Bachelor Thesis

Developing a strategic decision making model for EV-charging infrastructure and management for a company for optimising revenue

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Developing a strategic decision making model for EV-charging infrastructure and management for a company for optimising revenue

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Preface

Dear Reader,

You are about to read my Bachelor Thesis “Developing a strategic decision making model for EV-charging infrastructure and management for a company for optimising revenue”. This research has been conducted at Company X as a final assignment for my bachelor’s degree Industrial Engineering and Management at the University of Twente. The goal of this research is to evaluate current business practices regarding charge points at Company X, and developing a strategic decision making model that maximises the revenue generated.

Hereby, I would like to thank everyone that supported me during the time I performed my research. I want to thank Alessio Trivella, my supervisor from the UT for his time and effort to supervise my research. I am grateful for all the constructive and extensive feedback during our limited meetings. Most of all, I would like to thank him in giving a defined direction for my thesis. Next I would like to thank my supervisor from the organisation, Marco Rine for providing the opportunity to perform this research. He helped me a lot in defining the research, and mapping out everything that was of importance. His connections made sure that I came into contact with the right people, and he was always open to share his birds-eye view of the problem. I enjoyed our talks, our jokes, and just the time we had during the past months. I also want to thank Alexander Lambalk, for the support and for helping me reach out to people that were of significant help to the research.

Finally, I would like to thank my family as well as my close friends a lot, for the continuous and inexhaustible support during my research

I hope that you will enjoy my thesis!

Kind regards,

Coen Vleugel

Enschede, August 2024

Management Summary

Company X is a car dealership with multiple locations throughout the Netherlands. Their locations have parking lots, that are obliged to have a number of charging points. Moreover, as the EV (Electric Vehicle) market is growing, and Company X and clients are expanding their EV market share, the need for charging points is increasing continuously.

Company X started building charging points approximately 3 years ago (from 2021). However, there was no clear structure in what charging points to build at a location, how many charging points, and how the charging points were used. There was no clear image of the revenues and costs related to the charging points, and apart from monitoring and repairing faulty charging points, no attention was given to evaluation the functioning of the charging points. Company X expected that there were major missed revenue potentials in their charging point network, but did not have the resources to investigate this themselves. To solve this problem, a quantitative and qualitative analysis was performed on the performance of the current charging points, and the performance of a suggested charging point scenario. The following question is aimed to be answered:

"How can a general model be defined for optimising strategic charging point decisions for maximising revenues?"

Firstly a context analysis was executed to be able to understand the current situation and the environment of charging points at Company X. Conversations with relevant stakeholders and literature research were performed to investigate important characteristics in the charging point environment. The direction of the research is focused on these characteristics, and a first look of certain characteristics is given to illustrate and give emphasis on the gap of possible revenues.

A theoretical framework is constructed to understand the behaviour of different characteristics in the charging point environment. These different characteristics can be described as strategic decisions which are used in an optimisation model. The optimisation model can be defined as a Mixed Integer Quadratically Constrained Programming Problem (MIQCP). The optimisation model is constructed in Gurobi, Python, and solved for different locations. The model uses historical data from 2023 from the locations to model an optimal solution that maximises net revenue.

The solution analysis discusses 5 different locations and the solutions when implementing the model. Price elasticity, DC (Direct Current) utilisation, as well as a predetermined demand elasticity and their effects on the net revenue for locations are discussed, as well as a comparison between the current situation and the scenarios from the model. The scenario from the model has a positive difference on net revenue for the analysed locations of up to €10.000,-.

In the solution model, the HBE (Hernieuwbare Brandstof Eenheid) generated revenue is calculated for the 5 locations, equaling to €2.107,34. When considering that Company X has 33 locations with charging points, revenue creation from HBEs can possibly increase to €13.908,44.

The research concludes that currently the charging points at Company X have much more potential than what they are used for. There are multiple revenue opportunities missed, and costs are higher than necessary. This research does recognise that due to the scope, the quantitative approach taken to the analysis of the current situation and the scenarios from the model does not encompass all relevant factors in the decision making process. Preferences on decisions, as well as charging company owned cars (that are sold to customers) have not been taken into consideration. Therefore, if Company X were to use the model, the following points are recommended to further investigate for Company X, as well as for specific locations:

- Re-evaluate the model parameters (e.g. demand elasticity, price elasticity, DC utilisation) for specific locations, to provide more accurate and reliable solutions. Recalculate parameters when executing decisions and evaluating performance.
- Determine preferences and requirements regarding CPO/EMSPs (Charge Point Operators and Electric Mobility Service Providers) to make a first selection of eligible partners. Request quotations to use in the model and determine the optimal decision.

Next to recommendations for implementation of the model, the following recommendations are given for Company X generally, to ensure optimal use of charge points in the future:

- Improve data registration to determine if different types of tariffs are more profitable than kWh-based tariffs.
- Improve monitoring and evaluation of data
- Investigate charging demand at individual locations as well as the effects of future developments on charging demand.
- The tariff per kWh currently is €0,29, while the often used tariff is approximately €0,50, and the optimal tariff (according to the model) is €0,68. Increasing the tariff to €0,68 makes the CPs significantly more profitable.
- Incorporate HBEs and determine for individual locations the additional value of a PV-installation in terms of reduced electricity costs and increased revenue from HBEs.
- Estimate HBE revenue from charging EVs that are determined for sale.

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Abbreviations

EV Electric Vehicle

CPO Charge Point Operator

EMSP Electric Mobility Service Provider

CP Charging Point

kWh Kilo-Watt hour

kW Kilo-Watt

MWh Mega-Watt hour

AC Alternating Current

DC Direct Current

HBE Hernieuwbare Branstof Eenheid (Renewable Energy Unit)

CMS Charging Management Software

MIQCP Mixed-Integer Quadratically Constrained Programming

GoO Guarantee of Origin

GJ Gigajoule

TOU Time of Use

SOC State of Charge

1. Introduction

The introduction chapter introduces the research conducted at Company X, a car and truck dealership in the Netherlands. Section 1.1 introduces the company as well as the other parties involved in the research, and introduces the background of the assignment. Section 1.2 introduces the action problem and the core problem that this research is aimed towards. The methodology for this process is derived from the Operations Research cycle and the book “Operations Research An Introduction” (Taha, 2017). 1.3 transforms the problem identification and describes the research goal. Section 1.4 states the research questions necessary for achieving the research goal. Section 1.5 illustrates the research design, including the problem solving approach and an overview of the content in the remaining chapters of the research.

1.1 Background of assignment

EV Charging points are becoming increasingly more popular and necessary. Companies in the Netherlands with public parking lots are obliged to have a charging point per each 10 parking spaces (Rijksdienst voor Ondernemend Nederland, 2019). The EV (Electric-Vehicle) market is skyrocketing (IEA, 2023) but this market can only grow as long as there are enough charging points available to accommodate this growth. Several companies make it their core business to provide municipalities or the government with charging points along highways or public parking lots, and through detailed business models of the energy market and subsidies from the government these companies are able to turn a profit. For most other companies however, choosing, installing, monitoring and optimising charging points is not one of their core businesses. Employees lack the knowledge and understanding of either the technology, the energy market or the business models. Mistakes are made quickly by overlooking possibilities or not having the capacity to make well thought decisions. Moreover, monitoring, evaluating and optimising charging points practices is not performed by most companies, as they do not have the means necessary to continuously do this, and want to focus their attention on their own core business practice instead of a (seemingly less important) secondary revenue stream.

Companies tend to ignore the possibilities with charging points. Because this market is growing as quickly as it is, there are a lot of possibilities and choices for the hardware as well as the software side. On both sides the technological and financial differences can be substantial and future-proofing the charging points is essential as well for ensuring profits. Defining a model for charging point strategies of companies is valuable, as charging points can end up being a lot more profitable than currently is the case.

To explain why and how this is of importance for Company X, it is necessary to introduce the stakeholders of- and define their roles in the EV-charging value chain.

Company X

Company X is a car and truck dealership with several locations throughout the Netherlands. Facilities range from official brand dealerships (Mercedes, Kia, Ford, Smart, Fuso), to service facilities (repairs and maintenance), to used cars dealerships (for all brands).

Company X has 62 locations throughout the Netherlands, with parking areas for employees and customers. Most of their locations have charging points, as a number of employees have EVs that are leased from Company X and Company X wants to be able to give customers the ability to charge their EV at their location. Moreover, it is mandatory by the Energy Performance of Buildings Directive (EPBD III) that for every 10 parking spaces at least 1 charging point is available (Rijksdienst voor Ondernemend Nederland, 2019), as well as that dealer contracts oblige Company X to adhere to certain standards regarding charging point availability. Company X currently is a client at CPO/EMSP 1, who fulfills the CPO (Charge Point Operator) and EMSP

(Electric Mobility Service Provider) role for Company X, and provides a charging point management software in which the charging points can be monitored.

