically, a night tariff is possible, but it is not logical as this solution is especially intended for problems during the day. EV users are not expected to move their vehicles at night. It is also chosen not to combine it with a push to stop sessions or a blinker because that is not logical as well. The session stops automatically.

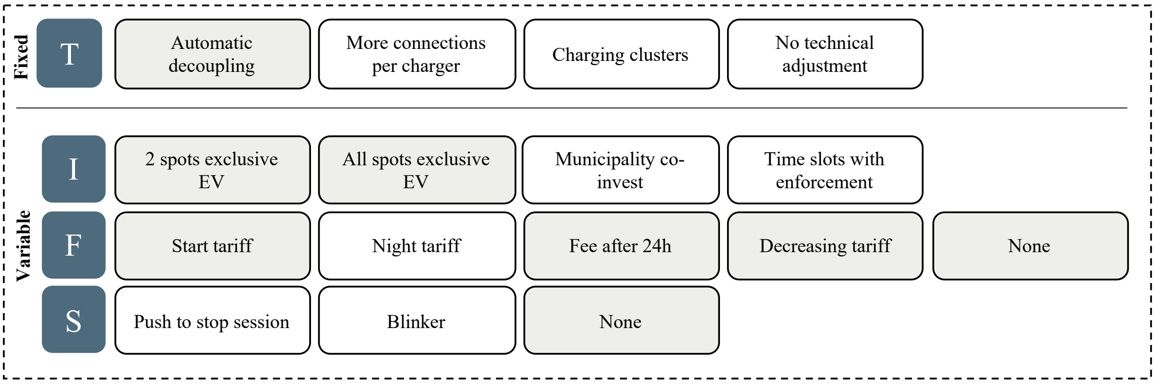


Figure 14 Possible combinations for automatic decoupling

T2: More connections per charger

This solution consists of more connections per charger unit, also called sockets. Most chargers have two connections. It is suggested to develop chargers with three or four connections. The same reasoning as for the first set applies to the rejection of the institutional instruments of co-investment and time slots. For this set, it is not logical to apply a starting tariff. This solution will predominantly be applied to chargers at night locations. These users are already connected for longer charge sessions, which makes a start tariff to push longer sessions unnecessary. A blinker as a social option is not chosen because it is expected that the benefit does not outweigh the costs.

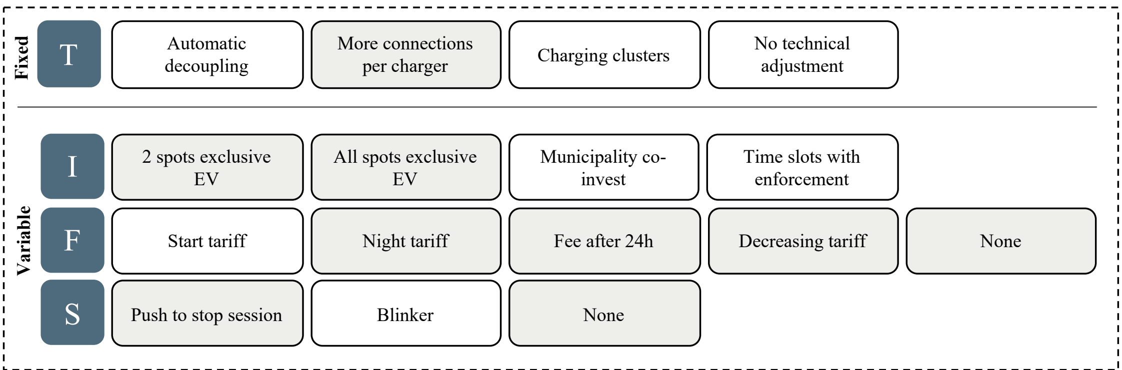


Figure 15 Possible combinations for more connections per charger

T3: Dynamic charging cluster
Clustered charging is upcoming the recent years, which entails connecting more chargers to one grid connection. However, dynamic crossing is extremely innovative. Section 5.5 explains what dynamic crossing entails.

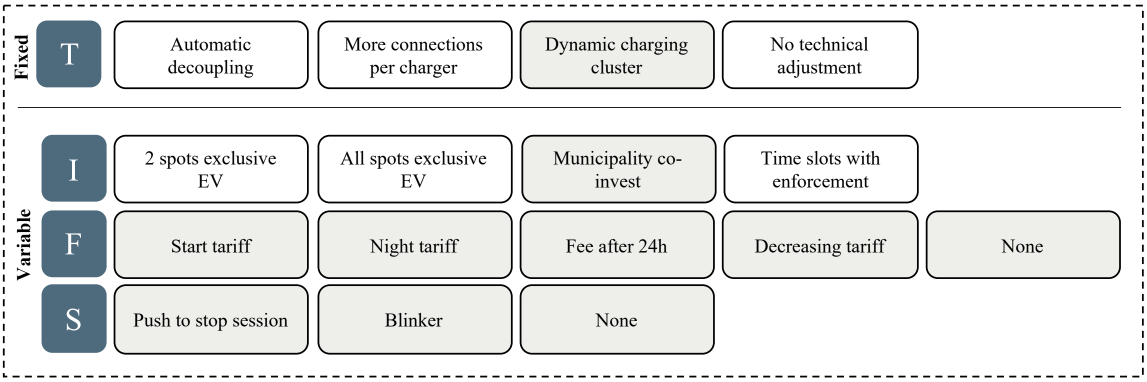


Figure 16 Possible combinations for charging clusters

T4: No technical adjustments
There are no technical adjustments for the last set. This last set is completely institutional. This set is included as well to examine if technical adjustments are even necessary.

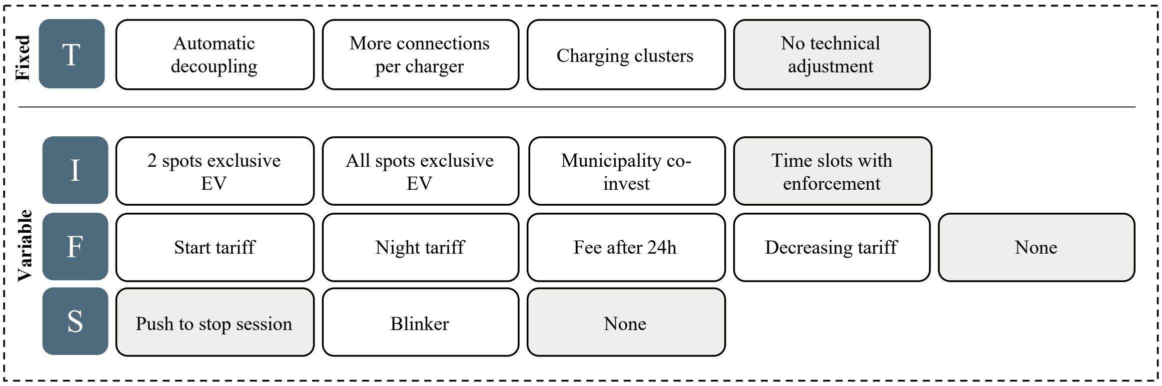


Figure 17 Possible combinations for no technical adjustments

From these figures can be derived that still hundreds of combinations are possible. Especially for the first three sets, a wide variety of combinations exists. The following reducing round deems to find the most preferred institutional, financial and social instruments.

5.4 Deducing process (phase 2)

Based on the degree of acceptance of the CPO, the municipality and the EV users is determined which policy instrument should be coupled to the technical innovations. The degree of acceptance is defined as the extent to which the policy instrument meets the stakeholders' objectives. Therefore, the objectives of the municipality and the EV users are described firsts. Subsequently, a table is constructed in which per policy instrument is indicated to what degree the stakeholders accept the option. This table is converted to a circle diagram. The core of the circles contains the policy instruments with the highest degree of acceptance. These policy instruments are assigned to the technical options and form the sets.

5.4.1 Objectives of municipality and EV users

Based on available literature, the objectives of the municipality and EV users are described. The objectives of the municipality have shifted over time. At the beginning of the development, the policy focuses predominantly on reducing (local) air pollution and increasing the adoption of electric vehicles (Wolbertus, 2020). This focus shifted to a broader scope when more actors entered the market. Now, the policy focus is also on providing sufficient infrastructure while managing the scarce parking resources. Especially at locations where parking pressure is high, the municipality needs to deal with complaints from residents and non EV users about privileged EV users (Wolbertus, 2020). When the chargers are under-utilized, the frustration increases. This stresses the importance for municipalities to ensure that the chargers are utilized (van den Hoed et al., 2019).

The CPO should also account for the objectives of the EV users. In chapter 4 already derived that convenient EV users are one of the core objectives for the CPO. Helmus & van den Hoed (2015) found that access to public charging is an essential requirement for EV users. Another study found that the effect of charging accessibility on EV adoption is stronger than the effect of parking fees (van den Hoed et al., 2019). This suggests that pricing strategies to influence charging behaviour will not be as effective as expected. However, when the second-hand car market develops, a new EV user group arises of which is expected that charge price is more important.

Chapter 4 already focused on the objectives of the CPO. When summarizing the objectives of the three stakeholders, the following table can be derived. This table roughly describes the main objectives per stakeholder.

Table 10 Objectives of the CPO, municipality and EV user

Stakeholder	Objective
CPO	Create a viable business case by maximizing the kWh per charger, while minimizing the costs and securing the user convenience
Municipality	Stimulating the rollout of charging infrastructure. Manage scarce parking resources, increase utilization of parking resources.
EV-driver	Availability of charging units

5.4.2. Degree of acceptance

Based on the derived objectives, statements during the interview sessions by policymakers and EV representatives, and brainstorm with an E-mobility expert [WSP2], the following assumptions per stakeholder are derived. These assumptions were used to assign a low, medium, or high degree of acceptance to the policy instruments.

CPO
It is assumed that the CPO is most interested in policy instruments that incentivize EV users to move their vehicles when the charging session is over. Especially instruments that require low investment costs are interesting for the CPO. To increase user convenience, the CPO wants to increase the availability and is thus interested in all parking spots exclusively for EV users.

EV users
EV users are most interested in policy instruments that increase availability, such as all spots exclusively for EV drivers. Regarding price incentives, whether it works or not, it is assumed that

positive price incentives are accepted, and negative price incentives are rejected. Globisch et al. (2019) found that EV users do not want to pay a basic fee for the possibility of using public charging infrastructure. Also, PO4, who is an EV representative, indicates that fee structures are undesired.

Municipalities

The municipality needs to balance the objectives of multiple stakeholders. It is assumed that the municipality is interested in options that increase the EV user convenience but balance this with the convenience of the non EV users. The municipality accepts incentivizing user behaviour to a certain degree, but instruments that really disadvantage EV users are rejected. This assumption is supported by PO2 (local policymaker), who says that the municipality does not want a panel policy with high tariffs and requires users to move their vehicles [PO2]. Also, the assumption is made that the municipality will prevent that all parking spots will be exclusively for EV users.

Lastly, it is assumed that the municipalities are not interested in co-invest in wide-scale implementation. The municipality has some money available to invest in a pilot. However, it is desired that the market becomes self-sufficient. Therefore, co-investing is perceived as having a low degree of acceptance.

These assumptions resulted in the following degree of acceptance table.

Table 11 Overview of the degree of acceptance

#	Variable	CPO	Municipality	EV user
I1	2 spots exclusively available for EV	*High*	*High*	*High*
I2	All spots exclusively available for EV	*High*	*Low*	*High*
I3	Municipality co-invest	*High*	*Low*	*Medium*
I4	Time slots with enforcement	*High*	*Medium*	*Low*
F1	Start tariff	*High*	*Medium*	*Low*
F2	Lower night tariff	*High*	*High*	*High*
F3	Fee after 24h	*High*	*Low*	*Low*
F4	Decreasing tariff	*High*	*High*	*High*
F5	No tariff	*Medium*	*Medium*	*High*
S1	Push to stop session	*High*	*High*	*Medium*
S2	Blinker	*Medium*	*Medium*	*High*
S3	No social	*Medium*	*Medium*	*High*

The outcome of this table can be converted to the degree of acceptance circles. The core of the circle contains the policy instruments that all stakeholders prefer, in other words, the degree of acceptance is high. These instruments are a lower night tariff (F2), a decreasing tariff (F4), and two spots exclusively available for EV drivers (I1). The social policy with the highest degree of acceptance is a push message to stop the charging session. Therefore, these policy instruments are also assigned to one of the final sets.

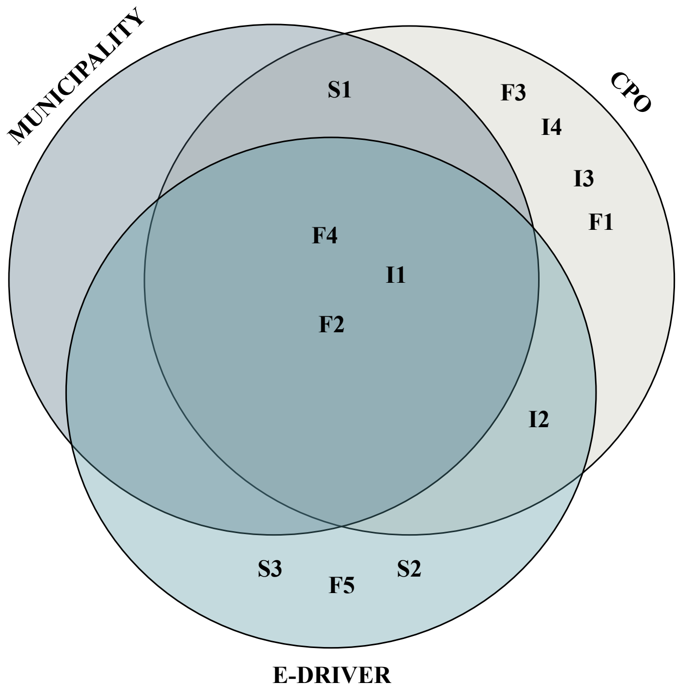


Figure 18 Degree of acceptance circles

Based on this circle diagram, the policy instruments are assigned to corresponding technical options. The following section illustrates which policy instruments are assigned to the four technical options. If multiple options were possible, it is explained why this instrument is chosen.

5.4 Final sets and a descriptive analysis

The selection process resulted in the following four sets: quantity-driven design (set 1), quality-driven design (set 2), hybrid design (set 3), and purely institutional design (set 4). For each set is described how it works and what system adjustments are expected. Also, the main limitations and opportunities of the sets are described. The description ends with a table that contains important information for the system's feasibility. By describing these sets is aimed to show the nuances linked to the choice of a specific set. The sets are described in the following order:

5.4.1 Quantity-driven design

The first set is named 'quantity-driven design,' abbreviated to quantity or QN. This name is chosen because of the pure focus on more sessions on one charger.

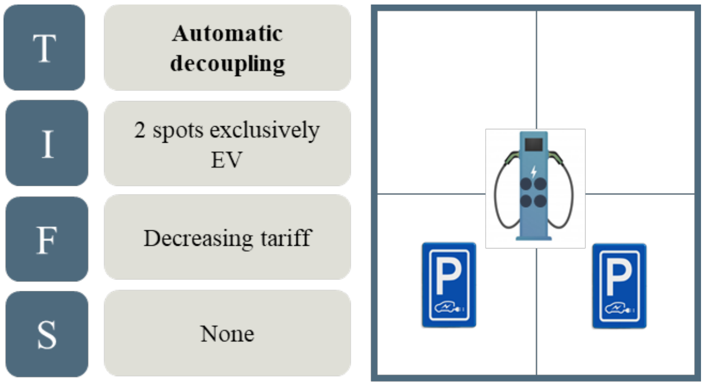


Figure 19 The components quantity driven design consists of.

System description and adjustments
This set features a system where the cable automatically decouples when the charging session is over. This way, the cable becomes available for a new EV user. This system is beneficial to circumvent charging hogging. In three out of four interview sessions, automatic decoupling is mentioned as a possible solution. In all the sessions, the additional requirement of fixed cables to the charging unit was a prerequisite. The cable must be fixed to the charger instead of detached, which is currently the standard for AC charging in the Netherlands.

The participants do question the usefulness of the detached cables for interoperability.

I am not sure whether the choice of the Netherlands for own cables was the right choice [P06]
The Netherlands needs fixed cables such as in the US, and this would make the infra easier and more efficient [P04]

P04 also mentions that it stimulates social behaviour.

Why would you not plug the charger in the car of your neighbour when your session is over? [P04]

Automatic decoupling with fixed cables makes that more accessible, according to this participant. Hence, the feeling amongst EV users that they should share the system can be increased, which is essential for the CPO according to WSP2.

Technically, the fixed cable requires a slight hardware modification. In addition, a software modification is required that indicates when the cable may be decoupled. Institutionally, it is crucial that automatic disconnection is approved, and a standard must be developed for these cables according to the participants [P04]. Thereby, it is important to change the setup of the charger unit. The setup should be strategic such that it can serve 3 to 4 parking spots. Institutionally, two of these parking spots are exclusively accessible for EVs.

Financially, a decreasing tariff is chosen to stimulate the EV user to charge more kWh per session. It is proposed to take 30 kWh as the tipping point. The average charging session is currently 15 kWh in Amsterdam (EVdata, 2021). One participant mentions that it is already technically feasible to implement such a decreasing structure. However, the main condition that this participant mentions is that the tariffs must be transparent, which is currently not the case.

The EV user should be informed about what they pay. User cannot be fined afterward [PO1]

Opportunities
The advantage of this solution is that the hardware adjustments do not affect the charge speed and do not require a different grid connection. Also, the number of vehicles that can charge simultaneously is unchanged; thus, no extra pressure is laid on the grid. Therefore, this adaptation can be directly implemented in the current public charging infrastructure without network adaptions. In addition, the chance that a charger is available probably increases substantially. The decreasing tariff can result in more extensive charge sessions, especially when the second-hand market for EVs evolves and new user groups arise that are probably more sensitive to price incentives.

Limitations
Most of the limitations are related to the condition of a fixed cable. First, the additional costs for the cable are passed on to the CPO. It is believed that this will negatively influence the business case.

The costs for the CPO will increase what negatively influences the business case [PO6]. Also, PO2 mentions that it could lead to a higher malfunction rate because people are less careful with those cables [PO2]

This could lead to a higher malfunction rate and increased variable costs for replacements of the cable. Another limitation that has not been covered in this set is what happens when the cable decouples. Municipalities do not accept loose cables on the ground. Also, the chance that a heavy vehicle will damage by driving over the loose cables is not desired. Possible solutions are to add a little hook to the charger where people can hang the cable. A more futuristic and thus costly solution is to apply the so-called 'snake modus,' in which a system stores the cable automatically. This opportunity was also mentioned by PO6 but rejected in the second phase of the reduction process.

Moreover, the governance aspects of this set are complex. The questions arise if it is allowed to start a transaction for another EV driver, and who is responsible for damages of the cables. New rules and regulations are required, which slows down the implementation process.