Although all 62 locations are run by location managers, they all belong and answer to Company X Automotive B.V.. Company X Automotive B.V. consists of a central management that defines and enforces policies, regulations and standards for all locations. The locational managers are responsible for carrying these out in their business processes. Their motto is 'CONFIDENTIAL' and they strive to make the customer feel as welcome as possible through all means necessary. This also includes the ability to charge EVs at locations of Company X.

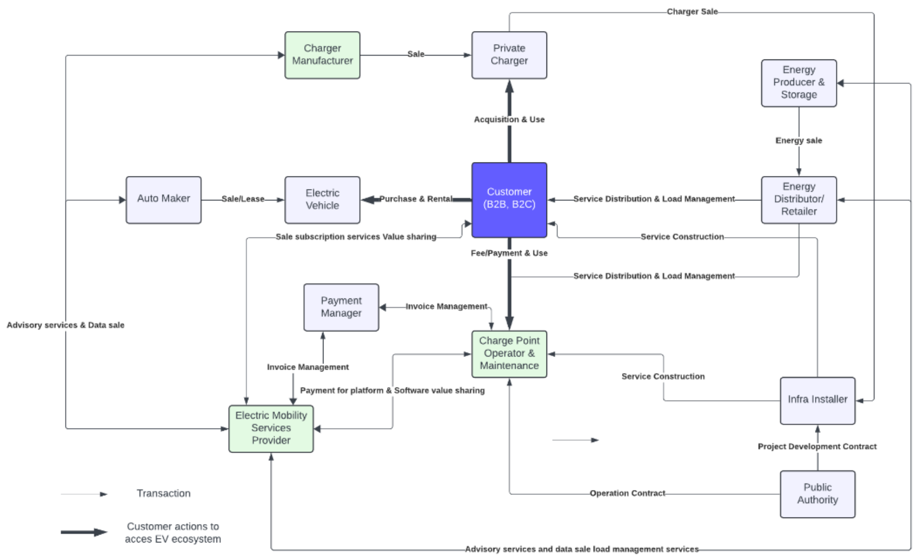

Figure 1 Key players EV-Charging Value Chain (adapted from Capgemini Invent)

EV-charging value chain

To get a general idea of the variables and decisions to make that influence the revenues Company X is able to receive from the charging points, the different actors that are involved in the EV-charging value chain need to be identified. These actors all add value in the value chain, and as such take a margin of the revenues (received from the customer) in one way or another. The following chart, provided by Capgemini (Capgemini Invest, 2019) illustrates an interesting overview of all actors involved in the EV-charging value chain. It is important to understand that this chart shows a customer-centered view. Company X fulfills the B2B customer role in this EV-charging value chain, while the car-users fulfill the role of end consumer of the charging points electricity.

The most important actors for this research include the Charge Point Operator (CPO), the Electric Mobility Service Provider (EMSP) and the Charger Manufacturer, as they are the most relevant actors in the EV-charging value chain and make up the charging network (Mosele, 2019/2020).

CPO

Charge Point Operators are responsible for the installation, maintenance and operationality, energy distribution, and charging management software of charging points. In short, they deal with most of the hardware side of the charging points, ensuring that the charging points are operational and a small part on the software side in charging management software (CMS). CMS is relevant for the owner of a charge point as it provides insight into valuable information of charge sessions and the charge point itself.

EMSP

Electric Mobility Service Providers offer a range of services that enhances user experience for EV drivers. The services consist of handling registration, authentication and billing for charge point users and enhancing user experience by providing platforms that consolidate multiple CPO networks in a single app, allowing users to locate a multitude of charging points and monitor their charging processes, while simplifying the payment process and enhancing the accessibility of charging stations (EVBox. 2023).

The CPOs and EMSPs have different roles and functions, but due to overlapping interests companies frequently combine these and fulfill both roles of the CPO and EMSP.

1.2 Problem identification

From discussion points mentioned by the service team leader excellence, and conversations with other stakeholders in the EV-charging value chain, the problem can be defined as:

Company X Automotive B.V. has the idea that charging points currently in use and future charging points can be used more optimally, but do not know what decisions they need to take and enforce to optimise their charging points.

The problem has been identified and the importance for Company X and the other stakeholders has been explained. The next step in the research is constructing a problem cluster that identifies the core problem. The problem cluster is a model that uses causes and effects and their connections to identify the core problem. Additionally, it places the problem in context and provides an overview of different aspects that are related to the problem. The problem cluster is shown in Figure 2, and explained by a short description of the different main causes.

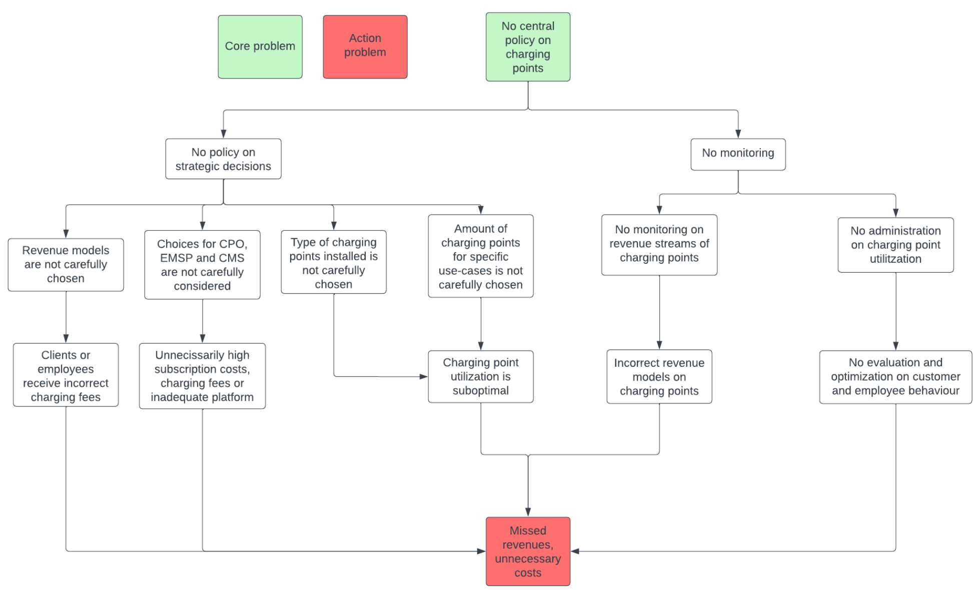

Figure 2 Overview of the problem cluster for Company X

Core problem

The above shown problem cluster identifies the main cause of why Company X thinks a general decision making model on charging points is desirable. The strategic decisions on charging points of Company X have not been evaluated yet, and existing opportunities to generate higher revenues are lost out on due to a lack of understanding and research on charging points and their possibilities. The EV sales have grown from 10.2 million in 2022 to 13.8 million in 2023, an increase of 35%, and the charging point business has grown just as much (IEA, 2024). This growth has resulted in the question that Company X has with regards to how their current charging points are used and how a general model on their strategic decisions could be beneficial in terms of costs and benefits. From the previously stated main cause a core problem can be derived and formulated as follows:

"Company X has no general policy on their strategic decisions regarding charging points."

Gap between norm and reality

A core problem should contain a description of the gap between the norm and reality. And this gap should be measurable through variables. From the book of Heerkens the norm and reality refer to the ideal conditions (norm) and actual conditions (reality)(Heerkens, 2017). The actual conditions at Company X are that there exists no policy on their strategic decisions as well as monitoring, evaluating and optimising their charging points. The ideal conditions of Company X are that there exists a general policy that optimises and evaluates their strategic decisions and their current charging point usage. To measure the gap between norm and reality through variables, the costs and revenues of the current situation are analyzed and compared to the costs and revenues when implementing the results from the strategic decision making model.

1.3 Research goal

The objective of this research is to illustrate how, and if a charging point strategic decision making model benefits Company X in their current and future business practice. It provides an insight into the current use of their charging points, and aims to give an advice on what decisions to make to improve the revenues received from charging points. This analysis should also consider the effects of the increasing demand of EV's and consequently the increasing demand of EV-charging points. The desired level of detail of the analysis to provide this elaborate but concise advice should be stated as well.

1.4 Research questions

The main research question is formulated as follows:

"How can a general model be defined for optimising strategic charging point decisions for maximising revenues?"