A final limitation refers to the fact that two parking sports are exclusively available for EV users. This set intends to increase the number of charge sessions by making the cable available for new EV users. However, it can appear that non EV users already occupy the two remaining spots.

	Description
Day/Night	This solution predominantly applies to day chargers. Th core idea is that chargers will be more often available during day. At night, E-drivers are not expected to move their vehicles.
Technology readiness	Technically, a charger that decouples automatically is possible. In the private domain, the first chargers with this system are developed. Not mature yet. Not implemented on large-scale.
Public implementation	Not yet in public domain.

5.4.2 Quality-driven design

The second set is called the 'quality-driven design,' abbreviated to quality or QL. This set focuses on longer sessions per charger instead of more sessions, as is the case for the first set. Thus, the focus is on the quality of one session. From the CPO's perspective, the quality of a charge session increases if more kWh is charged.

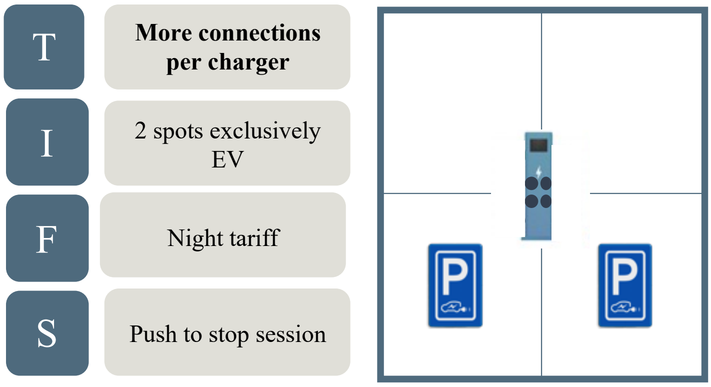


Figure 20 The components the quality driven design consists of.

System description and adjustments

This set involves a system in which the number of connections per charger is increased. Thus, instead of two connections, a charger has three or four connections. This increases the number of EVs that can charge simultaneously. The visual representation shows the four connections. PO2 mentioned that this solution should be combined with a strategic setup of the parking spots.

A solution would be to increase the number of EVs on one charger. This should be combined with a strategic setup to serve 3 to 4 electric vehicles simultaneously. [PO2]

A lower night tariff is applied to stimulate users to charge at night and shift their demand to low-peak hours. This decreasing tariff entails a reduction of approximately 2 cents from 10 pm to 8 am. At day times, a push message is sent to EV users to remind them to move their vehicle. An adaption in the back-office system of the MSP is required to enable the push message. However, no further consequences are applied for ignoring the message.

Opportunities

The main advantage of this solution is that it reduced investment costs for the CPO and reduced the number of chargers that should be placed in public space, as a substantial obstacle for public chargers is space scarcity.

Another opportunity of this set is that it is expected that more people charge at night when the demand on the grid is lower. Also, the lower night tariff could stimulate more EV users to charge at night, which results in lower occupation rates during the day. If only two cars are connected to the charger during the day, the charge speed does not decrease compared to the standard setup. The push message that is sent to the EV user is only applied to day charging. This hopefully ensures that the charger is available for EV users that desire to charge during the night. At night, people are not pushed to move their vehicles.

Limitations

The main limitation is that the charging speed will decrease when four vehicles are charging simultaneously at one regular charger.

Another obstacle for this set can be the number of available locations. A requirement for this set is crossed parking. However, Dutch cities like Amsterdam and Rotterdam have many queue parking.

	Description
Day/Night	Night because lower charging speed is not an obstacle then
Technology readiness	The first chargers with four connections are available, the market is not mature
Public implementation	Not yet in public domain

5.4.3 Hybrid design

The name of the third set comes from the fact that this is the only design that makes use of a hybrid system to determine which users can park or charge.

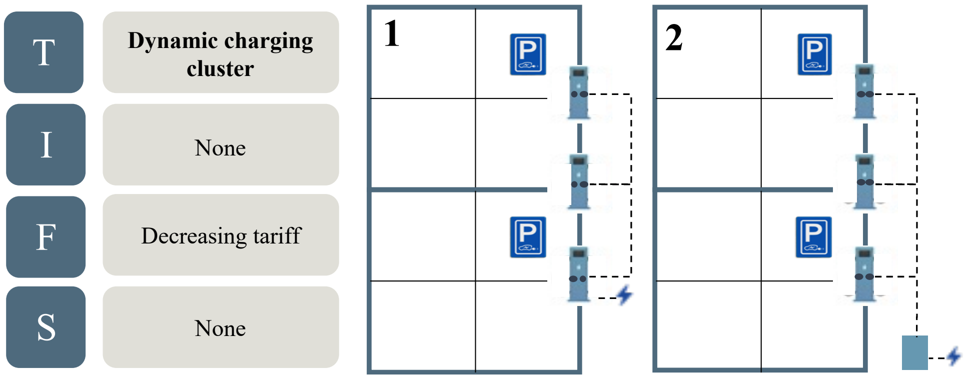


Figure 21 The components hybrid design consists of.

System description and adjustments
The third set is implementing clustered charging. Dynamic crossing is implemented to prioritize exclusively available parking spots for EV users based on parking pressure. In order to stimulate the charged kWh per session, a decreasing tariff is chosen again. A push message sent to the phone of the EV user is an extra optional incentive to improve the behaviour of the EV user. However, this push message only serves as a reminder for the EV user to move the vehicle. There are no further consequences for ignoring the message.

This solution requires some technical adjustments that are highlighted first. The chargers are connected to the grid differently. The difference between a charging cluster and concentrated chargers is that more chargers are connected to the same grid connection in a cluster. The exact definition for a charging cluster, according to NKL (2019), is: *'a charging cluster consists of more than two charging points for electric vehicles, which are not connected to the grid individually, but share one grid connection*'.

There are technically two variants available for the design of a charging cluster. Both variants are illustrated above. The first variant is the so-called 'master-slave' construction, and the second variant is the 'system-street cabinet' construction (NKL, 2019). The master-slave consists of one charger that is directly connected to the grid. The other chargers are the slaves and are connected to the master. The master charger is directly connected to the back-office system. Via the back-office system, the charger determines the charging speed. In the other variant, all chargers are connected to a street cabinet. The street cabinet is connected to the grid (NKL, 2019). The NKL provides a table that can be consulted to determine the exact design of the charging cluster.

The choice depends on the location. In general, a master-slave construction requires less space. As explained in chapter 3, new developments enable the connection of chargers to street objects. This could be a future possibility as well.

The idea of dynamic crossing is that parking pressure determines the number of spots exclusively for EVs. In this way, a hybrid system is created at which both EVs and ICEs can park. What type of EV user is allowed to park depends on the colour of the light. For example, in the pilot in Haarlemmermeer, the green light indicates that a charger is only available for EV charging and a blue light indicates that both EVs and ICEs can park. Therefore, another technical adjustment that should be made to the regular charger is a light that indicates what type of vehicle is allowed to park.

The decreasing tariff is chosen as the best suitable option to increase the charged kWh per charging unit. The same adjustments as described in set 1 apply to this set.

Opportunities
The hybrid system created is perfect for the transition period until EVs eventually become the dominant mode of transport. According to PO6, this system receives less resistance from non EV users. It is easy to scale up to a fully electric system in the future if needed. Another advantage of a charging cluster is that it is easier for the EV user to find charging spots, increasing the chance of a parking spot being available (NKL, 2019). This increases user convenience.

Limitations
There are some limitations applied to this system as well. Firstly, this is quite an advanced set of options. This makes the complete charging solution more costly. There is a chance that it will not be possible to create a viable business case for this solution. In that case, the municipality should co-invest in the charging solution. The question arises if the municipality is willing, and has the resources, to co-invest in this solution. Also, this differs among municipalities. A technical limitation to the solution is the requirement for a larger grid connection. Also, locations should be large enough to place for chargers. These two requirements result in a limited availability of spots where such charging solutions can be implemented.

Conditions
PO6 mentioned that the provision of clear and straightforward information is an essential requirement for this solution to work. In the beginning, especially the non EV users were hesitant to use such a hybrid system since they were not used to park at a spot with a charging unit.

	Description
Day/Night	This solution can be applied to day- and night chargers.
Technology readiness	Technically possible. Further developments. As aforementioned already tested in clusters.
Public implementation	In Haarlemmermeer, the first pilot with a dynamic crossing system was started. Not yet on large scale.

5.4.4 Purely institutional design

The last set is named 'purely institutional design' (I). This is the only set that is focussed on rules and regulations by the municipality.

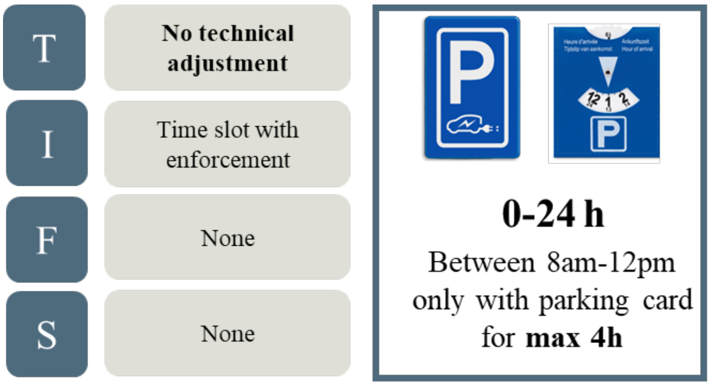


Figure 22 The components the purely institutional design consists of.

System description and adjustments

This is a purely institutional set that does not require any technical adjustments. This set is focused on strict enforcement to obligate EV users to move their EVs. The idea of this set is that the parking spots are twenty-four hours a day exclusively available to EVs. However, during the daytime (8 am-12 pm), EVs are only allowed to park and charge for a maximum of 4 hours. This restriction only applies to daytime charging to avoid that EVs should be moved at night. A parking card or parking meter is used to indicate the time of arrival. Just like parking with conventional vehicles, one can park for a maximum of 4 hours from the time of arrival. Exceeding this time limit results in a fine. This fine is considered the same as a parking fine. An important is the dependency of the CPO on the municipality to implement such a solution. The municipality should allow placing chargers in so-called 'blue zones.' Subsequently, the municipality should have enough research for additional employees that can conduct the required enforcement.

Opportunities

The advantage of this set is that it does not require additional investment costs for the CPO. Also, this solution can, in principle, be directly applied to current chargers. The fact that there is no need to place new chargers is also advantageous for the grid operators. This set does not put additional pressure on the electricity grid.

A significant advantage of this type of fine is that the costs are directly for the EV user. The fee is considered as a parking fee, which makes the EV user responsible. This rejects the problem of charging higher prices, which ultimately the boss pays if the EV is leased. The acceptance of this charging solution probably increases because it does not apply to night charging. This removes the argument that people cannot be obliged to move the vehicle at night.

The use of a parking card makes the solution easy to understand. PO4 mentions that the advantage of a parking card is that it is a standardized, well-known, and accepted method to indicate the arrival time. Not all people are willing to install complex apps to determine the starting time.

Lastly, the enormous advantage of the time limit of 4 hours is that the issue of charging hogging is solved. Although just 6% of the charging sessions lasted for over 24 hours in the four major cities of the Netherlands in 2018, this 6% was responsible for 27% of the connection time (Wolbertus et al., 2018). Especially at locations with high parking pressure, this solution can be advantageous.

Limitations
Although this solution does not require monetary investments costs, it does require investment in time to get permission to execute this set. This set requires new policies and time of people to enforce the rules.

The advantage that this set does not require people to move their vehicle at night also knows a downside. Some people argue that also people need to work at night. PO4 also mentioned this argument.

	Description
Day/Night	This solution can be applied to day chargers. It is especially effective at places that have high parking pressures.
Technology readiness	This solution can directly be applied to the regular type 2 chargers. These chargers are technologically mature and widely implemented.
Public implementation	Not yet in the Netherlands.

5. 5 Conclusion

This chapter applied a thorough reduction method to select a short list of the most preferred combinations of technical innovations and policy instruments. Hence, it was deemed to answer to third sub-question:

SQ3 Which combinations of technical innovations and institutional instruments are suitable for improving the success of EV-charging infrastructure?

The four most preferred sets are the quantity-driven design (set 1), quality-driven design (set 2), hybrid design (set 3), and a purely institutional design (set 4). The quantity-driven design contains automatic decoupling, including a fixed cable, two spots are exclusively for EVs, and a decreasing tariff to stimulate more charged kWh. The quality-driven design entails adding connections to the charging units and also reserves two spots exclusively for EVs. In this set lower night tariff is applied to stimulate overnight charging. Additionally, during the day, a push message is sent to the EV user to move their vehicle to ensure the charger is available for the night shift. The hybrid design is more technologically advanced because of dynamic crossing, in which the parking stress determines the number of parking spots exclusively for EVs. Here, a decreasing tariff and push message are applied to stimulate the desired charging behaviour. The last set does not contain technical innovations but depends on time slots with enforcement. Exceeding the time limit of charging for four hours results in a parking fee. In the next chapter, these sets are scored on the assessment criteria as identified in chapter 4.

Chapter 6 Scoring and analysing

In this chapter, the four final sets are scored on the assessment criteria as specified in chapter 4. In this way, it is deemed to answer the fourth sub-question:

SQ4 How do the combinations of options score on the predefined assessment criteria?

These sets are evaluated in an exploratory manner. First, a description of the expected performance of the sets on each criterion is given. These descriptions serve as the input for estimating the score of the four sets on the nine criteria. After deriving the scores on each criterion, the weights of each criterion are derived. Finally, a sensitivity analysis is conducted. This way, the last steps of the multi-criteria analysis as described in section 2.4 are performed.

6.1 Descriptive analysis and score

In this section, the four final sets are scored against the criteria as identified in chapter 4. It is chosen to evaluate the criteria on a plus and minus (--/++) scale. This level of detail is chosen as best suitable because of the limited data available on these relatively new sets. Nonetheless, this level of preciseness is enough to explore the expected changes in the assessment criteria.

The minus and pluses (--/++) scale is used to measure qualitative effects. The minus and pluses serve merely as indicators for the impact of a set on the criteria. The scale can generally be interpreted as follows (from -- to ++): big negative effect, small negative effect, no effect, small positive effect, and big positive effect. A negative effect entails a decrease in the first six criteria (C1 – C6) in this research. A positive effect entails an increase for these criteria. For the costs criteria (charging unit costs (C7), installation costs (C8), and maintenance costs (C9)), it is the other way around, thus increasing costs has a negative effect and decreasing costs a positive effect. A boundary of 10% is chosen in consultation with WSP2 to distinguish between a small and big effect. An increase or decrease of more than 10% on the selected assessment criteria can be evaluated as a significant increase.

Table 12 Scale to measure performance per criteria

Unit	**C1 – C6**	**Unit**	**C7- C9**
--	decrease >10%	--	increase >10%
-	decrease of ≤ 10%	-	increase of ≤ 10%
0	no change	0	no change
+	increase of ≤ 10%	+	decrease of ≤ 10%
++	increase >10%	++	decrease >10%

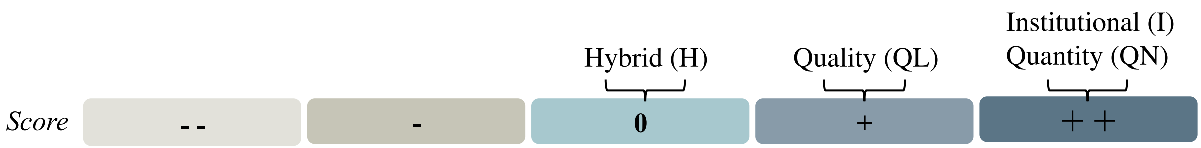
In order to assign the scores, a combination of literature, expert opinions, and rationale of the researcher is applied. The results of this analysis are shown in table 13. The following paragraph describes the interpretation that results in the assigned scores. It should be noted that this is a first attempt to evaluate the sets. In the discussion is described what further research is needed to evaluate the performance.

Table 13 Scores of sets against selection criteria

#	Criteria	Unit	SET 1 QUANTITY (QN)	SET 2 QUALITY (QL)	SET 3 HYBRID (H)	SET 4 INSTITUTIONAL (I)
C1	**Number of charge sessions**	--/++	++	+	0	++
C2	**kWh charged per session**	--/++	+	+	+	0
C3	**Average charge fee**	--/++	+	+	+	0
C4	**Charge security**	--/++	-	-	0	-
C5	**Charge speed**	--/++	0	--	0	0
C6	**Availability**	--/++	+	++	+	++
C7	**Charger unit costs**	--/++	--	-	-	0
C8	**Installation costs**	--/++	0	0	++	0
C9	**Maintenance costs**	--/++	--	-	0	0

The performance of each set on the criteria is described per criterion. This way, the decision to assign the minus and pluses is supported.

(C1) Number of charge sessions



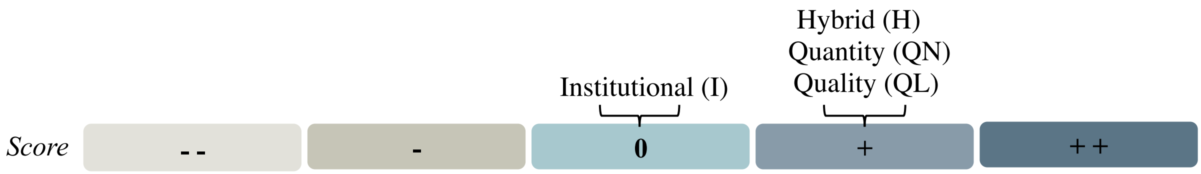
QN (++): This solution is intended for daytime chargers. According to Wolbertus et al. (2018) his study into factors that influence connection times, 90% of the charge sessions in Amsterdam take place during the daytime (morning 14.6%, afternoon 29.7%, evening 45.7%). This solution can be applied to 90% of the charge sessions increase the feasibility of a 10% increase. Moreover, the EV users indicated that they were willing to use such a system. However, one EV user was sceptical about possible damage to the car when other people are taking out cables.

QL (+): This solution is intended for locations where EV drivers predominantly charge overnight. The remaining 10% of the charge sessions take place overnight. The night tariff is intended to increase the number of charge sessions at night. However, the reduction of the tariff with a max of 2 cents per kWh does not make the difference for EV users. What does make the difference is the fact that the availability increases. This gives the EV user more security that a charger is available overnight. Therefore, an increase of less than 10% is expected.

H (0): It was not easy to score this set. The idea is that the charging cluster is easier to find, increasing the EV convenience and thus the number of charging sessions. Nevertheless, choosing the right location heavily influences the outcome. An undocumented conversation with the concession leads of Rotterdam and The Hague led to the conclusion that the number of charge sessions has not significantly increased at pilots such as Veerkracht (charging cluster Rotterdam). Hence, it was chosen to score it with a zero.