The main research question aims to achieve an answer to Company X's core problem. The research question is divided into multiple different sub-questions. These sub questions provide insights and contribute to achieving an answer to the main research question. The sub questions are based on the following steps, such that a clear structure can be kept throughout the research process:

- Illustrating the current situation regarding charging points at Company X compared to possible best practices
- Constructing an optimisation model to test strategic decisions
- Recommendations for implementing the model

For answering the different sub questions, several sub-sub questions are formulated to ensure that all important aspects of the sub questions are covered. The sub (and related sub-sub) questions are as follows:

Sub question 1: How is the charging point network at Company X set-up and performing in the current situation?

- What are the currently made strategic decisions?
- What are important characteristics of the EV-value chain that influence costs and revenues for Company X?
- What quantitative data is available?
- What are the current costs and revenues from the charging points?

Sub question 2: What is the mathematical formulation of the optimisation problem?

- What are mathematical formulations used for similar optimisation problems?
- What variables and constraints are necessary for the strategic decision making model?
- What assumptions have to be made to make the model as close to the real world practice as possible
- How can the optimisation problem be formulated mathematically?

Sub question 3: How can the mathematically formulated optimisation problem be translated into decisions recommendations and an implementation plan?

- How can the formulated optimisation model be solved?
- What is the accuracy of the results and limitations of the model?
- What conclusions can be drawn from the resulting solution?
- How can the result and accompanying limitations and conclusions be implemented into a general policy at Company X?

Based on the answers to these sub questions, a final answer to the main research question is formulated. Finally, conclusions and recommendations regarding the general policy and its implementation and future research is given.

1.5 Research design

This Section discusses the research design used for answering previously stated research questions. First the problem solving approach is introduced and the corresponding steps are explained. Next the useful research methods are explained and substantiated. Finally, the reliability, validity, and scope of the research design are discussed. The limitations are discussed in chapter 7.

Problem solving approach

Optimising decision-making can be classified as an operations research problem. Operations research is a field of study that combines mathematical modeling, statistical analysis and optimisation techniques to solve complex problems and make informed decisions in various organisational settings (Stanke, 2023). Figure 3 illustrates the problem solving approach of operations research study. This approach does not clearly contain the context analysis and the theoretical framework, which should be present in this thesis. The context analysis however, is performed and used in the steps 'Real system' and 'Identifying a decision problem' so it is not necessary to explicitly add this to the research. The theoretical framework is necessary to add, as it is not explicitly stated within the approach. To gain a better understanding of how the steps of this approach fit to this research, the steps are concretely elaborated on, and a model regarding where the steps are performed in the chapters of this research is shown. The steps identifying a decision problem is already discussed in chapter 1, and the model's scope is discussed at the end of this Section. The other steps are as follows:

Figure 3 Steps in Operations Research Studies (based on Stanke, B)

Real system

The real system describes the real world system on which the model is based, in this case the current charging point infrastructure environment at Wensink. The context analysis gives a concrete understanding of the environment in which the problem exists. This also includes the different actors that play a role in the problem, as well as important characteristics that should be taken into account when constructing the model. The context analysis also provides information that is used in identifying the decision problem. This includes a concise overview of different strategic decisions in the EV-charging infrastructure environment, as well as an analysis of the company's current business practice. This part answers the first sub research question, "How is the charging point network at Company X set-up and performing in the current situation?"

Theoretical framework

The theoretical framework summarises theory regarding EV-charging optimisation problems, the characteristics of possible optimisation problems (to classify what type of optimisation problem applies) and possible solution approaches for the specific optimisation problem in this research. The theoretical framework provides a basis on which the mathematical model can be constructed. Therefore, the step "deriving a solution methodology" is already discussed in the theoretical framework.

Constructing the mathematical model

Based on the theoretical framework and the context analysis of the charging point environment at Company X the mathematical model is formulated. The behaviour of the decision variables, parameters and constraints previously introduced is formulated mathematically. The general model without numerical data is stated, such that other companies with similar problems and data can implement the model as well. The theoretical framework and constructing the mathematical model both support answering the research question, "What is the mathematical formulation of the optimisation problem?"

Testing the model with real data

The model is tested with existing data gathered from the charging points management platform from CPO/EMSP 1. This process helps to identify errors in the model and allows for necessary adjustments or assumptions to make the model as close to the real world as possible. By comparing the model with real-world results the reliability and validity of the model is tested and improved.

Establishing controls over the solution

After a solution has been found and the model has been validated, certain controls must be established to make sure that the implementation of the model's solution is monitored. Monitoring can consist of feedback mechanisms that are put in place, performance metrics or regularly done evaluations to make sure that the solution is still effective, or to check whether a different solution is more optimal. These controls help with adapting to changes in the environment while still keeping in line with the main objective of maximising the profits of charging points. This is done by evaluating each location individually, iterating certain parameters that alter the solution according to the characteristics of the specific location, as well as evaluating the performance of implemented solutions at other locations, and using the model to evaluate currently implemented solutions.

Implementing the solution

Implementation of the solution of a validated model involves the translation of the results into understandable operating instructions to be issued to the people who will administer the recommended system (Taha, 2017). Meaning the optimal solution with corresponding decision variable values (and what they represent) should be translated into an understandable policy for Company X to carry out, together with recommendations and an implementation plan of the model and solution. Recall that the policy does not solely contain the solution to the optimisation problem, but also include control mechanisms that help maintain the main objective of the optimisation problem, maximising profits of charging points. Testing the model with real data, establishing

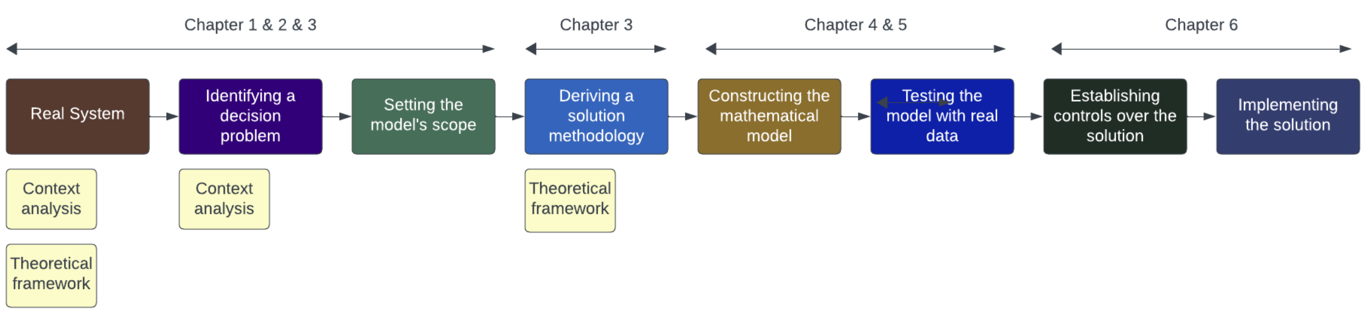

Figure 4 Research specific OR steps

controls over the solution and implementing the solution all support answering the final sub research question, "How can the mathematically formulated optimisation problem be translated into decisions recommendations and an implementation plan?"

Research methods are needed for collection and analysis of data. This research uses both qualitative and quantitative research. This research approach is a mixed methods research, which is beneficial for making quantitative results more understandable and understanding broader applicability of small sample qualitative findings (Harvard Catalyst). The research methods that were used consist of data collection and data analysis.

Data collection

Data collection is used for both qualitative and quantitative data. The qualitative data was gathered during semi-structured interviews with representatives from parties involved in the research. The team leader service excellence (and partly responsible for charging points) provided information for the context analysis.

Furthermore, interviews and conversations with representatives from Unica and from CPO/EMSP 1 on improving charging point utilisation, and illustrating best practices were done. The quantitative data used in this thesis comes from two different sources. First and foremost the charging point management platform (CMS) provided by CPO/EMSP 1 provides historical data from the charging points currently in use at Company X. Public records regarding different costs and income characteristics for charging points were gathered and used as qualitative data. Unica conducted research on utilisation rate of charging points at different locations and allowed their results to be used in this research.

Data Analysis

The gathered data is processed and analysed in Excel using Excel formulas. Excel is able to provide charts and graphs to make certain results and findings easily understandable. Gurobi (Optimisation model solver) and Python are used for the solution analysis, to model the different strategic decisions and iterating with different variable values to find optimal solutions.

Scope

The current charging point environment at Company X, and possible practices of charging points are outlined through contact with various stakeholders. The focus of this research is on determining an optimal strategic decisions that can be implemented and monitored. The strategic decision making model does not include possible vehicle to grid charging, due to the added complexity of the research. Moreover, the research focuses on the locations where regular cars of employees and customers are charged, locations where trucks are charged are outside of the scope of this research. Charging points that are currently not in the portal (i.e. CPs at maintenance locations) are also not considered. Next, this research exclusively aims to find an optimal solution while ignoring the grid capacity at locations. The research should provide an implementation and monitoring plan of the found optimal solution with regards to their current business practices.

2. Context Analysis

This chapter analyses the context of the problem and aims to give an understanding of the current situation and characteristics that are relevant for developing the reference model. Section 2.1 provides general information about the company, Company X, and the practices regarding their charging points and their performance. Section 2.2 provides general information about charging points and their characteristics, as well as the characteristics of other parties that are relevant to the EV-charging value chain. Finally Section 2.3 provides an insight in corporate charging point practices at other companies and how other companies influence the performance and revenues of their charging points.

2.1 Company X

Problem Statement

From the introduction we can conclude that Company X lacks a structured approach for making strategic decisions regarding their EV charging point infrastructure. This lack of approach has led to suboptimal utilisation and revenue creation from the EV charging points. The absence of an evaluation on current and future charging points results inefficiencies in the form of insufficient revenue creation as well as excessive costs. Company X needs a decision making model that supports their decision making process and optimises charging point infrastructure as to achieve maximum net revenues.

Company X

Company X has 62 locations throughout the Netherlands, generally spread as shown in Figure 5. The CMS Portal (provided by CPO/EMSP 1), the dashboard where Company X can manage their charging points, houses 82 charging points at 33 locations. An overview of the charging points per location is shown in Table 1.

Table 1 Number of charge points at locations Company X

Figure 5 Charging points Company X

The dashboard provides information about the status of charging points, whether they are online, offline, charging, available or faulted, and more. The dashboard also provides historical data on charging sessions for all charging points that exist in the portal, and certain characteristics of charging points, (i.e. charging point tariff, volume charged, etc.) some of which can be adjusted as well.

Characteristics Company X charging points

Currently, out of the 82 charging points Company X has in the CMS Portal, 81 are Level 2 type chargers and 1 is a DC charger (the types of chargers are discussed in section 2.2). Customers use their EV-charging pass to charge their EVs. Currently the tariff used at the charging points is the same for all charging points being "A3". From conversations with CPO/EMSP 1 and historical data, the tariff "A3" is equal to €0.29 per kWh charged, and €0.50 starting tariff per charge session.

Not all charging points are online, as for a charging point to be online certain costs are charged. These costs are €8,- for charging points with a single socket and €4,- extra for each added socket per month, and for charging points that are only used within Company X's service facilities, having the charging points online is unnecessary (as only Company X themselves charges the cars).

To get an overview of the charge sessions at Company X, the table below is constructed. This is based on exported datasheets of charge stations of different locations of Company X over the year 2023. To get a general understanding of the possible profits of these charge stations, the tariffs in the Netherlands range from €0.30 to €0.80, but €0.50 is mostly used for calculations (Athlon, 2024). The current tariff Company X uses is 0.29 cents, at all the charging points within the portal. Table 2 shows the revenues from various locations with the tariff currently in use based on the yearly data from 2023.

Location	**Volume Charged (kWh)**	**Total time charged (h:m:s)**	**Tariff (€)**	**Total income (€)**
Location 1	5.576,29	5564:01:40	0.29	1.617,12
Location 2	61.830,10	32036:44:15	0.29	17.930,73
Location 3	28.430,62	16786:47:08	0.29	8.244,88
Location 4	4.104,99	2239:34:10	0.29	1.190,45
Location 5	13.044,58	4112:51:09	0.29	3.782,93
Location 6	4.548,64	1640:04:00	0.29	1.319,11
Location 7	3.854,15	593:09:29	0.29	1.117,70

Table 2 Current revenues from 2023 of locations Company X

2.2 Charging Points

The charging point infrastructure environment has various aspects that affect the revenues and costs created by each charging point. The type of a charging points has different costs, but also affects the volume that can be charged (i.e. revenue created). The tariff chosen at a charging point, directly influences the revenue created, but the revenue is still dependent on how many kWh are charged at a CP. The different actors in the CP environment are briefly discussed in this section.

Types

One of the most important differences however, is in the power of the charging point. There is either Level 1, Level 2, or Level 3 charging (Chargelab, 2023). The key differences between these levels are that level 1 and 2 are AC chargers and level 3 is DC charging. Level 1 is equivalent to a power of 1.3 kW to 2.4 kW. Level 2 is equivalent to a power of 3 kW to 22 kW. Level 3 is equivalent to 50 kW to 350 kW. These types of charging points influence the total volume charged, as slower chargers can charge less in the same timespan as faster chargers. In this research, only Level 2 type chargers as well as DC chargers are considered. Chargers slower than Level 2 type chargers are not considered future-proof, and Company X has no interest in placing these chargers. Currently Company X makes use of mostly Level 2 type chargers, and only 1 DC charger is used. The utilisation rate of Level 2 chargers in March 2024 is equal to 7% while the utilisation rate of DCFC (DC chargers) is equal to 18.1% (Stable, 2024). This means that EVs are connected respectively 7% and 18.1% of the time for Level 2 type and DC chargers in 24 hours.

Tariffs

Various different tariffs can be chosen for charging points. Tariffs can be dependent on kWh charged, time connected, setup costs per charging session, as well as blocking costs when cars are connected to a charging station for a significant time. Increases in the price of a tariff has, similar to all goods, a price elasticity function. From a quantitative analysis on a real-world dataset in Shenzen, China, the price elasticity in the city is -0.76 (Github). A 1% increase in charging price decreases the demand by 0.76%. The price elasticity fluctuates per location, dependent on multiple different factors regarding type of charger, user behaviour as well as substitute availability, but generally 0.76% can be taken as a measure of price elasticity. For simplicity of the model, only volume based tariffs are considered, but the recommendations share information on whether a tariff based on a different factor could be more profitable.

Number of charging points

The number of charging points (and sockets) impact the total revenues as well as costs related to the model. Constructing multiple charging points increases the volume (i.e. revenue) charged, but also increases the costs. To get a general idea of how additional charging points affect the total volume charged, the current data of Company X is analysed. Company X has multiple locations with different amounts of charging points (locations with 1, 2 ,3 ,4 or more charging points). Certain charge points have 1 socket, others have 2 or more. To estimate the additional volume charged at a charge point, every socket is considered as a new charging 'opportunity' (i.e. 2 charging points with 2 sockets each equals 4 charging opportunities). In chapter 5 further research is done and a quantitative estimation is made regarding the effect of additional charging 'opportunities'.

Costs

The costs for EV-chargers are different for each charging point. Although there are various different brands and providers for charging points, the main difference is in the power of the charging points. These can range from 3kW to 22kW for Level 2 type chargers, and up to 300kW for DC chargers. The power differences are most influential in the equipment and installation costs of the charging points. Nowadays, most slow chargers sold are either 11kW or 22kW, both having either 1 or 2 sockets, and almost no chargers with lower powers are installed, as chargers that charge up to 22kW also support EVs with lower power capacities. As such, the charging point types can be narrowed down to Level 2 type chargers and DC chargers.

HBE's

HBE's are so-called Hernieuwbare-Brandstof-Eenheden (Renewable Energy Units). These can be obtained by charging EVs with electricity from green sources. HBE's can be compared to Guarantees of Origin, however GoO (Guarantees of Origin) are produced and can be traded by energy producing companies, while HBE's can be created by claiming deliveries of renewable energy in the Energy for Transport Registry. As such, HBE's can be created by any company instead of only by energy producing companies. Moreover 1 HBE is equal to 1 GJ (Gigajoule, 278 kWh) while 1 GoO is equal to 1 MWh. Between HBE's and GoO's, there are similarities as well as differences, but only HBE's are of importance in the calculation of net revenues for Company X. Typically HBE's are most profitable for locations that use PV-installations and directly use their produced electricity at their charging stations. However, in 2024 the percentage of renewable energy from the grid was equal to

39.9% (NEA). Consequently, when there is no PV-installation present, 39.9% of the kWh charged are eligible for HBE's. A single HBE is obtained after charging 1 GJ of renewable energy (i.e. 278 kWh). The average price of an HBE fluctuates between €10,- and €15,- (Soly, 2024). HBE's can only be obtained after purchasing an HBE audit. The costs for an HBE audit are approximately €2.500 (Joulz, 2024).