I (++): The average connection time on a Type 2 charger in the four largest cities in the Netherlands is 10,4h (Wolbertus et al., 2018). This is reduced to 4h max. This means that the charger can be used by 2,5 cars in that time. Considering that the place is not immediately occupied, it can still be used twice as much. An increase of 10% will thus be feasible. This is a theoretical optimum. Nevertheless, the EV users indicated that they were willing to use these chargers when high charging pressure.

(C2) kWh charged per session



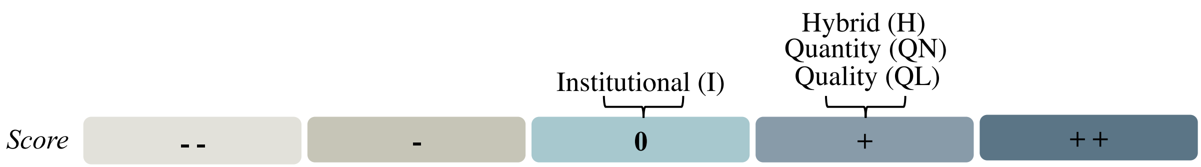
QN (+): Slightly increase. It is expected that a decreasing tariff will result in more charged kWh. However, this difference will not be huge since this start tariff will not be very high, and the boss pays.

QL (+): Expect that people will charge more overnight. The charging sessions will not increase due to possible longer charging times.

H (+): van Montfort et al. (2016) hypotheses that a higher charging station density (per acre) would lead to higher kWh usage (per charging unit). This hypothesis was confirmed based on the dataset of charging sessions in the Hague. Therefore, it is assumed that the kWh charged per session will increase. However, it was decided to score this set with an increase of less than 10%. This was based on the same conversation with the Rotterdam tender project manager, where charging cluster Veerkracht is located.

I (0): It was expected that this set does not increase the charged kWh charged. The charged kWh per session in Amsterdam was 14,72 kWh in 2020. For Rotterdam, this number was 15,51 kWh (EVdata, 2021). A charging session cannot be longer than 4 hours during the daytime. Theoretically, 44 kWh could be charged at a regular charger. However, it is not assumed that people will park at these charging units with an empty battery. From this estimation can be derived that the kWh charged will not decrease. Nevertheless, it is also not expected that the average kWh charged per session will increase. Therefore, this set is assigned a zero.

(C3) Average charge fee



The average charge fee will decrease in the first three sets because only the positive financial incentives are included in this research.

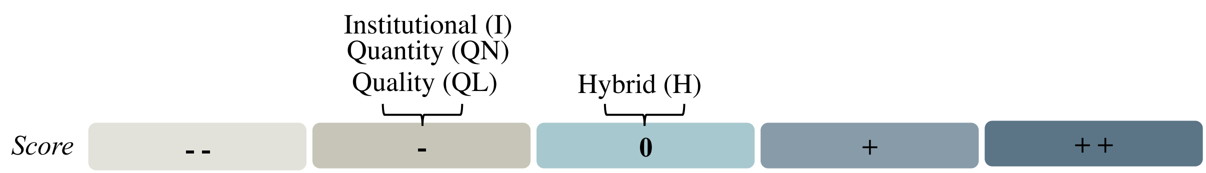
QN & H (+): Those sets suggest implementing a decreasing tariff. This aims to stimulate EV users to start charging when their battery is lower. This would result in a lower tariff for the EV user because they charge more kWh.

The average capacity of a Dutch electric vehicle was assumed to be 60 kWh. The average kWh charged per session is 15,1 kWh. It can be assumed that EV users charge at a 75% level of their battery. The CPO wants to stimulate the EV user to charge a minimal 50% of their battery in a best-case scenario. This means that the CPO should implement a decreasing tariff from 30kWh per session. Thus, the average charged kWh per session is desired to double. Only charge sessions over 30 kWh enjoy a lower tariff. In a best-case scenario, the EV users fully charge the battery, which is 60kWh. The average charge price is 0,245 cents when the vehicle charges 30 kWh for the regular price and 30 kWh for a 25% lower tariff. Compared to 60 kWh for the regular charge price, this results in a reduction of 12,5%. However, this is in the best-case scenario. Considering that, in reality, the advantage will be lower, it is assumed that the charge price will not decrease more than 10%. Therefore, set 1 and set 3 get one plus.

QL (+): In this set, a lower night tariff is applied. This entails that the tariff during the night is lower than at day between 10 pm and 8 am. It depends on what price the service provider asks for this tariff how it will influence the fee. WP2 indicates that they would decrease the price by 2 cents maximum. The current average charge price is assumed to be 28 cents, which means that the average charge price reduction will not be above 10 percent. One plus is therefore given for this set.

I (0): The average charging fee for this set is unchanged. There are no pricing strategies applied to improve the charging behaviour of EV users.

(C4) Charge security



Four EV users were consulted to derive the scores on the sets.

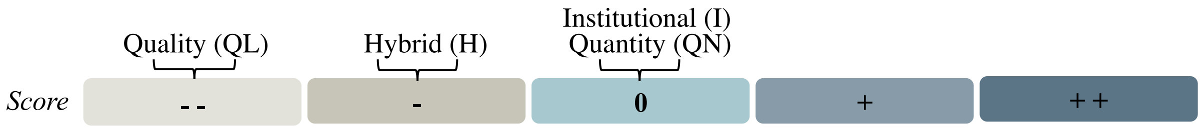
QN (-): The charge security for this set will slightly decrease. Some participants relied on the system and did not indicate a decreased security. Nevertheless, others were hesitant about the behavioural part and mentioned that weather conditions could result in decoupling the cable while charging. These types of hesitations resulted in a slightly decreased charge security.

QL (-): The reduced charge speeds lead to a decrease in charging security. The level to which a vehicle is charged heavily depends on the number of EV users connected. However, it was chosen to assign one minus to this set based on the opinions of the EV users. One EV user mentioned that at night, the decreased charging time is not important. The EV user was confident that the battery would be fully charged. The participant added that this was also due to the small range of the battery.

H (+): The charging security of this set is unchanged. The EV users indicated that the advantage would be the higher availability. However, in the end, they do not expect to experience a higher or lower charging security at a charging cluster compared to a stand-alone charger. Therefore, a zero is assigned to this set.

I (-): Slightly decrease. In principle, the system does not technically change for this set. The reason that the security decreases cannot be related to technical adjustments. However, the institution that the maximal parking duration is 4 hours makes the security that within that time frame, the battery is charged to the desired level is smaller. Therefore, one minus is assigned to this set.

(C5) Charge speed



QN (0): In chapter 5 is described that this set only requires a slight hardware modification. The grid connection remains unchanged. The number of cars that can connect at the same time does not change. Therefore, the charge speed remains the same.

QL (--): The charge speed reduces by more than 10 percent. The power given to the cars depends on how many vehicles are connected to the charger. In theory, the charging speed reduces by 50% when four vehicles are connected to the charger.

H (-): For charging infrastructure that can deliver a capacity of 3x25A (regular charger), there is a risk that the charging can deliver less power (NKL, 2019). When more EV users are charging simultaneously, the chance increases that the system cannot deliver the expected power and thus not the expected charging speed. The decrease will not be over 10%. Therefore, one minus is assigned to this set.

I (0): Technically, the system is unchanged. Hence, the charging speed is unchanged as well. The same reasoning applies for charging unit costs (C7), installation costs (C8), and maintenance costs (C9).

(C6) Availability

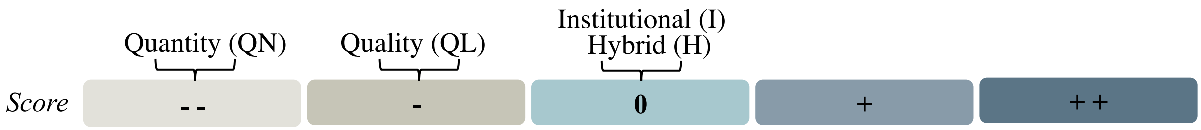
QN (0): The charger becomes directly available when a charging session is over (assuming that a remaining spot is available). This way, this set prevents charging station hogging. A study by Wolbertus & van den Hoed (2017) found that charging station hogging is not a substantial problem as expected. Only 1 percent of the charging sessions last more than 48 hours. Therefore, an increase smaller than 10 percent is expected.

QL (--): In this set, the availability increases the most. The four connections implicate that theoretically, twice as many users can charge per charger. The only condition for this increase is that only two spots are exclusively reserved for EV users. Nevertheless, considering that non EV drivers will sometimes use the remaining two spots, it is still assumed that the availability will increase by more than 10 percent.

H (-): The availability of a charger increases. When six charging units are clustered at one location, the chance that one charger is available increases compared to six chargers separately (NKL, 2019).

I (0): Average connection time on a Type 2 charger in the four largest cities in the Netherlands is 10,4h (Wolbertus et al., 2018). This is reduced to 4h max. This means that the charger can be used by 2,5 cars in that time. Considering that the place is not immediately occupied, it can still be used twice as much. An increase of 10% will thus be feasible.

(C7) Charger unit costs



To estimate the costs of the different sets, the sales manager of a charging manufacturer was consulted.

QN (--): The extra costs for the cable will be approximately 10%. Additionally, a software modification is needed that decouples the system when the desired charge level is reached. Therefore, an increase of more than 10 percent is expected.

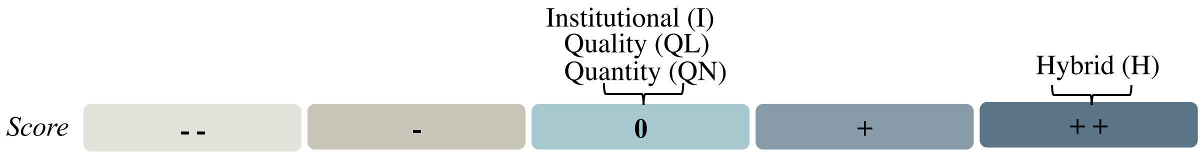
We offer such models mainly for the private and semi-public markets. These are usually more than 10% more expensive to purchase (including the cable).

QL (-): The costs for the additional sockets depends on the hard- and software design. Although, for this study is assumed that four connections are more expensive than two connections when the remaining hardware is identical. Due to the uncertainty, an increase of smaller than 10% is chosen.

The addition of sockets can be more expensive, but this depends on the design of the enclosure and hardware. Depending on the design, it can be cheaper or more expensive than a current charging station. This also depends on the sales potential.

H (0): This depends on how the system is evaluated. Nevertheless, the charger unit costs of a sole charger remain unchanged. For the whole cluster, a larger investment should be made at once.

(C8) Installation costs

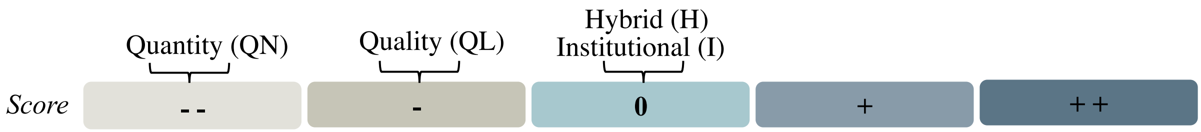


QN (0): The installation costs for this setup are unchanged. The same grid connection can be used, and the two spots are exclusively available for EV users.

QL (0): The installation costs for this setup are unchanged. The same grid connection can be used, and the two spots are exclusively available for EV users.

H (++): The installation costs decrease. More chargers can be connected to one grid connection. On the other hand, location determination will be more difficult. Nevertheless, these costs are less pressing on the total installation costs. This results in an expected decrease of less than 10%.

(C9) Maintenance costs



QN (--): This set is expected to exhibit the most significant increase in maintenance cost due to the required replacement for the fixed cable.

QL (-): It is expected that this set will slightly increase the maintenance cost for the charging unit due to the increased ratio of EVs per charger unit. It is expected that the lifetime of the charger unit will decrease.

H (0): Charging clusters are not expected to have increased maintenance costs compared to stand-alone charging units. Therefore, a zero is assigned to this set.

6.2 Evaluation

In this section, step 5 to 8 of the multi-criteria decision analysis is performed. Section 2.1 can be consulted for the methodological steps. This section describes the results.

6.2.1 Standardizing and weighting

The interval method is used as a standardization method. Although, it was not required to standardize because all assessment criteria already had the same units of measurement. In the interval method, the absolute highest score is ranked with a one and the absolute lowest with a zero (Janssen & Herwijnen, 2011).

The expected value method was applied to derive the weights of the criteria. Four E-mobility experts from a CPO were asked to rank the criteria on their importance. The average rank of these respondents is taken as input in Definite (Janssen & Herwijnen, 2011). The obtained weights are represented in table 14.

Table 14 The weight per assessment criteria

Number	Criteria	Rank	Weight
C1	Number of charge sessions	1	0,259
C2	kWh charged per session	1	0,259
C3	Average charge fee	2	0,129
C4	Charge security	5	0,129
C5	Charge speed	4	0,012
C6	Availability	4	0,043
C7	Charger unit costs	2	0,043
C8	Installation costs	3	0,083
C9	Maintenance costs	4	0,043

This method shows that, not surprisingly, the number of charge sessions and kWh is the most decisive criteria. Multiplied by the average charge fee, which was ranked as second most important, this is precisely the profit. It is also understandable that the charger unit cost is more important than the installation and maintenance costs for the CPO. The fact that charging speed obtained a lower level makes sense since the focus is on charging infrastructure in cities. In cities, public chargers predominantly serve as destination charging. At destination charging, the charging speed is less important than along highways (Motoaki & Shirk., 2017). The minor importance of charge security seems slightly unexpected. However, not all participants agreed on the lowest rank for charge security. One respondent valued both the installation and maintenance cost lower than charge security.

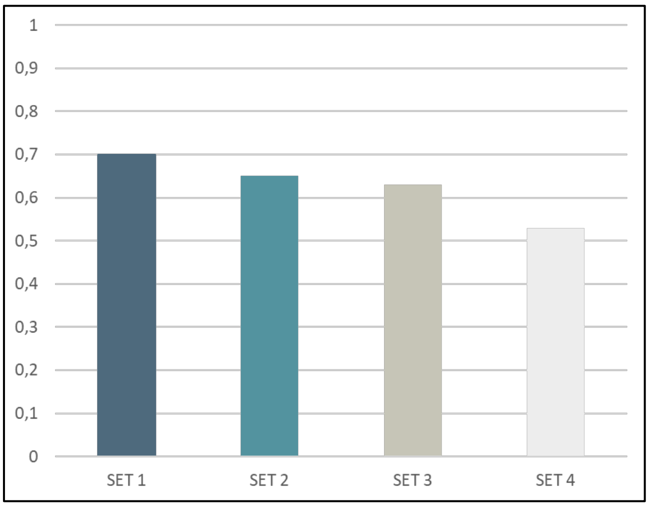


Figure 23 Ranking of sets

From this analysis, a quantity-driven design (set 1) seems the most preferred set. A quality-driven design (set 2) scored second best, a hybrid design (set 3) is the third best, and a purely institutional design (set 4), received the lowest score. However, the graph clearly shows the small deviation between the various sets. The scores between the sets range from 0.52 to 0.7.

6.2.2 Sensitivity analysis

The output of the sensitivity analysis can be found in Appendix IV. The graphical representations of the sensitivity analysis on both the weights and scores can be found here. This paragraph describes the main findings of the analysis. First, the sensitivity in the weights is analysed, and subsequently, the sensitivity in the scores.

Weight sensitivity

From the sensitivity analysis can be derived that not all criteria are sensitive to varying weights. The sensitivity analysis determines the ranking for all possible values of one selected weight (Janssen & Herwijnen, 2011). The weights of the remaining criteria are unchanged (Janssen & Herwijnen, 2011). By doing so is systematically analysed how a difference in one weight influences the overall outcome.

The following criteria are not influenced by varying weights: Average charge fee (C3), charge security (C4), and charge speed (C5). For these criteria, set 1 is preferred regardless of the assigned weight. For the remaining criteria, a variation in weight results in a different most preferred set. The table below gives an overview of this analysis.

Table 15 Results sensitivity in the weights

Criteria	Change
C1	Set 3 most preferred when lower weight
C2	Set 4 most preferred when lower weight
C6	Set 2 most preferred when higher weight
C7	Set 2 an eventually 4 most preferred when higher weight
C8	Set 3 most preferred when higher weight
C9	Set 3 most preferred when higher weight

Table 17 shows that changing one weight can result in whole different sets that are preferred. Also, it is not the case that one equal set is preferred instead. Per criteria, the set that is preferred differs. This shows how close the scores of the sets are.

Score sensitivity

The same analysis is applied to the score sensitivity. Here, it is examined if the ranking of the most preferred set changes by varying the scores (Janssen & Herwijnen, 2011). Again, one score is changed, and the others remain unchanged. It was found that only the outcome C4 to C9 is not sensitive to changes in scores. Set 1 (quantity-driven design) is the most preferred set on these criteria, regardless of varying scores. The rank of the remaining sets is also unchanged, except in charger unit costs (C7). In that case, hybrid design (set 3) and quality-driven design (set 2) reverse rank between the values – and 0. However, for the number of charge sessions (C1), charged kWh per session (C2), and average charge fee (C3), changes in score have a significant impact on the ranking. The graphical representations can be found in Appendix IV. The table with the results can be found below.

Table 16 Results sensitivity in the scores

Criteria	Change
C1	Set 1 and 2 reverse rank between values - and 0 Set 2 and 3 reverse rank between values -- and -
C2	Set 1 and 2 reverse rank between values - and 0 Set 2 and 4 reverse rank between values -- and -
C3	Set 1 and 2 reverse rank between values - and 0

It is not surprising that the effect of these scores on the outcome is huge. The number of charge sessions (C1) and kWh charged per session (C2) were assigned the highest weight. A change in these scores will have a more significant impact on the outcome. The fact that variations in average charge fee (C3) do impact the outcome, while charger unit costs (C7) which have the same weight, does not influence the most preferred set can be explained by the fact that the scores for average charge fee (C3) are almost equal. The quantity, quality, and hybrid design (sets 1,2, and 3) all received one plus. Changes in these scores do influence the results more. For charger unit costs (C7), the scores deviate more already. The heavy weight on charger unit costs (C7) can explain the reverse rank of the hybrid design (set 3) and the quality-driven design (set 2) between the values – and 0.

6.3 Conclusion

From the analysis in this chapter can be drawn that a quantity-driven design (set 1) performs slightly better than the remaining sets. The quality-driven design (set 2) scores second-best, the hybrid design (set 3) is third best, and purely institutional design (set 4) performs the worst. The sensitivity analysis shows that the weights have a significant influence on the outcome. Almost all weights influence the results. From this sensitivity analysis can also be derived that all sets can become the most preferred set if certain weights are changed. It is not the case that only set 1 (quality-driven design) and set 2 (quantity-driven design) reverse rank. However, the influence of differences in the scores is less influential on the outcome. Only the number of charge sessions (C1), the kWh per session (C2), and the average charge fee (C3) impact the outcome of the most preferred set. The reason for this result lies in the heavy weights that are applied to these criteria.

Thus, to answer the sub-question for this chapter. The quantity-driven design scores slightly better on the assessment criteria. The most influential scores for this result are the number of sessions (C1), the kWh per session (C2), and the average charge fee (C3). Differences in these scores heavily influence the outcome of the multi-criteria analysis. The remaining scores are less important for the outcome, which can be explained by less impact of the weights and more deviation in the scores.

In the recommendations is described how the CPO and municipality should implement this outcome of the evaluation table. It also describes the most preferred way to adapt these findings.

Chapter 7 Conclusion and discussion

7.1 Conclusion

This section provides the conclusion of the research and in this way deems to answer the main research question. The research question was the following:

What is the most preferred set of technical innovations and policy instruments to improve the success of public charging infrastructure in Dutch cities from the perspective of the CPO?

A successful public charging infrastructure from the perspective of the CPO is to maximize the charged kWh per charger unit and to maximize the EV convenience, whilst minimizing the costs. From this definition, an option creation process was conducted to find the most preferred sets which can meet these aims. The first conclusion is that this structured process resulted in a very large number of combinations of technical innovations and policy instruments, which shows the wide variety of possible combinations. The majority of these options were not found in literature. The identification that so many options exist is already a contribution in itself and strengthens the argument of the complexity in finding consensus on the design of the EV charging infrastructure. A structured approach was applied to reduce the number of options. From this process can be concluded that four sets seem the most preferred to apply in Dutch cities in the public domain: a quantity-driven design (set 1), a quality-driven design (set 2), a hybrid design (set 3) and purely institutional design (set 4). Table 19 exhibits the components these sets consists of. These sets have in common that they all aim to increase the number of charge sessions, or the kWh charged per session. This implicates that future design desires more focus on improved usage of charging units.

Table 17 The four most preferred combinations of technical innovations and policy instruments.

	Set 1: Quantity driven design	**Set 2: Quality driven design**	**Set 3: Hybrid design**	**Set 4: Purely institutional design**
T	Automatic decoupling	More connections per charger	Dynamic charging hub	No technical adjustments
F	Decreasing tariff	Lower night tariff	Decreasing tariff	None
I	2 spots exclusively for EV	2 spots exclusively for EV	None	Time slot with enforcement
S	None	Push to stop session	Push to stop session	None

Using an MCDA the following rank was derived: (1) a quantity-driven design, (2) a quality-driven design, (3) a hybrid design and (4) a purely institutional design. Thus, to answer the main research question: the quantity-driven design is the most preferred set for public infrastructure in Dutch cities.

7.2 Discussion

This section provides a discussion about the research contributions and reflects on the main assumptions that influenced the outcome of this research. The section is concluded with presenting the deeper connection between this research and the Complex Systems Engineering & Management master program.

7.2.1. Contributions

The research contributions of this study are both scientific as practical. First, the scientific contributions are discussed, after which the latter will be explored.

Scientific contributions

Two research gaps were identified as the basis for executing this research. These knowledge gaps were: (1) a lack of studies that combined technical innovations with policy instruments to improve the success of public charging infrastructure, and (2) a lack of the perspective of the CPO in current literature. This research aimed to bridge these gaps. In an attempt to fill these knowledge gaps, various contributors from current literature play a role.

The first research gap was a lack of studies that combine technical innovations with policy instruments. This research applied a multi-criteria decision analysis to find combinations of these two domains to improve the success of public charging infrastructure. This study emphasized the effectiveness of a multi-criteria decision analysis. It shows how the multi-criteria analysis can be used as the framework, but it is not static, which enables the conductor of the analysis to construct a personalized MCDA.

Although the multi-criteria analysis is a well-developed research method, this study applied it creatively. Especially, the options creation phase led to new insights. These options were not found in literature but were generated by means of interactive interview sessions with stakeholders from different backgrounds. It showed a wide variety of possible combinations. This identification is a contribution itself and strengthens the argument of the complexity in finding consensus on the design of the EV charging infrastructure. This makes it understandable that so many researchers are studying different aspects of the system. Subsequently, this study constructed a method to scientifically reduce this number of options and create a short-list of the most preferred options. In doing so, this thesis added value by constructing a well-shaped process to structure many options. Thus, the ultimate contribution is to provide knowledge on the wide variety of options available and reduce this number to the four most preferred sets. Also, this research defined selection criteria to evaluate the performance of the sets and attempted to score the four final sets.

The second research gap was the lack of focus on the perspective of the CPO. Current research only scratched the surface of the CPO perspective. To the researcher's best knowledge, this research is the first in investigating these sets from the CPO perspective, which makes this thesis unique. This study aimed to overcome the research gap by conducting various analyses to get a deeper understanding of the role and objectives of a CPO. A thorough analysis was conducted by constructing a comprehensive objective tree from the perspective of the CPO. This objective tree is a valuable addition to current literature. Based on this analysis, the definition of a successful infrastructure is slightly adapted by adding more dimension to the objectives of the CPO. This thesis merely investigates a few of these objectives. The remainder of the objectives could serve as input for new research directions, as described in section 7.3.

In conclusion, the research attempted to provide knowledge on preferred combinations of new technology innovation and policy instruments that CPOs can use to make EV charging infrastructure decisions. In this light, this research aims to contribute to the current theoretical knowledge on charging infrastructure and thus provides scientific relevance. Although the most preferred combination of technical innovations and policy instruments is based on the availability of the options in the Netherlands, this research approach can also be applied to other geographic regions.

Practical contributions

In section 3.5, it was described how rapidly the EV charging system is evolving. It almost seems as if the practice is outpacing science. In practice, the CPOs and municipalities run various pilots or even implement new infrastructure without thorough consideration. This thesis developed an academic method for the CPO, and other stakeholders, to draw conclusions based on scientific research. As a result, the stakeholders can make well-considered decisions on an academic foundation. This reduces the change of post-decision regret for CPOs and is likely to reduce the chance of sunk investments.

Section 3.5 also demonstrated which four sets have the most potential, namely, a quantity-driven design (set 1), a quality-driven design (set 2), a hybrid design (set 3), or a purely institutional design (set 4). The CPO can utilize the finding to initiate language for discussion and help them by making investment decisions.

Although this research focuses on the perspective of the CPO, it is expected that the results are interesting for other stakeholders. Especially the municipality will be interested, as they facilitate and cooperate with the CPO. Additionally, this method can be applied to different domains, such as the semi-public and private domains. On a broader level, the practical contributions can also be found in the societal relevance of this research. Due to a better business case for the CPO, a more successful infrastructure supports the pace of the transition to an electric transport system that reduces local CO2 emissions. This is in line with the aim to reduce GHG as agreed upon in the Paris Agreement in 2015.

7.2.2 Reflection

The main aim of this paragraph is to reflect on the assumptions that are made in this research. These assumptions have influenced the results. The most significant assumptions are described in this section. After that is reflected how these assumptions have influenced the results, this process leads to the identification of limitations of this research and new research directions. The further research directions are described in section 7.3.

Reflection on the scope of the research

Many of the assumptions were made to create a clear and focused decision context. As a matter of fact, the initial choice to focus on the public domain in cities already set the course to this research. Also, choosing to focus on the perspective of the CPO narrowed down the scope of the decision context.

These system boundaries were chosen at the start of the research. However, during the creation of the most preferred set of options, many assumptions were added. The first and foremost influential assumption was the choice to focus solely on the charged kWh per charging unit as a revenue stream for the CPO. Although this assumption was necessary to conduct relevant research in a limited timeframe, this assumption led to the rejection of other research directions and has influenced the identified sets. For example, this choice led to the assumption that charger hogging is not desired at all. However, it is known that it is not feasible to completely avoid charging hogging in urban areas due to the parking and refuelling behaviour. Therefore, it is interesting for the CPO to ensure some flexibility for the remaining connection time. Especially, when more renewable energy is integrated into the grid, this flexibility becomes more important. Another result of this scope was that the role of the grid operator in the EV infrastructure design is undervalued in this study because their role is more critical in smart charging, V2G, and energy storage solutions.

However, a nuance should be made. These assumptions were necessary and very relevant to make. It was part of the structure process. Without making these kinds of assumptions, the four final sets could not have been created. This research chose to focus on this scope, but there are many more aspects to discover. In the recommendation section, further research directions are suggested.

Reflection on applied research methods

This paragraph reflects on the applied research methodologies and how they can have influenced the results.

The primary research method was a multi-criteria decision-making analysis. A degree of subjectivity is inherent in an MCDA (Bernard, 2016). This thesis limited subjectivity by including experts, workshops, and interviews and objectively performed these. The small degree of subjectivity that cannot be avoided is aimed to make explicit by being transparent about the arguments that led to choices. For example, the choice for the criteria on which the evaluation was based. Including a different set of selection criteria would have led to different results. It could be that some choices were wrong, but by providing reasoning for certain choices, a room for discussion opens. This discussion can challenge existing ideas and lead to new insights and further academic research.

By executing the MCDA, a broad range of qualitative research methods, such as definition workshops, interview sessions, and expert opinions, were applied to perform the steps of the multi-criteria decision analysis. For these qualitative research methods, respondents were required. For the workshop, six participants that work at a CPO were included. This number is reasonable, considering how few people solely focus on electric mobility at the CPO in the Netherlands. However, the participants were all from the same CPO. Although it is expected that the critical objectives between the CPOs do not differ drastically, it could be the case that including electric mobility from other CPOs could have led to a slightly different objective tree.

In the option creation process, eight participants with different backgrounds were included. This group consisted of local- and national policymakers, service providers, an EV user representative, a consultant, and a marketeer. This is quite a varied group of respondents. However, including more participants would lead to more valid results. In this research, the ideas of one participant heavily influence the result. Including a larger group of participants would lead to observing similarities and differences. This way, statements could have been made about repeated responses, which would have indicated that most options were covered. In general, interviews are known for a certain degree of bias. Especially, the unstructured interview in which a discussion is initiated, there is a chance that the interviewer misinterprets answers. During an interview, another limitation is that the interviewee does not understand a question or situation entirely. A draft interview with three PhD researchers was performed to decrease this uncertainty (see section 2.4). Despite the aforementioned efforts to reduce uncertainty, there is always a chance that the interviewee does not entirely understand the context. Another point of concern could be that the discussion led to a hierarchy between participants.

Brainwriting ensured that all initial ideas were captured and reduced this effect. However, in the discussion, the hierarchy could still be apparent.

The evaluation of the sets was based on six respondents and available literature. However, still, a part of the scores is derived from brainstorming and logical reasoning. The sensitivity analysis showed that especially the scores in the number of charge sessions (C1), charged kWh per session (C2), and average charge fee (C3) influence the outcome. The assumptions in deriving these scores do influence the results. Moreover, the sensitivity analysis in section 6.2 shows that the weighs heavily influence the outcome. These weights are assigned based on the opinion of four E-mobility experts while the prioritization deviated. Different prioritizations lead to different outcomes.

The abovementioned arguments show that different aspects require further evaluation is. Section 7.3 describes how further evaluation should be performed.

Reflection on the identified sets

The results of the option creation process have some implications on the EV users and the municipality. This paragraph reflects on how the sets influence these two stakeholders.

A first reflection is that none of the designs does increase the charging speed or charging reliability for the EV user. This slightly influences the EV user negatively. However, this inconvenience is compensated by a lower charge tariff and higher availability of chargers. Since the availability of chargers is the most prominent requirement for EV users is expected that the slightly lower charge speed and reliability is not a big issue for inner-city charging. The biggest implication for the EV user is behavioural, especially in the case of the quantity-driven design. This would entail that another EV user can start a charge session for each other. The question arises if this will be socially accepted.

However, the implications for the municipality are more evident. These sets show that the EV infrastructure market is not ready to become self-sufficient yet. The CPO is still very dependent on the regulating power of the municipality. In the case of a hybrid system, co-investing is probably required because these innovative chargers are too expensive for the CPO. The question arises if the money available for pilot studies is sufficient. Also, it seems that the municipality's facilitating role should increase to execute these sets. For example, the system for automatic decoupling requires the development of new standards. Also, legal questions arise concerning the ability to start a charging session for another EV user.

7.2.3 Link to CoSEM

This research contains many elements that make it a Complex Systems Engineering & Management (CoSEM) research. The complexity of the EV infrastructure, the many stakeholders involved, the combination of technical and policy aspects and the link between the public and private domain are all indicators of how this research is connected to the master program.

The knowledge acquired throughout CoSEM is reflected in this research. A system analysis from both a technical and institutional perspective is performed. Also, the most important stakeholders for the decision-making are identified. In doing so, the socio-technical system of EV infrastructure design is described. Describing this system from those perspectives is a typical assignment of a CoSEM student. Techniques to identify objectives and structure are applied, and system boundaries are set. This research is not only focused on a systematic approach to find the most preferred set, but also on the implications of these sets on a system level. Finally, the suggested implementation in section 7.3 explores how the CPO should communicate the design to the municipality. This holistic view is typical for a CoSEM student.

7.3 Recommendation

This section provides recommendations for scientists in terms of further research direction. Subsequently, a recommendation for the CPO is described and how to communicate it to the municipality and EV users.

Further research directions

This paragraph starts with recommendations for a scientist to strengthen this research. Subsequently, other interesting research directions are described.

Building on the reflections in section 7.2, a few recommendations are derived to strengthen this research field further. It was found that further evaluation is required in both the adopted methods to generate options as the method to evaluate the process. The recommendations are described in chronological order of the applied methods.

The definition workshop with experts of the CPO could be conducted with electric mobility experts from various CPOs in further research. This would strengthen the derived definition.

For the interviews to generate options, two recommendations apply. First, it is recommended to shape the interview process even more. It should be emphasized that only options that improve the charged kWh per charging unit are sought. This way, a more detailed discussion arises, and better suitable options will be found. It will also be easier to combine the options. Furthermore, the phase of the deducing methods will require less time. Secondly, it is recommended to conduct interviews with a larger group of respondents. The results would improve when three participants per stakeholder group would be included. To evaluate if sufficient stakeholders are included, a saturation curve can be utilized. This curve indicates if adding new participants leads to new options. If the curve is saturated, the number of participants suffices.

The second phase of the deducing method consisted of a first attempt to fill in the degree of acceptance table. It is recommended to find more respondents from both perspectives (municipalities and EV users) to determine more precisely the degree to which the stakeholder accepts different options. The addition of more stakeholders from these two perspectives will make the results more representative. Also, it is recommended to add an additional dimension to this reducing step. For example, including different locations can be valuable. This is an example of a contextual factor that was excluded. Nonetheless, locations have different characteristics that can be of importance. At different locations, different grid connections are available. Also, parking durations and parking set-ups differ amongst locations.

For the evaluation of the sets, it is also recommended to find a larger group of respondents. Also, if future sets will be tested in pilots, the data of these findings should be included. Especially data on the number of charge sessions and kWh per session lacks in this research. In section 7.2, it was found that a more precise determination of the weights is needed. Therefore, a larger group of respondents is recommended consisting of electric mobility experts from different CPOs.

With regards to the criteria, further recommendations come into play. Future research can evaluate the set on a more extensive set of criteria. This paper was limited to a small set of criteria. Examples of criteria that can be included as well are criteria environmental criteria, social criteria and more criteria that measure the market potential. Besides this, further evaluation on the correlation between criteria is recommended. Non-redundancy can be applied to observe if criteria are measuring the same effect. A correlation coefficient can be calculated to find out whether the included criteria are correlated with each other and thus have a more significant effect on the outcome than expected. For example, the number of transactions and availability could potentially be correlated. A higher availability means a higher number of transactions.

Except for further research built on this research, different research directions can also be derived from this research. The objective tree served as the foundation of this research. It was chosen to focus on selected objectives but choosing other objectives would lead to other research directions. The most evident research direction is to investigate the potential of selling flexibility. This research stresses multiple times that this potential is unclear as of this moment. It is interesting to find the right balance between charger unit hogging to have the flexibility and between selling kWh for a CPO. This is interesting from both a technical as an institutional perspective. The role division of a grid operator and a CPO becomes interesting in this research direction. The following questions arises: who is responsible for the flexibility? Who is in charge of the operation? During peak demands, are the grid operators allowed to stop charging sessions? These types of questions are very relevant in future research.

The interviews also led to new interesting research directions. These directions were out of scope for this research but can be taken into account in future research. For example, more research should be conducted on price transparency. Another interesting research direction is to develop a reward system as a social instrument to stimulate better behaviour. It would be interesting to investigate the potential of a reward system, especially literature on social incentives is currently lacking. The last argument is to align public and semi-public charging better. It would be interesting to investigate if it is possible to use, for example, company parking spots during the weekend. Thus, it may be interesting to explore how these two domains can be better aligned.

Practical recommendations for the CPO

One of the research objectives was to provide an academic foundation that supports the CPO in making investments decisions. This thesis provided an academic method for the CPO to support them in the decision-making process. Therefore, the first recommendation for the CPO is to use the MCDA as a foundation to make charging infrastructure investment decisions. The outcome of this research intends to support the CPO in their decision-making process by providing knowledge on suitable combinations, not to make decisions for them. It is recommended that the CPO use the results as input for new discussions. Nonetheless, this paragraph exhibits a possible example of an interpretation of the results.

In the researcher's opinion, it is best to simultaneously implement a quantity-driven design (set 1) and a quality-driven (set 2) design. Combining these sets is advantageous because the first design applies to locations where users predominantly charge during the day and the second design to locations where users predominantly charge overnight. In order to successfully implement this design, coordination with different stakeholders is required. Figure 24 illustrates the design components and indicates the stakeholders with whom coordination is required. Section 5.3 can be consulted for in-depth descriptions of these designs.

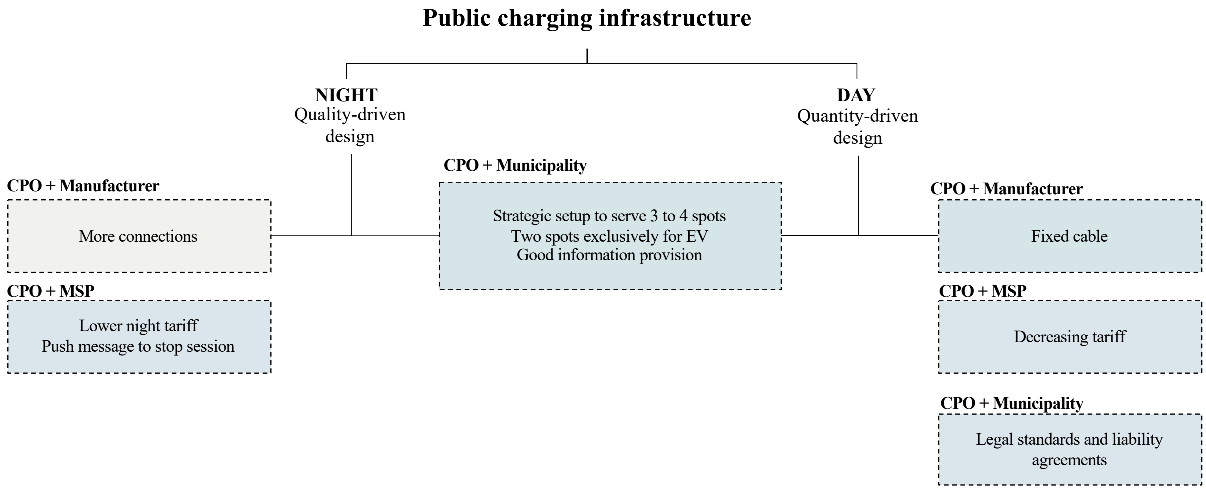


Figure 24 Recommend charging infrastructure in the public domain and coordination between stakeholders.