Volume Decrease

The volume charged at charge points is different for every location, as it is dependent on a lot of factors. What is clear however, is that after a set number of charging points are built, the costs for building a new charging point outweigh the revenues created, as the cumulative volume charged at the charging points does not increase linearly. A formula of the form $y = aX^b$ can be used to model this expression. Further discussion on the usage and behaviour of this formula is done in chapter 5.

CPO/EMSP

A charge point operator (CPO), is responsible for the hardware, and a small part of the software of the charging points. Important for this research and the mathematical model, is researching what different CPOs exist, what parts of the EV-value chain they accommodate and what influence a choice for a certain CPO has on the cashflow of the charging points. The current CPO of Company X is CPO/EMSP 1. CPO/EMSP 1 provides the charging management software for Company X, and makes sure the charging points installed are working. They fulfill the task of CPO as well as EMSP, as they provide the complete hardware as well as the complete software side of the charging points. CPO/EMSP 1 has several different revenue streams that they receive from Company X. Firstly, the starting tariff per charging session (currently being 0,50€) is the payment for the CPO services. Secondly , subscription costs for managing charging point in the CMS. In table 3 an overview is given of the costs related to certain CPO/EMSPs. These are costs incurred by the CPO/EMSP to Company X.

CPO/EMSP	**Monthly Subscription (€)**	**Start Tariff (€)**
CPO/EMSP 1	8,- for a CP, 4,- extra for each added socket	0,50
CPO/EMSP 2	4,95 per socket	0,35
CPO/EMSP 3	10,- per charge point	0
CPO/EMSP 4	14,95 per charge point	0
CPO/EMSP 5	8,95 per charge point (+2,95 per extra socket)	0

Table 3 Cost overview CPO/EMSPs

As stated above, CPO/EMSP 1 also fulfills the role of EMSP for Company X. An EMSP is responsible for the registration, authentication and billing of charge points. Next to CPO/EMSP 1 there are several others that provide these services. For this model, we only consider parties that perform both services, as for these parties it is certain that the charge points, software, and charge passes have synergy and can be used combined with each other.

2.3 Conclusion

The context analysis described several important characteristics relevant for the problem. The characteristics discussed are not all of the important factors relevant to the problem as well as the solution, but they do provide some first information that is necessary to understand how the solution model should function. Furthermore, it gives a quick overview of the revenues currently created as well as one of the main decisions regarding costs. Comparing these costs and revenue streams with the costs and revenue streams from the solution model aims to give an answer to how a strategic decision making model can be defined and implemented in order to maximise profitability. Finally, the context analysis provides information regarding the different strategic decisions in the CP infrastructure environment that a company can make that affect their CP business performance.

3. Theoretical framework

This chapter provides information about the existing literature on optimisation problems, strategic decision making and EV-charging points. The first Section gives a brief overview of different optimisation problem types, and discusses the different characteristics that are of importance in defining the theoretical framework. The second Section provides a more elaborate explanation on strategic decision making in optimisation problems and discusses ways to solve these optimisation problems.

3.1 EV Charging Points

The literature regarding EV charging points is broad and getting increasingly widespread. As EV charging points are still relatively recent technology, many new discoveries and innovations are made. Consequently, a lot of topics are already discussed regarding EV charging points, but as their behaviour is majorly location dependent and changes a lot due to the growing EV market and customer behaviour as well, research reports with similar goals can have very widespread results, and every report is valuable in its own right. In this section, literature regarding optimisation problems in the EV charging point environment are discussed.

Research has previously been conducted on dynamic pricing strategies and control for EV charging stations with solar generation (Cedillo, 2022). Next to dynamic pricing, research has been conducted on smart charging, based on a model considering TOU (Time of Use) price and SOC (State of Charge) curve (Cao, 2011). This second study aimed at minimising charging costs, while the first focused on maximising charging revenues. Smart charging has further been investigated in the form of localisation of charging points, where the goal was to find the charging station that ensures the minimum charging time, travel time, and charging costs (Moghaddam, 2017).

Next to smart charging and pricing, sizing of charging points has also been researched previously. Optimisation processes regarding sizing and siting of charging point, as well as variables that define the charging demand have been investigated (Jia, 2012). Next, a cost based model on optimal siting and sizing has been investigated, which considers demand response programmes to minimise investment costs, connection costs, total costs of losses and demand response costs (Simorgh, 2018). Research has also been performed on planning of workplace EV charging infrastructure with smart charging opportunities, analysing the decision problem of optimal number of EV charging stations for a workplace manager and taking advantage of smart charging opportunities (Ferguson, 2018). Analysing business driven EV charging infrastructure planning while considering the traveler-infrastructure interactions in a transportation network has also been investigated, focusing mostly on establishing a theoretical foundation from both modeling and computational aspects. (Guo, 2016)

This literature, and much more has been previously investigated in the EV charging infrastructure environment. Although some studies have touched upon parts, few studies have actually focused on a generalised view of strategic decisions in the EV-charging point environment for business CPs, and how strategic decisions can be made to ensure maximum profitability. As such, this research is the first step in proposing a generalised model for business owners to support their decision making processes regarding EV charging point infrastructure.

3.2 Optimisation problems

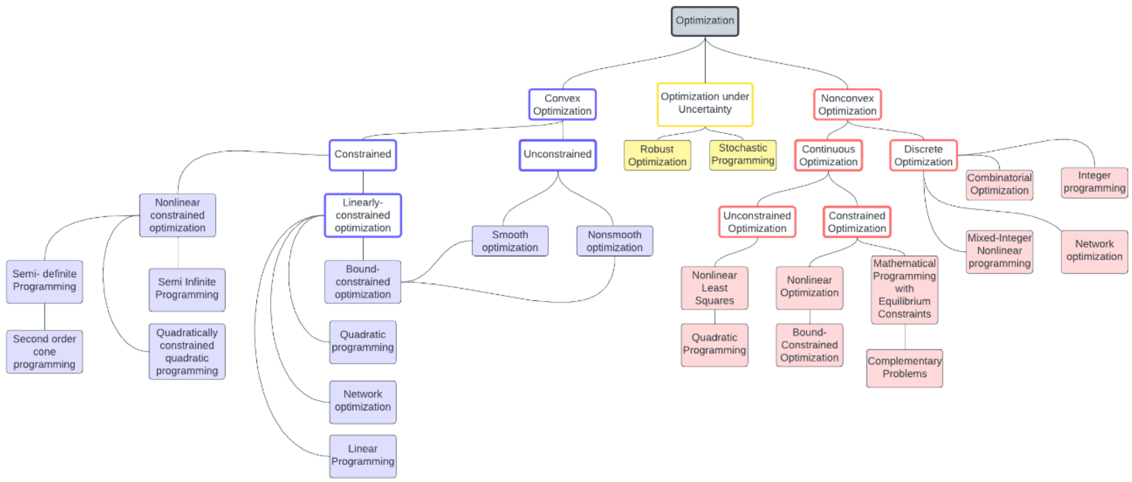

Figure 6 Different Optimisation Problem Types (adapted from Neos Guide)

There are many different optimisation problem types, and one of the most important steps in the optimisation process is classifying the optimisation model, since algorithms for solving optimisation problems are tailored to a particular type of problem (Neos Guide, 2023). The first difference can be made with Convex and Non-Convex functions. Convex functions have a unique global minimum and non-convex functions can have multiple local minima (Ruman, 2023). These functions however, assume that the data for the given problem is known accurately, while many problems have data that is uncertain. Optimisation Under Uncertainty therefore, is another type of optimisation problem that takes into account uncertainties in optimisation problems, i.e. future product demand or price for a time period.

To determine the optimisation problem type, it is important to illustrate what the important characteristics in optimisation problems are, and how they behave in the theoretical framework. The characteristics specific for the optimisation problem in this thesis are further discussed in Section 2, and defined in chapter 4 .

Characteristics of optimisation problems

Optimisation problems have several key attributes that define the structure and how the optimisation problems can be solved. The main attributes are the following:

Objective:

The objective represents the goal of the optimisation problem. It is a mathematical expression, that quantifies what needs to be minimised or maximised. The objective function is (generally) given by $f(x)$,where the decision variable x is a value such that $f(x)$ is either maximised or minimised.

Decision Variables:

The decision variables are the unknown variables that are determined during the optimisation process. These represent the decisions that the problem owner can make to find the optimal solution to their problem. In a general model the decision variables are given algebraic designations such as $x = (x_1, x_2, \dots, x_n)$, but in specific situations notations such as x_{ij}, y_k or $z(i, j)$ might be more convenient (University of Texas, 2023). If all variables are assigned a value, a solution to the optimisation problem is found. Iterating with different variable values will subsequently find an optimal solution.