This figure exhibits that coordination is suggested with the following three stakeholders: The manufacturer, the Mobility Service Provider (MSP), and the municipality.

- Manufacturer: Cooperation with a charging unit manufacturer is required to make technical adjustments to the chargers.
- MSP: Cooperation between the CPO and MSP is required to create a transparent billing system. A suggestion for the CPO is to display the charge fee at the charging unit. This way, the EV user is less dependent on not completely reliable apps.
- Municipality: Cooperation between the CPO and municipality is needed on different aspects, which are: location determination, liability by damage, development of legal standards, and communication strategies.

The focus should be on the coordination with the municipality, as they have the regulating power to approve and implement propositions. The CPO should convince the municipality that this design is preferred over the current design.

The suggested design, has an edge over other solutions, given that fewer chargers are needed to meet demand. According to NAL, 1.7 million charging points are required to fulfil future charging demand. The solution as portrayed in this thesis, would create three to four available charging points, whereas current chargers only facilitate two. Given the assumptions presented above, it becomes clear that a significantly lower number of chargers would satisfice, which results in various advantages for the municipality:

1. **Less pressure on public space**. The municipality has to satisfy and uphold different stakeholder interests, including those of EV users and non EV users. With the design as presented above, less (new) chargers would have to be placed in the public space. In doing so, the municipality would keep all parties satisfied, given that the charging demand is met without an extensive placement of charging units.
2. **The solution can be applied to current infrastructure.** This design does not require new grid connections. Also, in theory, the current chargers can be adjusted. Thus, with relatively little interference, significant efficiency steps can be made.
3. **The business case for the CPO improves.** It is expected that the fewer chargers required (lower investment costs) and increased kWh charged per charging unit result in a more viable

business case for the CPO. The better the business case of a CPO, the higher the charging placement price they are willing to pay the municipality.

4. **Leading the transition.** The Netherlands is a European leader in EV-charging infrastructure. Innovation and continuous improvements are essential to maintain this reputation. By implementing this design, the municipality takes a step further into the innovative landscape of electric mobility.

This design should not be implemented on a large scale immediately. First, it is suggested to start running a pilot with the municipality. Results of this pilot should determine if this design is also feasible in practice. If this is the case, it is recommended to begin by modifying the current charging units. If this is achieved, the infrastructure can be expanded with charging units that already have these new features. Ultimately, this design can be communicated to other urban areas that want to shift to electric mobility in the future.

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Appendices

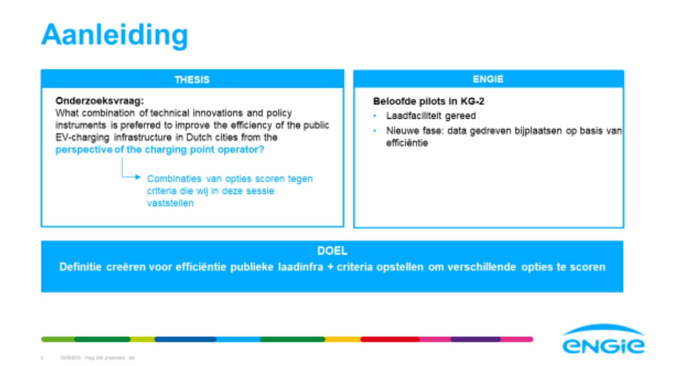
Figure 25 Overview structure of appendices

Appendix I: Workshop report 13/04/2021

List of participants

Interview ID	Company	Function	Background/expertise
WSP1	ENGIE	E-mobility consultant	Management of Technology
WSP2	ENGIE	New business developer	Complex Systems Engineering & Management
WSP3	ENGIE	Project Lead E-mobility	Strategic Innovation Management
WSP4	ENGIE	Management Trainee	Engineering Policy Analysis
WSP5	ENGIE	Management Trainee	Sustainable Energy Technology
WSP6	ENGIE	Data scientist	Industrial Design

Workshop process

<table>
<tr><th>Slide</th><th>Explanation</th></tr>
<tr><td>


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- **Introduction: why this workshop**
- **Purpose of the workshop**

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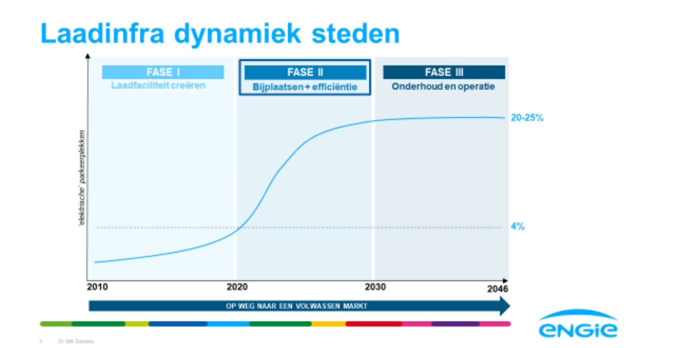

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- **State of the art**
- **Social relevance**

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- **Setting the scope: Public infrastructure and perspective of the CPO**

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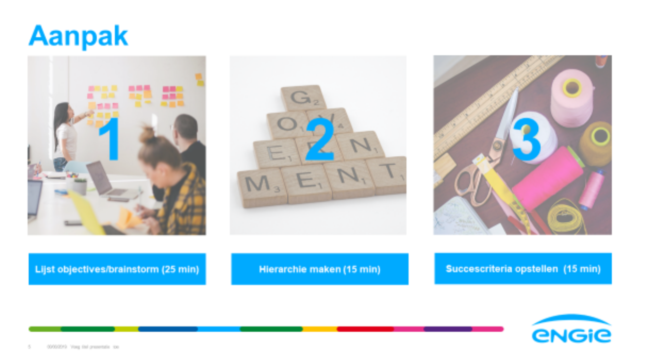
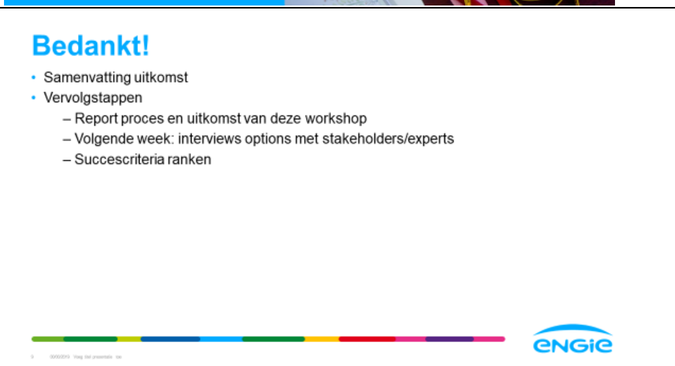


- **Method and structure**
- **1. Brainstorm to obtain list of objectives**
- **2. Building the objective tree. From overall objective to fundamental objective.**
- **3. Set metrics for fundamental objective.**

- **Brainstorm via Teams Whiteboard**
- **5 min per team member**
- **Discussion and explanation for objectives**

- **Ranking via Microsoft Whiteboard**
- **Searching for categories and similarities between members**

- **How to measure end-objectives**
- **Focus on how performance on objective can be assessed**



- **Summary of the session**
- **Next steps**

Workshop output

Main findings

Interview ID	Notes	Explanation
WSP1	• Kwh / charger = Business Case • Create feeling parking availability • Smart charging during peak hours • Spread service deployment throughout the day	• kWh/charger is one on one our BuCa. If we can maximize kWh/charger is good for BuCa. • Occupancy rate not in line with complains customers • CPO pays significantly more during peak hours • Serving more E-drivers
WSP2	• Revenues: maximize kWh/charger. Connection to HBEs (green certificates for mobility) • Uniform working principle for chargers • Equal distribution amount chargers • Possibility to scale energy up and down • Predictive use of energy • Align different user groups	• kWh to get ROI • For CPO easier if chargers have same hardware/software • Not 1000 placements one week and 0 other • Save costs on energy purchase • Make money with flexible charging • Make parking spots available for other user E-types when i.e. taxis are not connected
WSP3	• 100% uptime • Cross parking spaces • Availability transparent • Flexible use shared mobility	• Fix failures remotely • Example Utrecht: charge square, but policy won't let CPO cross all spaces there • Lack of 1 app that integrates all chargers from different providers and makes availability interesting for users • Municipalities should allow us to allow shared mobility
WSP4	• Satisfied end users • Good relationship with client • Easy placement process	• More charging (at your charger) when satisfied • Easy coordination with municipalities or grid operators • Quick response to new situations/demands
WSP5	• Optimum sticking at charger and flexible use of capacity • Efficient use of energy • Balance on BRB	• Cars that park for a longer period can be used in flexible charging • Energy purchase 10 years ahead whilst market is on 15 min or even seconds. Obtain info (#EVs, sun/wind, unform rules) to predict more precisely.

		• PPA always under dimensioned
WSP6	• Good information provision for E-driver • Ideal: 100% charging, 100% charge occupancy • Minimal burden on grid operator • Minimize failures	• Charging locations, charging availability, failures, expectations • Maximal kWh sold • Ensure that CPO can continue placing charger

Agreement on

- Main importance business case. The business case – kwh/charger. All participants agreed on the fact that the kWh/charger is one on one the business case for them. The main aim om the CPO is to sell as much energy as possible. If you can maximize that, that's inherently super important for business case.
- Relationship with partners and customers. Besides the business case is the CPO an service provider. Therefore the objective is to have convenient end users. It is important to create a feeling that there is enough space. The 'feeling' is because there are complaints about busy spot, while occupancy rate is at 10/20 percent. Has to do with perception when it is busy. So then it's about amplitude between peak and average.
- Increasing importance of prediction of energy demand/EV trends and ..
- The cohesiveness amongst EV-driver should be increased. In the beginning the early adopters. They believe electrics driving is cool. Now, EVs are becoming cheaper and more widely available. New type of users that er not necessarily pro electric. The solidarity decreases. Tend to stay longer at a charger, less urge to move vehicle. This behavior is difficult. Should create a new feeling that we should share the infra.

  Leads to question of creating a 'shortage' to ensure people feel the urge to move their car again, which is good for the BuCa. Other hand thinks WSP1 that more chargers will lead to a higher occupancy rate. Same as with highways. More highways lead to more cars on the road. However, WSP1 doesn't know if this is better for the BuCa. People will tend to keep their car longer because they wont have the feeling that others do need it.

Disagreement on

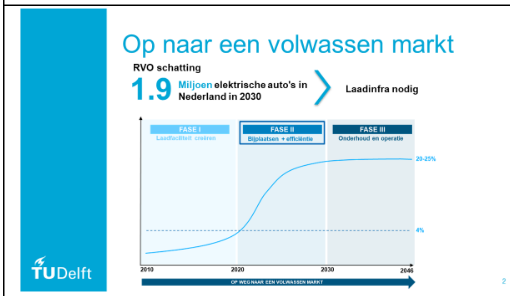
- Role and power of CPO/DSO in grid balancing. The participants differ in their opinion of the extent of responsibility for of the CPO to balance the grid. WSP6 argued that the CPO should minimize the burden on the grid, to ensure the can continue placing chargers. WSP5 argues that it is the role of the DSO to enable the CPO to fulfill their function as developing an infrastructure. The case was compared to Germany, where DSOs can turn off chargers when the grid gets overloaded. WSP5 stresses the importance to remain in charge in this process.

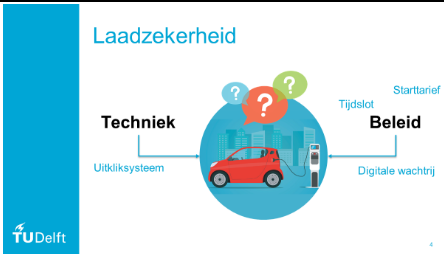
Uncertainty about

- Value of revenues flex charging. An aim is to find an optimum between 'laadpaal kleven' and flexible use remaining time. However, it is unclear what flex use is worth on the market. Currently little insight what part is flexible. The revenues of flex will always be lower is expected. The chance is small that flex will earn as much as selling electricity is small. They cannot imagine a situation in which it would have been better not supplying energy.

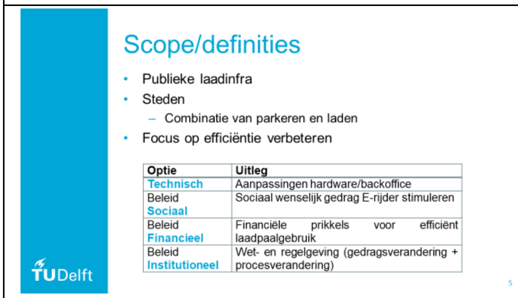
Appendix II: Report interactive sessions for option identification

Part I: Introduction and scope (10 min)

Slide	Description
	Thank you for participating in this session. I am curious to hear your insights on new technologies and policy instruments to increase efficiency on the public charging infrastructure. What will this session look like? This is not a session in which I will use a question/answer model. It will be an interactive session in which we will look for combinations together. I will start by briefly explaining the reason for this session, the scope of the research and then I will be curious to hear your options and combine them.
	As the Netherlands, we lead the way in facilitating a charging infrastructure for electric cars. Together with new legislation (new cars sold must be electric by 2030), this will result in a strong increase in EVs. The RVO estimates that by 2030 there will be about 1.9 million electric cars on the road in the Netherlands. This will lead to an increasing demand for corresponding public infrastructure. At the moment, we can see that a fairly comprehensive charging infrastructure has already been realised in the major Dutch cities and that this infrastructure is actually ready for the next phase. This phase is mainly about adding and optimising the charging infrastructure. That is why I want to look at this next step with you in this session; how can we improve the infrastructure?
	The trend I have just described leads to the question of how the charging infrastructure can be designed more efficiently. The aim here is to look at COMBINATIONS of technological innovations and policy instruments to realise this. The reason for looking at combinations is that we should not see these systems as separate from each other, but as complimentary. So the point of combinations is to look at how technology and policy can complement/reinforce each other.



An example to create more of a feeling for this and to give an idea of the level at which combinations are sought. The creation of loading security is important. To this end, the technical set-up can be adapted by creating an unclipping system. This ensures that the plug becomes available again for a new EV driver. In addition, a financial incentive could be the introduction of a starting charge. This could lead to E-drivers charging for fewer short sessions. It could also be decided institutionally to cross 2 parking spaces at once, so that 2 cars can immediately be parked at a pole. Finally, a digital queue could be created via an app.



Before we start the brainstorm, I would like to reiterate that we focus on public charging infrastructure (so no B2B poles etc.) in cities (so parking and charging). We focus on improving efficiency (QUESTION: Even though for CPO it might be kWh/pole, for other stakeholders it is also interesting. For example, less poles is interesting for the municipality, for non-EV drivers, for capacity on the grid (?).

Technical: Do you have any ideas by using new charging techniques and/or adjustments to the hardware/back office to give options for better use of the charge point;
Policy:
Social: Do you see possibilities to stimulate E-drivers to show socially desirable behaviour?
Financial: What possibilities do you see for providing financial incentives to the E-driver to use the charge point efficiently?
Institutional: What laws and regulations are desirable to make the charging infrastructure more efficient (rules that promote efficient use, but also an efficient placement process/integration/standardisation)?

I hope that you now have a sense of the purpose of this session: finding combinations of technology and policy to improve infrastructure. Now, I would like to ask you if you can help me think about this. The idea is to use the Whiteboard to brainstorm together about possible options. I will mainly have a facilitating role in this, as it is not my intention to steer you in a certain direction. The idea is to first create a list of loose options. In the whiteboard, I have created 4 groups. You can add notes to each group that you think might be interesting options.

	The idea is to generate as many options as possible within 15 minutes. Then it is time to combine different options with each other. In this way, different sets of options are created.

Part 2: Creation (15 min)

<table>
<tr><th>Slide</th><th>Description</th></tr>
<tr><td>
</td><td>I have made a brief start and my question is whether you can add to it. What do you see as concrete options to improve efficiency? I am looking for examples such as: introducing a starting tariff of e.g. 1.50 to stimulate that many kWh are charged in 1x and not 'stimulate charging a lot'. Is it clear to you what type of options are being asked for?
[5 min brainstorm]</td></tr>
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Part 3: Combining (20 min)

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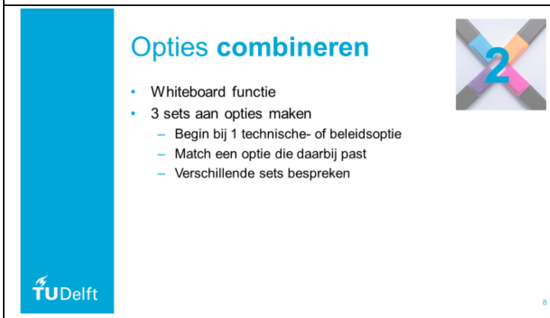
<tr><td>
</td><td>Now that we have lists of different options, let's see which you think would work best in combination and why. [Depending on the number of people/time, I'll ask them to make 2-4 sets of options that they see as fitting together]. I would like to ask you again to think about this for 5 minutes. The remaining 10/15 minutes we will have a discussion about this and hear why you think this is a smart combination.</td></tr>
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Part 4: conclusion (5 min)

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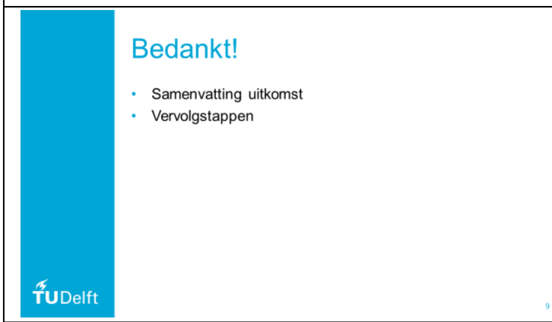
<tr><td>
</td><td>We are done. We have found x sets together. Do you have any additions to your answers/found sets? Interested in receiving my research?

Thank you very much for your participation.</td></tr>
</table>

Results

Options found during workshop session with ENGIE

Date: 13-04-2021 / 09:00-10:30

Category	Options
Technical	Fix failures remotely, 'totaalpalen'

Institutional	Make parking spots available for other user E-types when i.e. taxis are not connected, possibility to cross parking spaces by CPO, fining connecting without charging
Financial	Smart charging during peak hours, cars that park for a longer period can be used in flexible charging, price difference in neighborhoods with lease
Social	1 app that integrates all chargers from different providers and makes availability interesting for users, customer loyalty through savings system
Organization	For CPO easier if chargers have same hardware/software, uniform working principle for chargers

Options found by external stakeholders interviews
Session 1
Date: 21-04-2021 / 10:00-12:00

ID	Company	Role	Experience in E-mobility sector (years)
PO1	Joulz	Service provider	4
PO2	Municipality of Rotterdam	Policy (regional)	15
PO3	Ministry of Infrastructure and Water Management	Policy (national)	2 (infra since 1992)

<u>Output – List of options</u>

Category	Options
Technical	Smart charging, V2G, charging robot, more vehicles to one charger, charging square with 6 vehicles, dynamic crossing, pull-out system, fixed cables
Institutional	Zero emission zones, charger data accessible for everyone, stimulate policy to decoupling, enable parking facilities at businesses in the weekends,
Financial	V2G (feed energy to the grid), BuCa with start and stop tariffs, flexible tariffs (cheaper in combination with solar panels), smart charging, real-time payments
Social	Push message to stop charging session, social app, parking app (pas provider uses app to start session), information sessions ANWB environment centers, training and education car manufacturers, education installers, charging etiquette
Organization	Transparency of tariffs, open standards accessibility to data, facilitation who good providers are and insights in charge costs, standardization between policy and technician.

<u>Quotes</u>

PO1

- Training of mechanics is important. Education is not enough.

- It should be technically feasible to have more connections to a charger. When one car is charged move on to the next.
- You can also see cross off as transition mode. Communicate with user of pass. Remote charging session stop. Social app. It would be more convenient if we had charging points with fixed cables. People very afraid of cable being stolen.
- Technically possible to insert time that finished charging and then it disconnects the charging station. That development is already there. Now someone can get away with the cable. Piece of policy. When you have finished charging, it must be possible to disconnect it. The developments are there technically, but policy is rigid.
- After certain kWh you start paying per min. Technically that is possible. You can set it up. However, information should be given about these rates. Not a penalty afterwards. AFM have been busy on this point. Financially it is not clear what they pay when they start charging. Or rate what is on charging pole is not what you pay. The payment method determines that.
- Flexible rates. Suppose you have charging stations public with solar cells on the roof. Can you charge cheaper during the day. Much more spread out.
- We should look much more at parking spaces at businesses and find collaborations there. Which are not used during the day to use them more. Semi-public. But who can come up with cooperation for combinations. Incentive to get better acceptance in neighborhoods as well.
- Payment methods really not flexible enough.
- Companies within cities have policy that suppliers supply zero emission. Promote electric driving.

PO2

- Electricity important environment
- Livable city important. We actually don't like autos on the street
- Tension field with street with few electric autos and many gasoline and high parking pressure. Will clash and hurt. Our mayor wants to keep everyone happy. Penal policy with higher rates and sending autos away is not what he wants. Always some tension.
- Options to cross/not cross parking spaces, or do it dynamic. At time of higher parking pressure then hurts more. More available for other autos.
- More autos on 1 charger. Something to do with charging areas in which we have 6 autos on 1 charger.
- Experimenting with charging square now: 10 parking spaces but 6 marked off.
- Difficult for enforcement officers that the plug is in, but you don't know if it is fully charged. According to PO1 piece of knowledge, there is policy needed.
- Tariffs > see that target group changes. Now the lease driver who may not find it so important. But soon also the second hand market and private drivers who find it important.
- Inner city and residential areas have different dynamics and demand. Good insight into who is charging. You can make policy on everything that helps with this. Sticking together is not desirable in the city center.
- Charging etiquette. Address people on social norms in a positive way.

PO3

- Laainfra helps boosting car adoption
- July 2 by law all charging station infra publicly available so in apps can see. Open standards availability for the data.
- Enough chargers is convenient for accessibility

- Turns out people charge too much, confiscate charging stations when not needed. Is piece of awareness. Electric charging have feeling that every 60km in charging station. Leads to overuse of infra.
- Information via anwb environmental centers
- Training and education of people in the automotive sector pay too little attention to electric driving. Also link with solar panels at home.
- Important government task is to guarantee safety. Ensure that capacities in the neighborhood remain up to standard.

Session 2

Date: 21-04-2021 / 14:00-16:00

ID	Company	Role/perspective	Experience in E-mobility sector (years)
PO4	VVE – association for E-drivers	EV interest representative	6
PO5	Royal Haskoning	Consultant/Service Provider	12

Output – List of options

Category	Options
Technical	Smart charging (predict when someone leaves), automatic pull-out system, more connections to one charger, charging square, DC charging at in/exit of cities, type 2 chargers with fixed cable, strategic setup to serve 3 or 4 parking spots,
Institutional	Dynamic crossing, stimulate EV's with more capacity, discourage hybrids, time slots, stimulate multimodality, stimulate infra at business locations, stimulate charging infra at parking lots and VVEs
Financial	Connection tariff, charging in off-peak hours cheaper, charger after 24h more expensive
Social	Price difference not too big, digital waiting line,
Organization	Facilitation of municipality up, vision creation, quick scan facilitation/subsidies to stimulate charging in parking lots, smart charging as standard

<u>PO4</u>

- Financial incentive: rates is for electric drivers a kWh can be 3 times as much at one charger as another charger. Difference public and private is big. Gasoline price differences are not that big.
- Electric cars in city pay much because they rely on public charger or even fast charger, which usually charge much higher rates. Tricky point to make even more financial differentiation in.
- Sending a message before the charging session ends is going too far. This is often returned to in tests. Fee of course only for the day. Again complicated with people working nights.
- Tricky financial incentives for efficient charging station use that also bites with other interests. Looking to the future, we want cars to stay longer to balance the energy grid. To spread out charging sessions and apply V2G.
- Tech really needs a fixed cable like in the US. With fixed cable, piece could become easy and more efficient. Strategically set up that charging station can serve 3 spots. Can even serve 4 if strategically set up. Was at work possibility to take cable out and plug in at your place. This

encourages social behavior. Requires car and charger to be able to do that though. Already very different from chargers with their own cables.

- Setup can be better as far as he is concerned. The standard is charger with 2 connections. Can be more strategic so that more places can serve.
- Dynamically cross off. Charging spots for electric cars and non-electric cars bite each other in some spots. Creates a distorted view. Experimental site in Hoofddorp where spots are marked off dynamically. System takes pressure into account.
- Policy: Stimulate 3 things: 1. A lot of attention to public, underexposed charging infrastructure at work locations. In the Netherlands, a large number of people are unable to build their own charging infrastructure and are dependent on the public. These people do go to fixed charging stations at work. But work locations are lagging behind. In the Netherlands 1 in 4 people on charging pole and simply because we have many high-rise buildings. 2. Charging infrastructure in garages and VVEs, investment expensive, but also that investment in own charging station takes time to pay off. The municipality must interfere to the extent that they facilitate or subsidize QuickScan. Interest of municipalities to have charging infrastructure here so they have to sacrifice fewer parking spaces. 3. Encourage EVs with more range, difficult for municipalities but perhaps for government. At 500km range you start charging much more opportunistically. Then use more work charging than public. And even bigger batteries offer fast charging faster alternative.
- Fast charging at entry and exit cities. Missing from the plans.
- Hybrid should not be encouraged. Also for emissions. And not efficient for charging infrastructure use.
- Flexible capacity charge is important for smart charging. Grid operator wants system where you determine tariff. Now no incentive for CPO to arrange that and pass it on to end user.
- No advocate for indicating when you are leaving. Solve more with cars with more range. The system must then be built into the car. That you say up to 200km I need to be full and then you can use it for smart charging. But it just has to be smart.
- Public and logistics charging is logistics constituency not attractive and they want largely home locations and depots. Particularly aspect of differentiation large companies and small companies disagree.

<u>PO5</u>

- Financial incentive. Come from situation where everyone always wanted battery full regardless of cost and time. Connection fee where you got request to move car t. If not. Then a tariff per time unit as a kind of parking fee. This died a quiet death at the expense of the environment. Withdrawn because you do EV drivers short.
- Debacle with reserving charging stations can, but causes exclusion. Then you have to have penalty fee.
- Green zone > you pay more but more guarantee. Blue zone > you pay less but less guarantee. With a model you segment different groups of people. Different needs.
- Financial incentive can work the other way too. Lease car doesn't matter where you charge. Lease policy stated that you can charge max 40% at premium spots along highway. From thought it doesn't matter because boss pays. Why not monitor with max 40% fast charging.
- Highlight multimodal use. Struggle that you can't estimate how far ahead in time. Striving consistency can be used. Need to bring different audiences together. Where to find public facilities where you can get everything to flow together. Centralize places where large vehicles and small vehicles meet.
- Theme snags, but now clear claim to provinces and municipalities that they should facilitate everything. The playing field of electric uptake is diffuse and treated very diffusely. It is

hoped that playing field will move up from facilitative nature of municipality. Waste trucks, public transport, delivery vans all have to go with it.

- Charge security. Battery always full everywhere. Now, after 9 years a lot easier to deal with. Now I can say 1 time per 2 days charging is fine. You have to know where you can charge, in combination with increasing battery packs. Soon 2nd hand market. Thesis: the balance of the need to charge is going to shift.
- The need to charge will shift across the board, especially at home and in the semi-public sector, and the need to increase charging security across the board. It is now safe to say that you can drive around for a day with a 20 percent battery.
- Technology can be much better: smart charging now balancing time and capacity. But with smart supply and demand, you have to predict what time someone will leave.
- Time slot discussion whether everyone is going to be happy with this.

Session 3

Date: 22-04-2021 / 10:00-12:00

ID	**Company**	**Role**	**Experience in E-mobility sector (years)**
PO6	SlimLaden	Service Provider	30

Output – List of options

Category	Options
Technical	Vehicle recognition, cross-parking (2 connections with 4 spaces), pull-out system, snake mode (automatic disconnection), hybrid system (parking and smart charging),
Institutional	Predict parking time (enter end time), cable on streets during transition
Financial	OR-payments, night tariffs, municipality invest/subsidize parking solutions,
Social	Social charging app, blinker when car is not allowed to park, explain/educate neighborhood
Organization	Combine parking and charging (ParkMobile), easy communication E-driver,

<u>Output</u>

- Cross parking. 2 charge points with 4 parking spaces. Then you can make a lot of progress with the click-out system. Can also be done with 2 spots and 1 charge point.
- EU has chosen for each his own cable, is that logical is the question. There is a demand for cable standards. Now it is still sensitive. It's someone else's pole, and you can't touch it. So that would be easier.
- A lot of standardisation is needed. They are going to be one of the first to provide OR code payments. Now you always have to deal with roaming and storage transfers from provider to provider. It is a very complex system. CPO benefits but EV driver pays cost.
- Car recognition in terms of technology. You just plug in your cable, and behind the scenes, someone figures out how to pay for it.
- Combined parking - hybrid parking. Really a transition solution. In 8 years' time, 50% will be electric and you won't have to organise it all.

- Enforcement is difficult if there is no sign, according to the law, this is quite rigid, if it is a transition solution, why can't enforcers enforce more easily. Governments should make things easier in transition.
- Cable over the pavement is also an example of a transition solution. Why can't it be allowed more easily.
- Combination of parking and charging. Start charging session in ParkMobile. The two actions are undesirable. Reservation is part of it.
- Night rate can be a financial incentive for residents to come and park.
- He would very much like to enter end time, must be combined with parking. Can already be done in park mobile. End time of parking time is something they have to work on.
- With a car they can still offer 22kW. Helps with traffic flow. Shame that posts are back to 11kW. Loading speed and profiling are still often misjudged.
- Social charging app are good initiatives. Helps social awareness of system.
- Cross parking you come to a practical point. How do you do traffic decision. Green box and sign currently. 2 charging points and 4 spots. Take traffic decision on 2 spots and other two spots work with different marking. You can mark without a traffic decision. Sometimes things get stuck and have to be different and flexible. Municipalities must take a step in this direction. Another piece that governments need to make transition mode easier. Can be easier in terms of policy. Tolerance or transition form or pilot form.
- A fixed cable is interesting for a design in which the cable rolls back, for example. Fixed cable is favourable for industry. On the other hand, CPO incurs more costs and probably more failures due to fixed cables. They wear out faster, and people don't handle them as well. So business case might be a bit worse. But need to research which cable should do it exactly. In the cable is a button that releases the system. Such a release system can be easily facilitated. The charging station manufacturer must facilitate this. The choice for loose cables was that we had different types like type 1 and type 2, but that is all gone now, actually. It will even be possible in snake mode in the future - that it pulls itself out and goes in.
- Parking solution makes charging solution quite expensive. Twice as expensive. Municipality wanted to help pay for parking solution. They have fun with it. Not having to give up entire parking space electrically.
- Communication is important. Be clear meaning of the light. But it wasn't so difficult to explain from experience.
- Social charging really is an app for enthusiasts but the general public is really not going to download that. Parker

Session 4

Date: 22-04-2021 / 14:00-16:00

ID	Company	Role	Experience in E-mobility sector (years)
P07	Draka	Marketing developer	2
P08	Vattenfall UX-designer	Flexibility developer	3

Output – List of options

Category	Options
Technical	Own charger on street, system that predicts mix on the grid > optimal charging moment, shared charger, OR code on charger, hybrid cables, induction, DC charging, V2G, coupling to renewable generation

Institutional	Possibility to place charger on sidewalk, semi-public more possibilities, hybrid model (normal vehicles can also use places)
Financial	Cheaper when more kWh, cheaper when use of renewables,
Social	Indication of free chargers (app),
Organization	Keep the system simple

Output – combinations

Pull-out system – indicate what level you want to charge – indicate charging level at charger - third party for facilitation – keep it simple for E-user

Induction charging -

Central management system – load balancing – V2G - solar panels – renewable generation

Informed consent Interactieve Sessies E-Mobility Future Charging [HvA x TU Delft]

Doel van het onderzoek

Het doel van de twee sessies is als volgt: het verkennen van techniek- en beleidsfactoren ter behoeven van het bevorderen van de laad efficiëntie, en het identificeren van perspectieven en prioriteiten in de ontwikkeling van het publieke laadsysteem, aan de hand van drie geschetste toekomstscenario's.

Uitvoering

Wij communiceren door het videoplatform Microsoft Teams en maken gebruik van de enquêtesoftware Qualtrics (in beheer van de Hogeschool van Amsterdam). De data zal op een veilige en verantwoordelijke manier worden opgeslagen. Voor meer informatie kunt u het privacy statement doornemen.

Uw bijdrage

Uw deelname voor dit onderzoek is gebaseerd op uw ervaringen met e-mobility als deskundige, beleidsmaker, technicus, belangenrepresentant, service provider, netbeheerder, of andere relevante speler in het veld. Door uw deelname kunnen wij kennis opdoen van verschillende perspectieven in het veld. Dit geeft ons de mogelijkheid die kennis in te zetten voor maatschappelijk relevant onderzoek.

Uw deelname stoppen
U kunt op elk moment uw deelname stopzetten door dit voor, tijdens of na het interview aan te geven. Vanwege de resultaatverwerking verzoeken wij u om bedenkingen binnen 4 weken na deelname bekend te maken.
Contactpersonen
U kunt voor vragen, opmerkingen of opt-out terecht bij de onderzoeker Mylene van der Koogh (m.l.van.der.koogh@hva.nl)

Deelnemen aan het onderzoek	**Ja**	**Nee**
Ik heb bovenstaande informatie gelezen en begrepen, en/of het is aan mij uitgelegd. Ik heb de mogelijkheid gehad om vragen over het onderzoek te stellen en al mijn vragen zijn beantwoord.	□	□
Ik geef toestemming om vrijwillig deel te nemen aan dit onderzoek. Ik begrijp dat ik het beantwoorden van bepaalde vragen kan weigeren en dat ik op elk moment kan stoppen met het deelnemen zonder het hebben van een (geldige) reden.	□	□
Ik begrijp dat het deelnemen aan dit onderzoek inhoudt dat ik: een interview zal afleggen met de onderzoeker waarin audio-opnames worden gemaakt ter behoeve van transcriptie en er een vragenlijst zal worden ingevuld in de HvA Qualtrics omgeving.	□	□
Gebruik van informatie voor het onderzoek		
Ik begrijp dat de informatie die ik zal verstrekken zal worden gebruikt in een Master Scriptie onderzoek en een PhD Scriptie onderzoek aan de TU Delft, en dat de scripties worden gepubliceerd onder wetenschappelijke portalen van deze onderwijsinstellingen.	□	□
Toekomstig gebruik en hergebruik door derden		
Ik geef toestemming dat de geanonimiseerde interviews, ingevulde enquêtes en de daarop gebaseerde resultaten mogen worden bewaard op de VPN beveiligde interne HvA servers zodat het kan worden gebruikt voor toekomstig onderzoek en onderwijs.	□	□

Handtekeningen

____________________ ____________________ ________
Naam deelnemer Signature Date

____________________ ____________________ ________
Naam onderzoeker Signature Date

____________________ ____________________ ________
Naam onderzoeker Signature Date

Appendix III: Data reducing process

Phase I

Option	#transactions	kWh/transaction	No
Technical			
Automatic decoupling without fixed cable	X		
Automatic decoupling with fixed cable	X		
Charging robot	X		
More connections per charger		X	
Charging square		X	
Car recognition			X
More 22 kW chargers	X	X	
DC charging at in/exit of cities	X	X	
Cross parking/strategic set up to have 3 to 4 spots	X		
Type 2 chargers with fixed cable			X
More 'totaalpalen'			X
V2G			X
Smart charging			X
Institutional			
Governments ease transition by enabling cables over sidewalks			X
'opstalvergoeding' easier			X
'verkeersbesluit' not on all spots, other marking			X
Parking duration / end time enter / parkeerschrijf	X		
Possibility as CPO to cross-off parking spots			X
Fining connecting without charging	X	X	
Dynamic crossing	X		
Zero-emission policy 2030	X	X	
Time slots with enforcement	X		
Financial			
Start and stop tariffs		X	
Night tariff		X	
Flexible tariff (cheaper when use of solar)			X
Increasing tariff after 24 hours	X		

Decreasing tariff when more kWh		X	
Municipality co-invest in charging/parking solution			X
Own charger/invest in own charger			X
Social			
Digital waiting line			X
Push message stop charge session	X		
Social app	X		
Blinker by wrong parking	X		
Customer loyalty by saving system	X	X	
Charging etiquette	X	X	
Educate communities and local residents	X	X	