Constraints:

Constraints are certain set conditions that have to be met for a solution to be feasible. The constraints set boundaries for where the decision variables can fluctuate in. Constraints can be expressed as e.g. $w_i(x) \leq b_i$ or $h_j(x) = d_j$ where w_i and h_j are functions representing the constraints and b_i and d_j are the so-called bounds. So in general, a constraint $w_i(x) \leq b_i$ represents a firm requirement or specification that limits the possible choices (Boyd, Vandenberghe, 2004)

Feasible Region

The feasible region is the set of all possible values for the decision variables, that operate within the constraints. The feasible region is also known as feasible set or solution space, and it represents the space in which the optimal solution exists. Suppose that the decision variable x is part of a set L^n and has to answer to the previously stated constraints, the feasible region $\boldsymbol{S}$ can then be defined as: $\boldsymbol{S} = \{x \in L^n \mid w_i(x) \leq b_i, h_j(x) = d_j\}$.

3.3 Strategic decision making in optimisation problems

Recall that finding a solution to the optimisation problem is dependent on the type of optimisation problem, and the type of optimisation problem is dependent on the behaviour of the characteristics of the problem. In this Section, these behaviours of the characteristics specific for this optimisation problem are discussed. A general description of the constrains and feasible region is given, and a theoretical model is described. In figure 7, the variables defining the theoretical model are illustrated. From this theoretical model, the nature of decision variables, parameters and constraints can be retrieved and the type of optimisation problem is derived.

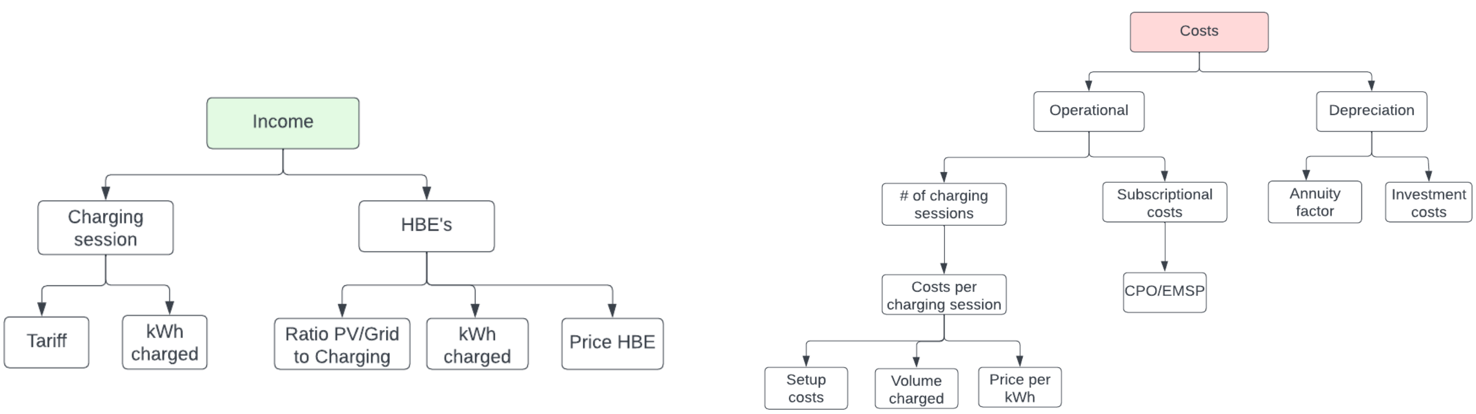

Figure 7 Theoretical model structure of income and cost

Objective:

The objective of the optimisation problem, is maximising the profits received from charging points. The objective function therefore is defined by $f(x)$, where $f(x)$ represents the profits from charging points and x is the decision variable that will be controlled and adjusted. This simplified objective function is adjusted when more decision variables or parameters are added. The profits are determined by the two main components, income and costs on which further elaboration is given in Section 4.2 and 4.3

Decision variables:

The decision variables are key in determining the type of optimisation problem and the subsequent solution approach. The decision variables are derived from the previously illustrated textual model, as well as information from interviews and literature on charging points, and consist of the following decisions:

Decision Variable	Type
Construct charge point	Binary
Tariff chosen	Continuous
Volume charged	Continuous
Sessions charged	Continuous
Choose CPO/EMSP	Binary

Table 4 Decision Variables types for determining type of optimisation model

The binary decision variable can either 1 of 0, depending if a charging point is built or not. The tariff chosen can be within a range (continuous), similar to the volume and sessions charged which can theoretically range from 0 to infinity. The CPO/EMSP is, just like the CP, either chosen or not chosen.

Next to the decision types, there also exist parameters that influence the objective function and the performance of the decision variables. These parameters, and their types, can be described as follows:

Parameter	Type
Base Volume	Continuous
Base Sessions	Continuous
Costs charge points	Integer
Starttariff	Integer
Electricity Cost	Integer
Costs CPO/EMSP	Integer

Table 5 Parameter types for determining type of optimisation model

The parameters for base volume and sessions are input parameters, and can theoretically range from 0 to infinity. The costs per charge point, starting tariff, electricity costs and costs for CPO/EMSP are preliminary chosen integer values.

Constraints

Various constraints are of importance in this optimisation problem, and define the linearity or non-linearity of the optimisation problem. The constraints are fully defined in Section 4.1, but they can be classified as the following types of constraints:

- Binary Constraints
- Linear Constraints
- Recursive Constraints
- Logical Constraints
- Quadratic Constraints

From the formulation in section 4.1 the types of these constraints can be derived. Optimisation problems that include these types of decision variables and parameters (integer and continuous), as well as the different relationships in the constraints (as previously stated) fall under the category of Mixed-Integer Quadratically Constrained Programming (MIQCP)(Del Pia, A. Dey, S.S. Molinaro, M., 2014). Various solution approaches can be found in literature for this type of optimisation problem. In the following Section some of these different solution approaches are discussed.

3.4 Solution approaches for solving Mixed-Integer Quadratically Constrained Programming

MIQCP have previously been solved using both exact algorithms as well as heuristic algorithms. A combination of these algorithms can also be used to solve MIQCP problems. Gurobi is used for solving the model, and uses various methods to solve MIQCP problems. From the official documentation of Gurobi, MIQCP problems are solved using either a linearized, outer approximation approach, an approach that solves QCP Relaxations at each node or heuristics (Gurobi, 2020).

Branch and Boand

The two main parts of the branch and bound algorithm are, branching and bounding. Branching divides a set of feasible solutions into smaller subsets, and bounding finds a lower bound on the optimal value, to eliminate subsets that do not contain the optimal solution. Bounding is generally based on relaxations of the feasible space and Gurobi uses quadratic convex relaxations to perform the steps in branch and bound. (Elloumi, Lambert, Neveu, Trombettoni, 2024)

Outer approximation

The outer approximation method works by iteratively solving linear approximations of nonlinear constraints. Quadratic constraints are replaced by linear approximations, and these linearizations are refined until the solution fits the initial quadratic constraint. Outer approximation has been used to solve MIQCP problems based by extending the framework for constraint integer programming (Berthold,, Heinz, Vigerske, 2012).

Heuristics

Heuristics can be divided into constructive heuristics, improvement heuristics and compound heuristics (Oliveira, Carravilla, 2001). Where constructive heuristics aim to build a solution according to a set of rules defined beforehand. Improvement heuristics applies changes to an existing feasible solution (either from constructive heuristics or elsewhere) to improve the existing feasible solution. Compound heuristics is the combination of a constructive and improvement heuristic.

There are many different heuristic algorithms, specifically aimed towards solving certain types of problems. Gurobi houses more than 30 heuristic algorithms, both constructive and improvement heuristics and adaptive strategies decide when to apply each heuristic (Wunderling, 2022).

3.5 Conclusion

Chapter 3 discusses the available literature regarding EV-charging points as well as optimisation problems. Firstly, previous research regarding EV-charging point infrastructure and optimisation problems in the environment is discussed. Secondly, literature regarding optimisation problems is discussed and indicated that the model is of the form MIQCP. Finally, Gurobi Python is used as a solver. Gurobi makes use of combinatorial algorithms of Branch and Bound, Outer Approximation as well as heuristics to provide optimal solutions.

4. Mathematical model

This chapter introduces the mathematical model, which is constructed and solved using Gurobi and Python, for the optimisation problem. The model provides an answer to different strategic decisions regarding charging points. Historical data and literature substantiate the values of the optimisation model, however the model is constructed in such a way that these values can be altered easily and the model can be easily improved and implemented in different situations. Section 5.1 discusses the mathematical formulation, firstly assessing the different aspects of the optimisation problem, and secondly the problem modeling. Section 5.2 discusses the model validation.