<u>Phase 2</u>

Number	Variable	Description
I1	2 spots exclusively available for EV	Two parking spots are made exclusively available to electric cars
I2	All spots exclusively available for EV	All parking spots are made exclusively available to electric cars
I3	Municipality co-invest	The municipality invests in a specific charging solution. For example, the municipality had invested in the smart charging square in Haarlemmermeer
I4	Time slots with enforcement	Chargers are placed in so-called 'blue zones', in which the EV users are allowed to charge an park their car for two hours max. Users that exceed this time limit are fined.
F1	Start tariff	The EV users has to pay a fixed tariff at the beginning of the charge session. This fee is added to the regular charging fee
F2	Lower night tariff	The EV users pays a lower charge fee a night to stimulate charging at night and thus shifting demand
F3	Fee after 24h	The EV user pas a fee when it occupies a charging point > 24h
F4	Decreasing tariff	The EV user pays a lower tariff when it chargers more kWh
F5	No tariff	No tariff structures are applied to change the charging behavior
S1	Push to stop session	The EV user receives a notification on their phone which stimulates to move their vehicle
S2	Blinker	The blinker is a light signal at the charger that indicates when a car is incorrectly parked. For example, in a dynamic system, when a fossil fuel car is parked at a spot for electric cars. But it can also indicate when a car is connecting without starting a charge session.
S3	No social	No social incentives are applied to change the charging behavior

Appendix IV: Scoring + Definite output

Rank E-Mobility experts

Number	Criteria	Rank	Rank	Rank	Average	Final Rank
C1	Number of charge sessions	1	1	2	1	**1**
C2	kWh charged per session	1	1	1	1	**1**
C3	Average charge fee	2	2	5	3	**2**
C4	Charge security	5	6	6	6	**5**
C5	Charge speed	5	5	5	5	**4**
C6	Availability	3	5	6	5	**4**
C7	Charger unit costs	4	2	3	3	**2**
C8	Installation costs	6	3	4	4	**3**
C9	Maintenance costs	7	4	3	5	**4**

Scores

C1

Number	Type of car	Lease?	Private charger?	Score
EV1	Mini cooper	Yes	No	+ / + / 0 / +
EV2	Tesla model 3	No	Yes	++ / + / 0 / +
EV3	Tesla model 3	Yes	No	+ / + / 0 /+
EV4	Jaguar I-PACE	No	Yes	+ / - / + / +

C2

Number	Type of car	Lease?	Private charger?	Score
EV1	Mini cooper	Yes	No	0 (lease)/ + / 0 / 0
EV2	Tesla model 3	No	Yes	+ / + / + / 0
EV3	Tesla model 3	Yes	No	0 (lease) / + / + / 0
EV4	Jaguar I-PACE	No	Yes	+ / 0 / + / 0

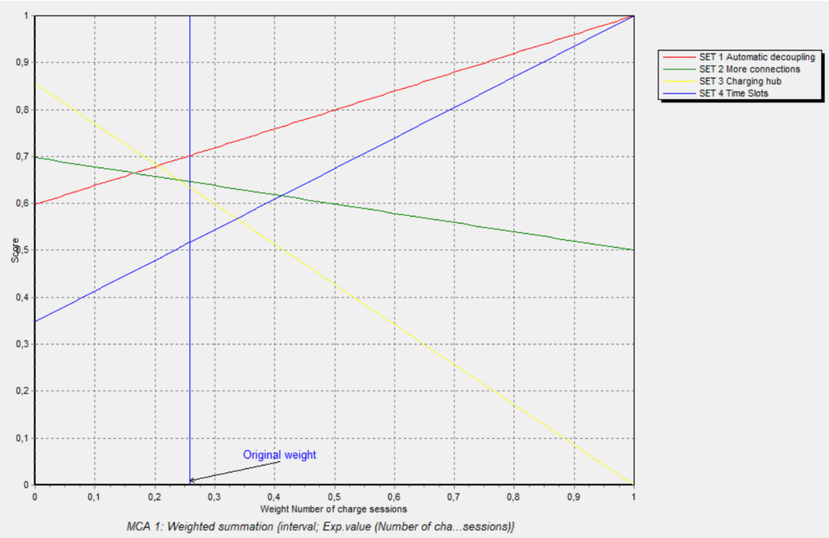
C5

Number	Type of car	Lease?	Private charger?	Score
EV1	Mini cooper	Yes	No	-/ - / 0 / -
EV2	Tesla model 3	No	Yes	0 / - / 0 / -
EV3	Tesla model 3	Yes	No	0 / 0 (short range) / 0 / 0 (short range)
EV4	Jaguar I-PACE	No	Yes	0/ - / 0 / 0

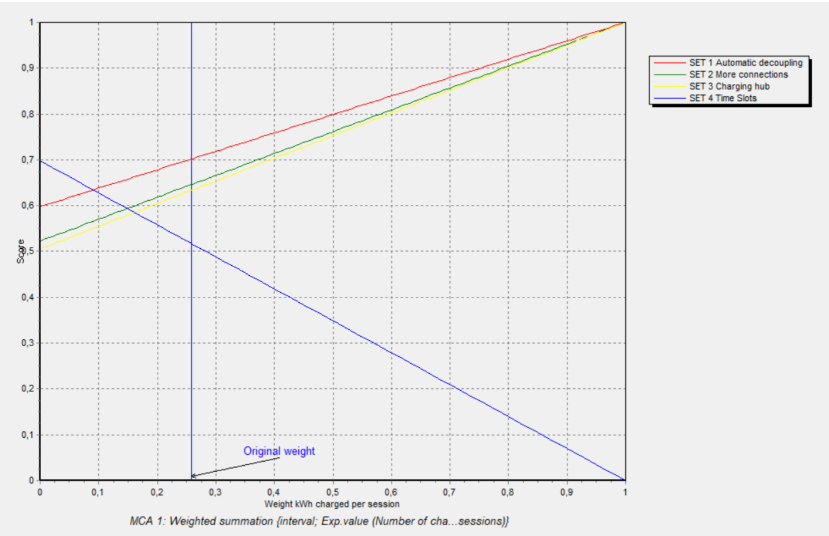
Weight sensitivity

Red	**Quantity-driven design (set 1)**
Green	**Quality-driven design (set 2)**
Yellow	**Hybrid design (set 3)**
Blue	**Purely institutional design (set 4)**

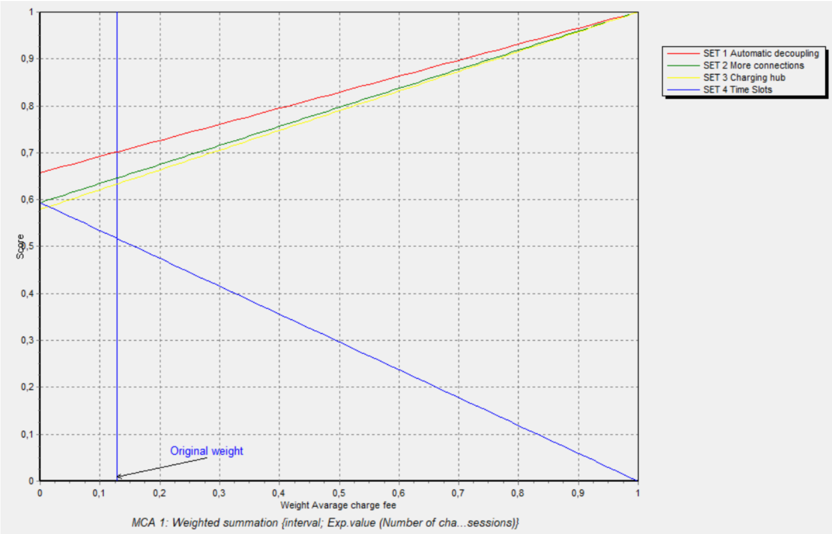
C1



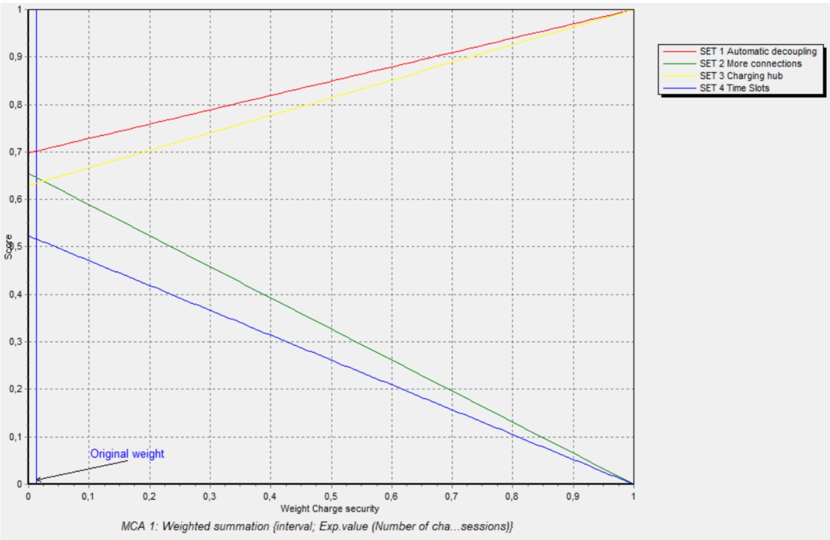
C2



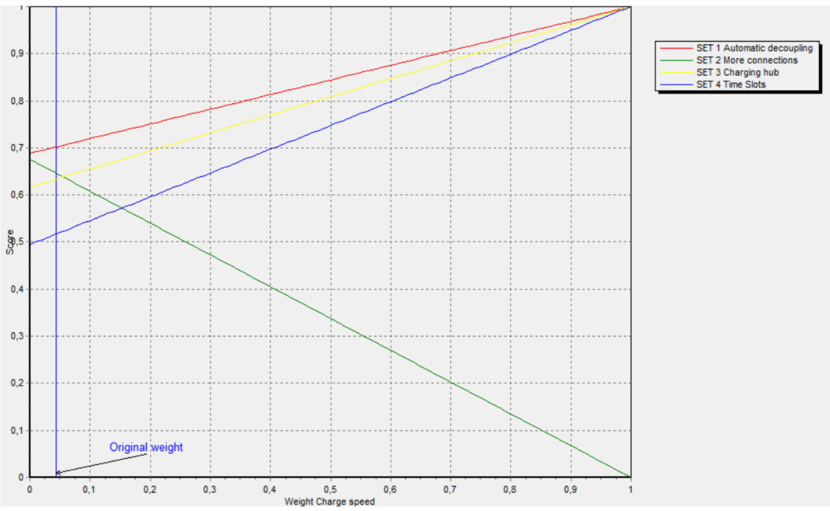
C3


SET 1 Automatic decoupling
SET 2 More connections
SET 3 Charging hub
SET 4 Time Slots
Score
Original weight
Weight Avarage charge fee
MCA 1: Weighted summation {interval; Exp.value (Number of cha...sessions)}

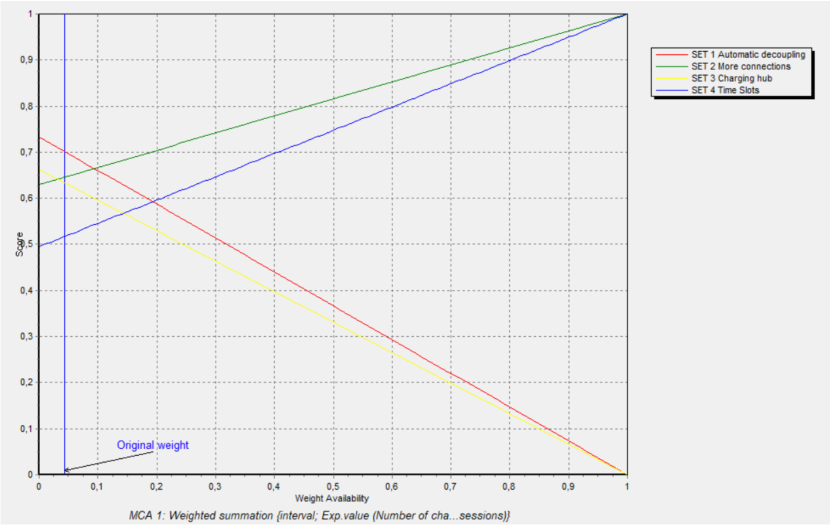
C4


SET 1 Automatic decoupling
SET 2 More connections
SET 3 Charging hub
SET 4 Time Slots
Score
Original weight
Weight Charge security
MCA 1: Weighted summation {interval; Exp.value (Number of cha...sessions)}

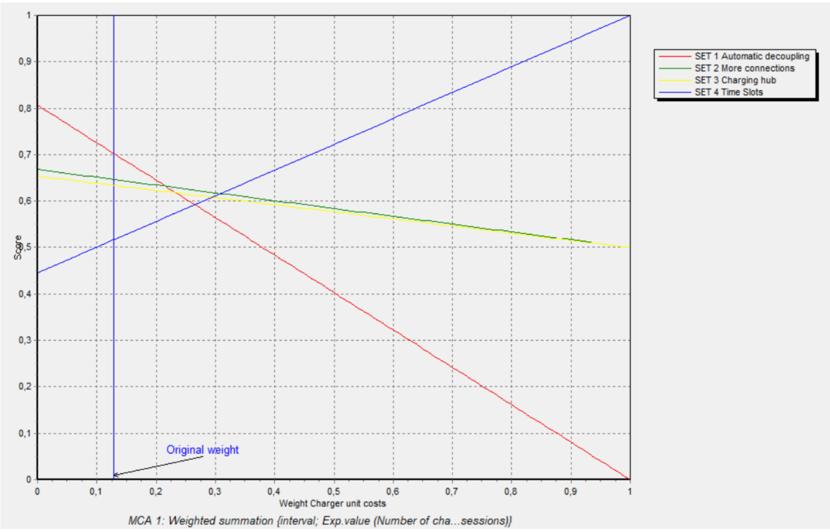
C5


SET 1 Automatic decoupling
SET 2 More connections
SET 3 Charging hub
SET 4 Time Slots
Score
Original weight
Weight Charge speed

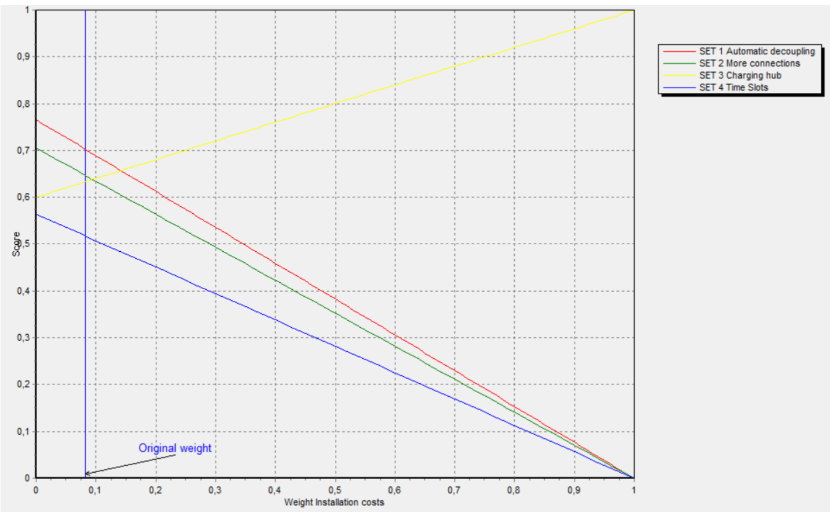
C6


SET 1 Automatic decoupling
SET 2 More connections
SET 3 Charging hub
SET 4 Time Slots
Original weight
Score
Weight Availability
MCA 1: Weighted summation {interval; Exp.value (Number of cha...sessions)}

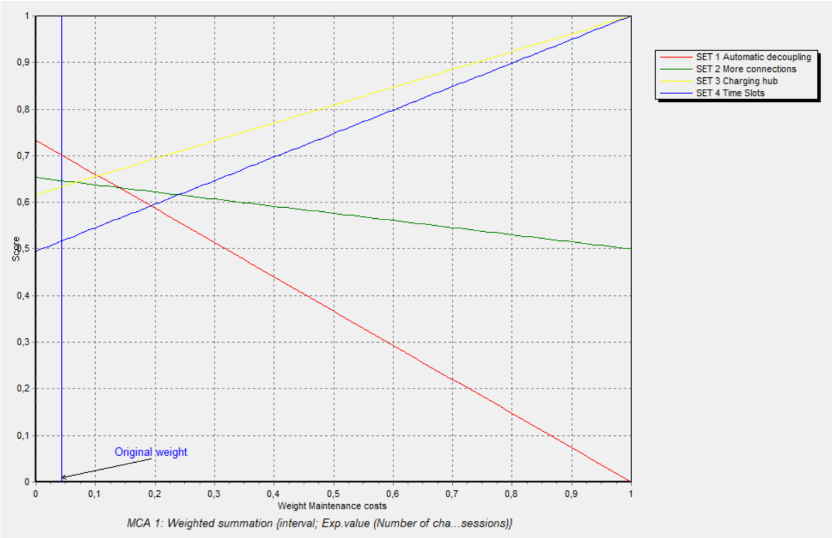
C7


SET 1 Automatic decoupling
SET 2 More connections
SET 3 Charging hub
SET 4 Time Slots
Original weight
Score
Weight Charger unit costs
MCA 1: Weighted summation {interval; Exp.value (Number of cha...sessions)}

C8


SET 1 Automatic decoupling
SET 2 More connections
SET 3 Charging hub
SET 4 Time Slots
Original weight
Score
Weight Installation costs

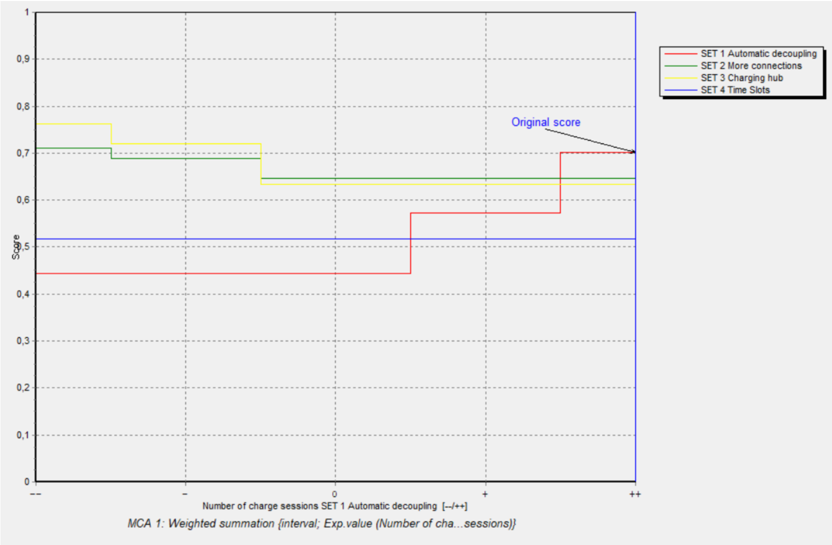
C9



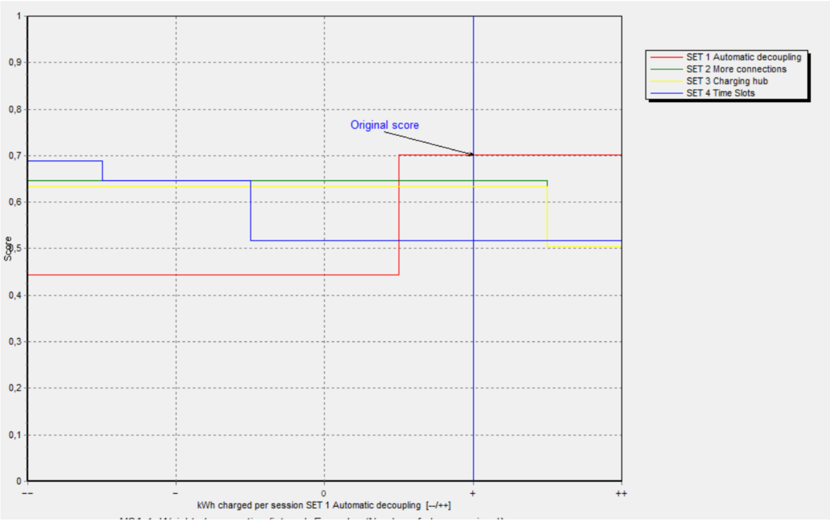
Score sensitivity

Red	**Quantity-driven design (set 1)**
Green	**Quality-driven design (set 2)**
Yellow	**Hybrid design (set 3)**
Blue	**Purely institutional design (set 4)**

C1

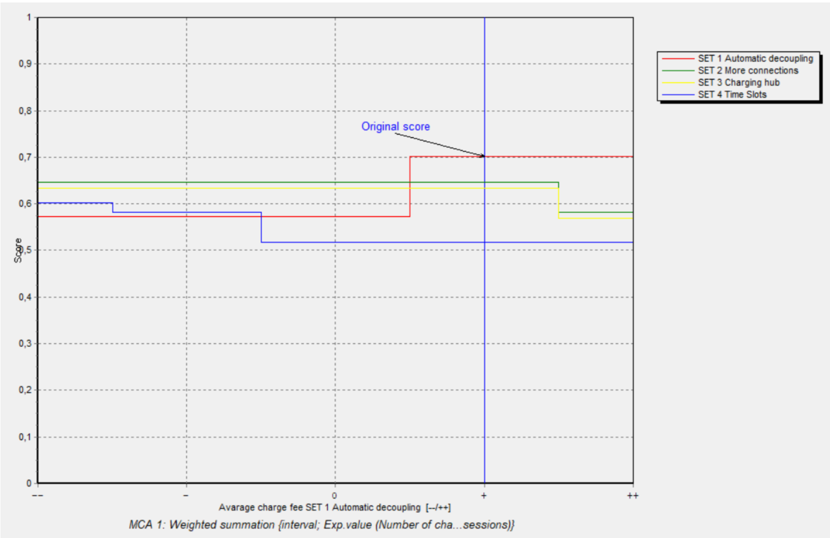


C2



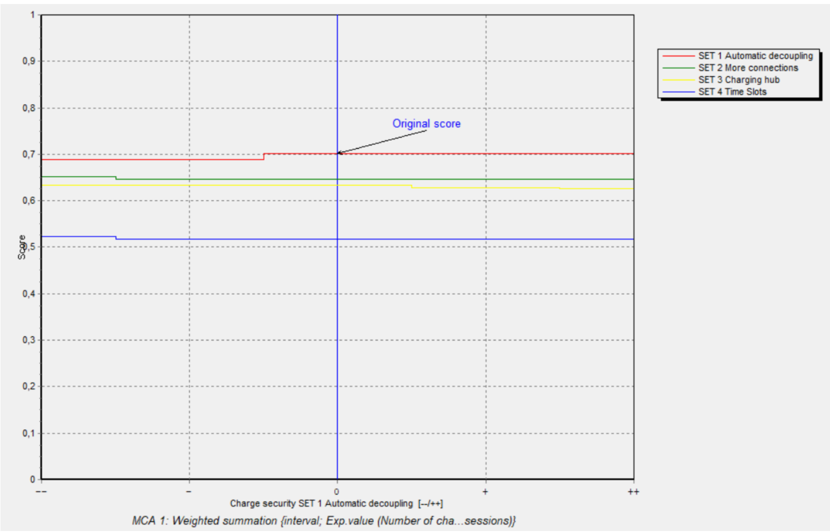
SET 1 Automatic decoupling
SET 2 More connections
SET 3 Charging hub
SET 4 Time Slots
Original score
Score
kWh charged per session SET 1 Automatic decoupling [--/++]

C3



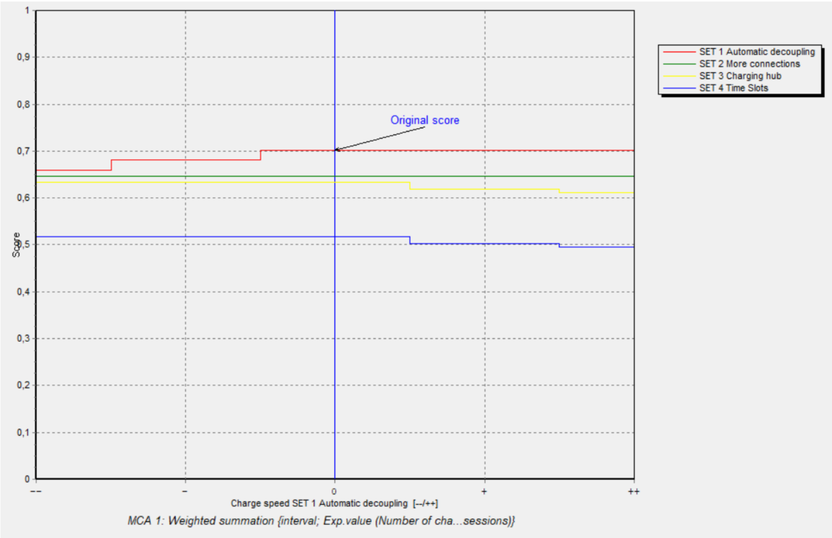
SET 1 Automatic decoupling
SET 2 More connections
SET 3 Charging hub
SET 4 Time Slots
Original score
Score
Avarage charge fee SET 1 Automatic decoupling [--/++]
MCA 1: Weighted summation {interval; Exp.value (Number of cha...sessions)}

C4

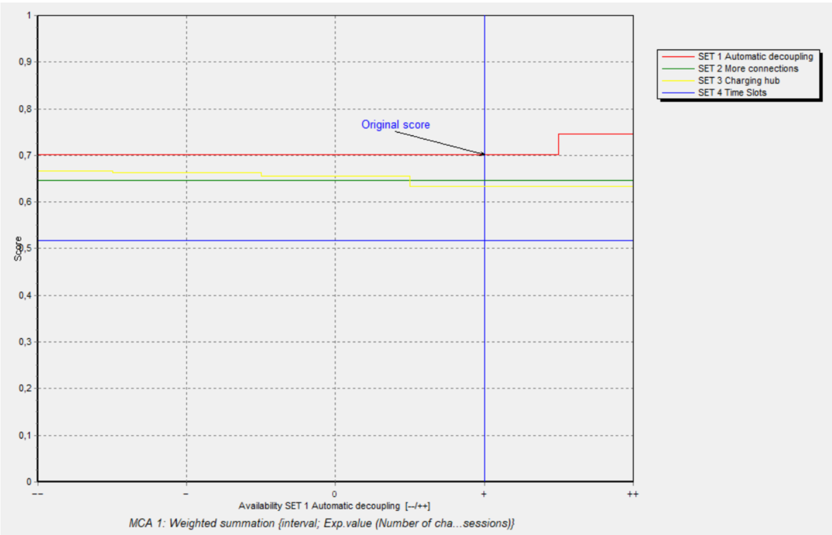


SET 1 Automatic decoupling
SET 2 More connections
SET 3 Charging hub
SET 4 Time Slots
Original score
Score
Charge security SET 1 Automatic decoupling [--/++]
MCA 1: Weighted summation {interval; Exp.value (Number of cha...sessions)}

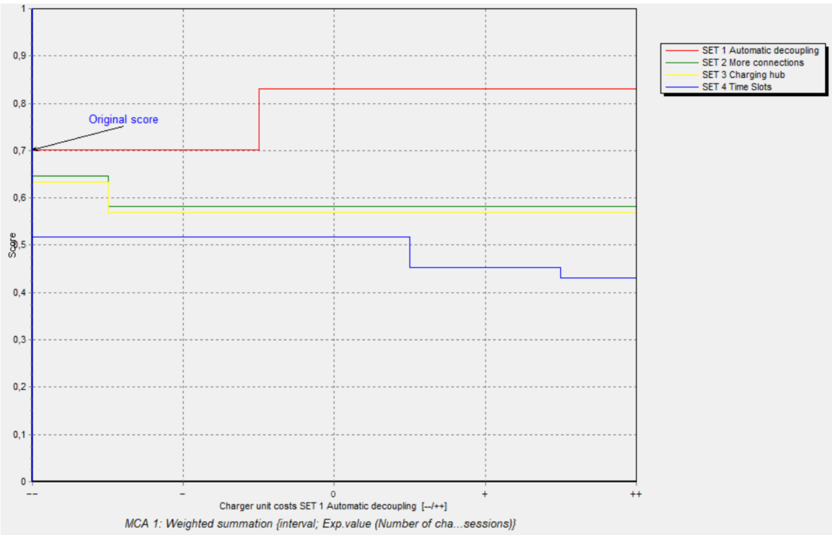
C5


SET 1 Automatic decoupling
SET 2 More connections
SET 3 Charging hub
SET 4 Time Slots
Original score
Score
Charge speed SET 1 Automatic decoupling [--/++]
MCA 1: Weighted summation {interval; Exp.value (Number of cha...sessions)}

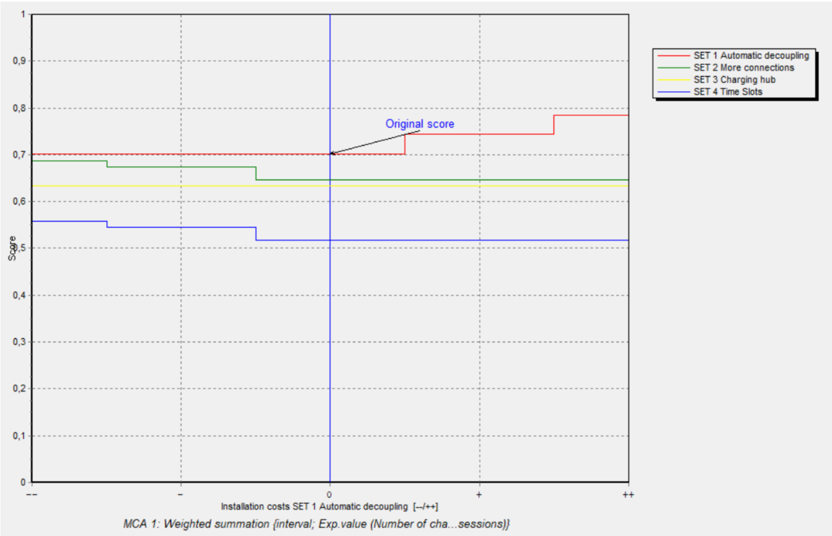
C6


SET 1 Automatic decoupling
SET 2 More connections
SET 3 Charging hub
SET 4 Time Slots
Original score
Score
Availability SET 1 Automatic decoupling [--/++]
MCA 1: Weighted summation {interval; Exp.value (Number of cha...sessions)}

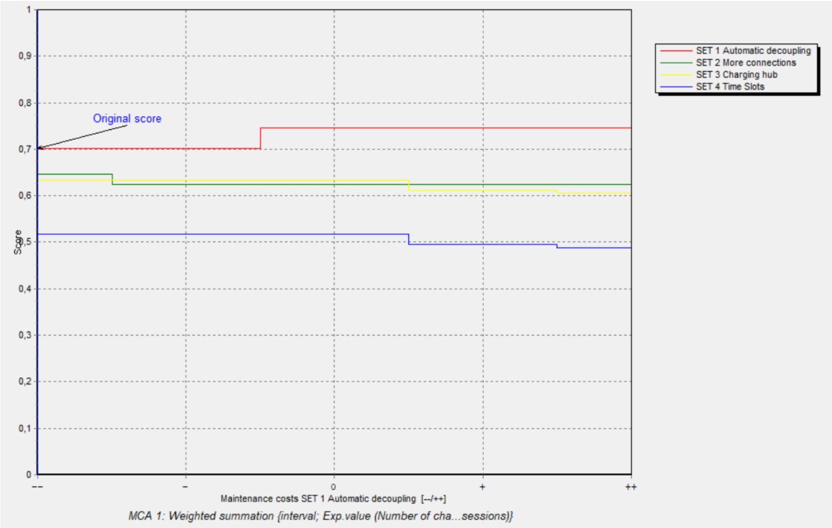
C7


SET 1 Automatic decoupling
SET 2 More connections
SET 3 Charging hub
SET 4 Time Slots
Original score
Score
Charger unit costs SET 1 Automatic decoupling [--/++]
MCA 1: Weighted summation {interval; Exp.value (Number of cha...sessions)}

C8


SET 1 Automatic decoupling
SET 2 More connections
SET 3 Charging hub
SET 4 Time Slots
Original score
Score
Installation costs SET 1 Automatic decoupling [--/++]
MCA 1: Weighted summation {interval; Exp.value (Number of cha...sessions)}

C9


SET 1 Automatic decoupling
SET 2 More connections
SET 3 Charging hub
SET 4 Time Slots
Original score
Score
Maintenance costs SET 1 Automatic decoupling [--/++]
MCA 1: Weighted summation {interval; Exp.value (Number of cha...sessions)}

Appendix V: Other

Onderdeel	Detailering kosten	Benchmark 2013	Benchmark 2016	Benchmark 2017	Benchmark 2018	Verwachte daling 2025/2030
Eenmalige kosten (Totaal)	totaal	€ 4.655	€ 3.655	€ 3.110	€ 3.270	+/- 15% daling
Inkoopprijs paal (3x25A, 2 Sockets)	totaal	€ 2.000	€ 1.400	€ 1.330	€ 1.330	
Locatiebepaling	totaal	€ 700	€ 550	€ 320	€ 350	
Inrichting parkeervak (locatie & nemen verkeersbesluit)	totaal	€ 700	€ 450	€ 380	€ 450	
Aansluitkosten netbeheerder	totaal	€ 655	€ 655	€ 690	€ 750	
Plaatsingskosten aannemer	totaal	€ 600	€ 600	€ 390	€ 390	

Onderdeel	Detailering kosten	Benchmark 2013	Benchmark 2016	Benchmark 2017	Benchmark 2018	Verwachte daling 2025/2030
Periodieke kosten excl. energie	jaar	€ 835	€ 610	€ 580	€ 510	+/- 5% daling
Periodieke kosten netaansluiting 3X25A	jaar	€ 210	€ 210	€ 210	€ 190	
Communicatiekosten	jaar	€ 125	€ 75	€ 50	€ 70	
Verzekeringspremie (schade)	jaar	€ 25	€ 25	€ 25	€ 25	
Onderhoud/reparatie	jaar	€ 450	€ 275	€ 270	€ 190	
Service bij gebruikersproblemen	jaar	€ 25	€ 25	€ 25	€ 35	

Onderdeel	Detailering kosten	Benchmark 2013	Benchmark 2016	Benchmark 2017	Benchmark 2018	Verwachte stijging 2025/2030
Vergoeding leverancier (inkoop)	kWh	€ 0,06	€ 0,06	€ 0,06	€ 0,07	-
Energiebelasting	kWh	€ 0,10	€ 0,10	€ 0,05	€ 0,05	**100% stijging**
Afschrijvingstermijn	jaar	5	7	9,2	9,2	-
Verkoop per kWh excl. Btw	kWh	€ 0,25	€ 0,28	€ 0,27	€ 0,25	-
Verkoop energie (kWh/dag)	dag	5	8,5	8,6	9,9	**+/- 50% stijging**

Cost benchmark public charger 2013-2030 (Blok, 2018)

Variable	Number of individuals	Number of charging sessions	Hours connected to charging station	Mean connection time
Duration bin				
0–1.5 h		400,558 (15.8%)	323,422 (1.2%)	0.8 h
1.5–7 h		804,458 (31.8%)	2,812,083 (10.8%)	3.5 h
7–11 h		355,768 (14.1%)	3,243,855 (12.6%)	9.1 h
11–24 h		819,704 (32.4%)	12,537,271 (47.7%)	15.3 h
24 + hours		151,353 (6.0%)	7,209,409 (27.6%)	47.6 h
Day of the week				
Monday		369,922 (14.6%)	3,666,802 (14.1%)	9.9 h
Tuesday		389,372 (15.4%)	3,756,545 (14.4%)	9.6 h
Wednesday		392,170 (15.5%)	3,757,452 (14.4%)	9.6 h
Thursday		391,348 (15.5%)	3,876,661 (14.9%)	9.9 h
Friday		375,404 (14.8%)	4,251,672 (16.3%)	11.3 h
Saturday		315,168 (12.4%)	3,546,883 (13.5%)	11.2 h
Sunday		298,457 (11.8%)	3,270,022 (12.6%)	10.9 h
Time of Day				
Morning		370,358 (14.6%)	2,356,822 (9.3%)	6.4 h
Afternoon		752,799 (29.7%)	5,898,752 (22.6%)	7.8 h
Evening		1156,553 (45.7%)	14,765,927 (56.2%)	12.8 h
Night		252,131 (10.0%)	3,104,539 (11.8%)	12.3 h
Type of charger				
Level 2	3490 (98.6%)	2467,878 (97,4%)	25,812,611 (98,8%)	10.4 h
Charge Hub	29 (0.8%)	39,346 (1,6%)	296,995 (1,1%)	7.5 h
Fast charger (50 kW DC)	20 (0.6%)	24,617 (1,0%)	16,436 (0,1%)	0.7 h
Use Type				
Taxi	336 (1.3%)	46,034 (1.8%)	339,766 (1.3%)	7.4 h
Frequent	17,166 (26.4%)	2092,221 (82.6%)	23,467,036 (89.9%)	11.2 h
Visitors	46,643 (71.8%)	205,629 (8.1%)	943,137 (3.6%)	4.6 h
Car sharing	818 (0.5%)	187,957 (7.4%)	1,376,101 (5.1%)	7.3 h

Descriptive statistics average connection times in four major Dutch cities (Wolbertus et al., 2018)