4.1 Mathematical formulation

The decision variables, sets, parameters, and constraints are defined as follows

Sets:

A set of different types of chargers

$$A = \{Level\ 2\ Single, Level\ 2\ Double, DC\}$$

B set of different CPO/EMSPs

$$B = \{CPOEMSP\ 1, CPOEMSP\ 2\ , CPOEMSP\ 3, CPOEMSP\ 4\}$$

C set of number of charging points

$$C = \{1, \dots, N\}$$

Decision variables:

$x_{t,i}$, binary variable, $x_{t,i} = 1$ if a charging point of type t is built as charging point number i

$$x_{t,i} \ \in \{0,1\}, t \ \in A, \forall i \in C$$

CP_i, binary variable, $CP_i = 1$ if a charging point of any type is chosen as charging point i

$$CP_i \in \{0,1\}, i \ \in A$$

NSC_i, continuous variable, number of sockets chosen for charging point *i.*

y_t, continuous variable, y_t representing the tariff chosen at a charging point of type t

$$y_t \ \in \begin{cases} [0.5, 0.9] \ \ if\ t = Level\ 2\ Single, Level\ 2\ Double \\ [0.73, 1.19] if\ t = DC \end{cases}$$

$v_{t,i}$, continuous variable, $v_{t,i}$ representing the volume at a charging point of type t when it is built as charging point number i

$$v_{t,i} \geq 0, t \in A, \forall i \in C$$

$s_{t,i}$, continuous variable, $s_{t,i}$ representing the number of sessions at a charging point of type t when it is built as charging point number i

$$s_{t,i} \geq 0, t \in A, \forall i \in C$$

CE_j, binary variable, $CE_j = 1$ if a CPO/EMSP of type *j* is chosen.

$$CE_j \in \{0,1\}, j \ \in B$$

VDF_t, continuous variable, representing the volume decrease factor of a charging point of type t

$$VDF_t \in [0,1], t \in A, \forall i \ \in C$$

$AR_{t,i}$, continuous variable, representing the auxiliary revenue at a charging point of type t when it is built as charging point number *i*

$$AR_{t,i} \geq 0, t \in A, \forall i \ \in C$$

$AC_{t,i}$, continuous variable, representing the auxiliary costs at a charging point of type t when it is built as charging point number *i*

$$AC_{t,i} \geq 0, t \in A, \forall i \in C$$

$AV_{t,i}$, continuous variable, representing the auxiliary volume at a charging point of type t when it is built as charging point number *i*

$$AV_{t,i} \geq 0, t \in A, \forall i \in C$$

$AS_{t,i}$, continuous variable, representing the auxiliary sessions at a charging point of type t when it is built as charging point number *i*

$$AS_{t,i} \geq 0, t \in A, \forall i \ \in C$$

$TCCE_j$, Total Cost CPO/EMSP

$$TCCE_j \geq 0, j \in B$$

Parameters

$TotalVolume$, Total volume from historical data

$TotalSessions$, Total number of charging sessions from historical data

S, Number of sockets in dataset

E, Margin green energy used for charging

TC, Total number of charging points used for calculating HBE audit cost per charging point

$PHBE$, Price per HBE

$CAGR$, Compound Annual Growth Rate EV Market

PE, Price Elasticity EV-charging demand

$UtilizationDC$, Utilisation Rate DC Chargers

$PowerDC$, Influence of power of DC charger on ratio kWh/hour charged

B_{slope}, Demand elasticity of curve for multiple sockets

A_{Volume}, Initial Volume of a single socket

$A_{Sessions}$, Initial number of sessions of a single socket

BV_t, base volume for each charging point type t

$$BV_t \geq 0, \forall t \in A$$

BS_t, base number of charging sessions for each charging point type t

$$BS_t \geq 0, \forall t \in A$$

c_t, costs for building a charging point of type t

$$c_t \geq 0, t \in A$$

CEC_j, fixed costs for CPO/EMSP j

$$CEC_j \geq 0, j \in B$$

$CEST_j$, starting tariff for each charging session associated with CPO/EMSP j

$$CEST_j \geq 0, j \in B$$

BT_t, base tariff for charging point type t

$$BT_t \geq 0, t \in A$$

ec, electricity cost

$$ec \geq 0$$

Objective:

$maximize\ revenue - total\ cost$

Where

$revenue = \sum_{t \in A} \sum_{i=1}^{N} x_{t,i} \cdot AR_{t,i}$

$total\ cost = \sum_{t \in A} \sum_{i=1}^{N} x_{t,i} \cdot AC_{t,i} + \sum_{j \in B} TCCE_j$

Constraints:

$$(1)\ \ BV_t = \begin{cases} \frac{CAGR \cdot TotalVolume}{S^{B_{slope}}} & if\ t = Level\ 2\ Single \\ \frac{2^{B_{slope}} CAGR \cdot TotalVolume}{S^{B_{slope}}} & if\ t = Level\ 2\ Double \\ \frac{2^{B_{slope}} CAGR \cdot TotalVolume}{S^{B_{slope}}} \cdot PowerDC \cdot UtilizationDC & if\ t = DC \end{cases}$$

$$(2)\ \ BS_t = \begin{cases} \frac{CAGR \cdot TotalRows}{S^{B_{slope}}} & if\ t = Level\ 2\ Single \\ \frac{2^{B_{slope}} CAGR \cdot TotalRows}{S^{B_{slope}}} & if\ t = Level\ 2\ Double \\ \frac{2^{B_{slope}} CAGR \cdot TotalRows}{S^{B_{slope}}} \cdot PowerDC \cdot UtilizationDC & if\ t = DC \end{cases}$$

(3) $\sum_{t \in A} x_{t,i} \leq 1, \forall i \in C$

(4) $\sum_{i \in C} CP_i = \sum_{t \in A} x_{t,i}, \forall i \in C$

(5) $\sum_{i \in C} NSC_i = \sum_{t \in A} x_{t,i} \cdot SocketsPerType_t, \forall i \in C$

(6) $\sum_{j \in B} CE_j = 1$

(7) $sc = \sum_{j \in B} CEST_j \cdot CE_j$

(8) $VDF_t = 1 - PE \cdot \left(\frac{y_t}{BT_t} - 1\right), \forall t \in A$

$$(9)\quad AV_{t,i} = \begin{cases} BV_t \cdot VDF_t & for\ i = 1 \\ AV_{t,1} \cdot ((i)^{Bslope} - (i-1)^{Bslope}) & for\ i \geq 2\ and\ t = Level\ 2\ Single \\ AV_{t,1} \cdot ((i+1)^{Bslope} - i - 1^{Bslope}) & for\ i \geq 2\ and\ t = Level\ 2\ Double, DC \end{cases}$$

$$(10)\quad AS_{t,i} = \begin{cases} BS_t \cdot VDF_t & for\ i = 1 \\ AS_{t,1} \cdot ((i)^{Bslope} - (i-1)^{Bslope}) & for\ i \geq 2\ and\ t = Level\ 2\ Single \\ AS_{t,1} \cdot ((i+1)^{Bslope} - (i-1)^{Bslope}) & for\ i \geq 2\ and\ t = Level\ 2\ Double, DC \end{cases}$$

(11) $v_{t,i} \leq x_{t,i} \cdot AV_{t,i}, \forall t \in A, \forall i \in C$

(12) $s_{t,i} \leq x_{t,i} \cdot AS_{t,i}, \forall t \in A, \forall i \in C$

(13) $AC_{t,i} = c_t + sc \cdot s_{t,i} + ec \cdot v_{t,i} + \left(\frac{2500}{TC}\right), \forall t \in A, \forall i \in C$

(14) $AR_{t,i} = y_t \cdot v_{t,i} + \left(\frac{E \cdot v_{t,i}}{278} \cdot PHBE\right), \forall t \in A, \forall i \in C$

$$(15)\quad TCCE_j = \begin{cases} CE_j \cdot CEC_j \cdot (NSC + CP) & if\ j = CPOEMSP1 \\ CE_j \cdot CEC_j \cdot NSC & if\ j = CPOEMSP2 \\ CE_j \cdot CEC_j \cdot CP & if\ j = CPOEMSP3, CPOEMSP4 \end{cases}$$

Constraints (1) and (2) determine the base volume and sessions of each type, when the first charging point is installed. These are calculated using historical data, and multiplied by the CAGR for taking into account the growth of the EV-market. The first charging point built follows the previously described curve of the form $y = aX^{b_{slope}}$, to determine BV_t and BS_t. Constraint (3) ensures that a charging point is either built or not built. Constraint (4) and (5) respectively determine the total number of charging points and sockets built. Constraint (6) ensures that only a single CPO/EMSP is chosen. Constraint (7) makes sure that the setup costs used in the calculations of the model is determined by the chosen CPO/EMSP. Constraint (8) calculates the Volume Decrease Factor based on the price elasticity function of demand.

Constraint (9) and (10) respectively ensure that the correct calculations of volume and sessions are used for t and *i.* The first charging point built is based on BV_t (and BS_t) and the VDF_t. The subsequent charging points are determined by use of the formula $y = aX^{b_{slope}}$, where the additional volume of a charging point is calculated by subtracting the formula using X and X-1 (or X+1 and X-1 for types with 2 sockets).

Constraint (11) and (12) ensure that the volume and session variables are only activated when a charging point of type t built as charging point number i is used.

Constraint (13) determines the auxiliary costs, based on the costs for each charging point type, the setup costs previously determined, the number of sessions of each charging point of type t built as charging point number *i,* the electricity costs and the volume charged, as well as the costs for an HBE audit (~€2500,-) divided by the total number of charging points used for the HBE audit.

Constraint (14) ensures that the auxiliary costs are calculated by the tariff chosen multiplied by the volume of corresponding charging point built as charging point number *i*, as well as the revenues generated from HBEs. The revenues from HBEs are determined by the electricity margin and the volume of a charging point, divided by 278 (kWh to GJ) multiplied by the price of an HBE.

Constraint (15) calculates the total cost related to the choice for a CPO/EMSP. For certain CPO/EMSPs (CPO/EMSP 3, CPO/EMSP 4) these are only determined by the number of CPs, while for CPO/EMSP 2 this is determined by the number of sockets and for CPO/EMSP 1 it is determined by both the number of CPs as well as number of sockets.

4.2 Model validation

At first, the model was constructed with costs for the charging points being calculated with a lifetime of the charging points of 10 years, and the investment and installation costs derived from literature. After discussing the model with Company X, the lifetime of the charge points was changed to 8 years, as they often need to be replaced or upgraded after 8 years, which is why 8 years is used as their depreciation time in the solution analysis. The adjusted annuity factor is 0,147 and the corresponding costs for the type of charging points used in the model are as follows:

Type	**Levelised Cost per Year**
Level 2 Single	€301,93
Level 2 Double	€545,81
DC	€5.112,50

Table 6 Redetermined levelised annual costs EV-chargers

These costs have been validated once again through conversations with Company X, stating that they 'could be a bit lower, but seemed quite accurate'. However it should be noted again, that the costs for a DC charger are not as simple as they might seem. As the installation costs for a DC charging station are quite high (e.g. necessary cables) most of the time a DC charging station with multiple DC chargers is built. In the model the costs for a single DC charger are used, but it has to be taken into account that subsequently installed DC chargers are likely to carry lower costs than used in the model.

4.3 Conclusion

This chapter defined and discussed the mathematical model, and the validation of the model. The model simplifies the problem into 2 sides, revenues and cost which can easily be compared to the revenues and costs from the current situation.

The revenue side of the model is based on 2 aspects. Firstly and most importantly, the tariff and volume of a charging point. The tariff is decided differently for DC chargers and for Level 2 type chargers, and is based on a price elasticity of demand function. The volume charged is more complex, as it is dependent on how many previous charging opportunities are present, the type of charger placed (and chosen tariff), and the historical data of the location used in the model. How the previous charging opportunities affect the volume is described via a curve ($y = aX^b$), depending on historical data and a parameter B_{slope} which determines the slope of the curve.

The second part determining the revenue is the revenue created by HBEs. The revenue generated by HBEs is a combination of the volume, the green electricity margin and the price for HBEs. The revenue from HBEs can be increased by building PV-installations and as such increasing the green electricity margin. The revenue from HBEs is significantly smaller and also comes with a cost for an HBE audit, analysing possible and current revenues of several locations can indicate whether doing an HBE audit is profitable.

The costs calculated in the model are determined by operational costs and fixed costs. The operational costs consist of the electricity costs and setup costs per charging session, as well as the costs for housing the CPs in a CMS which is used for collecting and monitoring data as well as implementing decisions. These costs and their calculations differ for each CPO/EMSP, and each CPO/EMSP has different advantages and disadvantages outside of their costs. The advantages and disadvantages of the CPO/EMSP are not considered in this research, as they are dependent on preference and not eligible for a generalised model.

Next to the operational costs are the fixed costs, which are related to the acquisition and installation of the CPs. Different types (and power) of chargers determine the fixed costs and annualising these costs provides an overview of when a CP becomes profitable.

Finally, different parts of the model were discussed with Company X and adjusted according to their feedback to improve the validity of the model.

5. Numerical study

This chapter provides information about the quantitative data gathered to construct and implement the mathematical model that is discussed in Chapter 4. The first section provides information about the output from the CMS portal and gives a general explanation to make the subsequent analysis easier to understand. The second section explains how the income of the charging points is defined providing information about revenues from charging sessions and revenues from HBE's. The third section explains the opposite side being the costs, providing information about the fixed costs as well as the operational costs.

5.1 Output CMS platform

Company X uses the CMS portal to monitor all of their charging points. This portal also collects and stores historical data of the charging points. This data is valuable to construct the mathematical model, as it provides information about charging point utilisation as well as costs and income. The data from the portal can be exported as CSV file. The CSV files can be exported per charging point or per location.

The output data consists of various empty or duplicate columns, and multiple columns that are not of importance in the data analysis. Removing these from the data sheet provides us with a cleansed data sheet.

The important columns are those that are needed for the mathematical formulation of the optimisation problem. These can either be aspects of constraints, decision variables or parameters and consist of the following columns:

- Charge session ID
- Duration
- Volume
- Tariff Type
- Charge Point ID
- Calculated Cost
- Reimbursement Cost

Where these columns are of importance within the mathematical formulation is described in the following sections. Moreover, other important parameters and their behaviour in the model are also discussed in the according sections.

5.2 Income

The income from charging points can be derived from the data sheets from the columns 'Volume' and 'Tariff Type'. The income obtained from HBEs in the current situation is 0, as HBE audits have not been performed yet. As such these are disregarded in the initial data analysis of income. For various locations of Company X, the current cumulative revenue from charging points is stated in table 8

Location	**# of charge points**	**Cumulative Volume (kWh)**	**Revenue (€)**
Location 1	3	5.576,29	1.617,11
Location 2	10	61.830,10	17.930,73
Location 3	10	28.430,62	8.244,88
Location 8	2	2.763,92	801,54
Location 9	2	13.719,21	3.978,57
Location 5	5	13.044,58	3.782,93
Location 7	1	3.854,15	1.117,7035

Table 7 Revenue from charge points in 2023 (€0.29 per kWh)

Recall section 2.2, where the volume decrease was first discussed. As previously stated, the volume charged at charge points is different for each location as it is dependent on a variety of factors. The volume decrease can be estimated using historical data from similar locations. Company X has location 1 and location 7, having respectively 3 and 1 charge points (5 and 2 charging sockets). These locations can be analysed and plotted with their data entries (cumulative volume). The graph for the cumulative volume decrease can be plotted as follows:

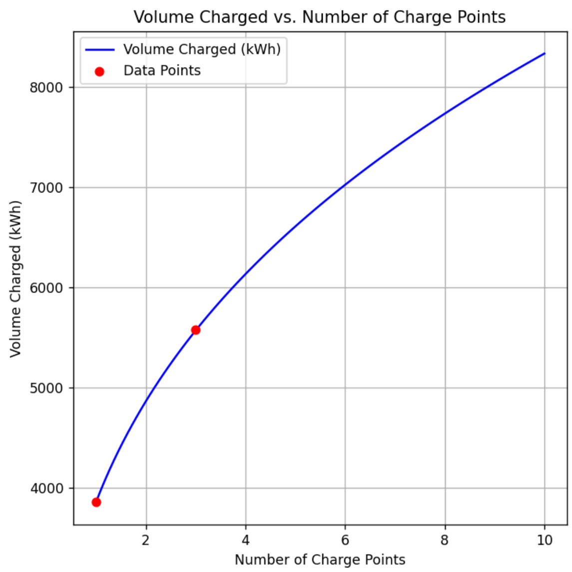

Figure 9 Cumulative volume charging sockets Location 1

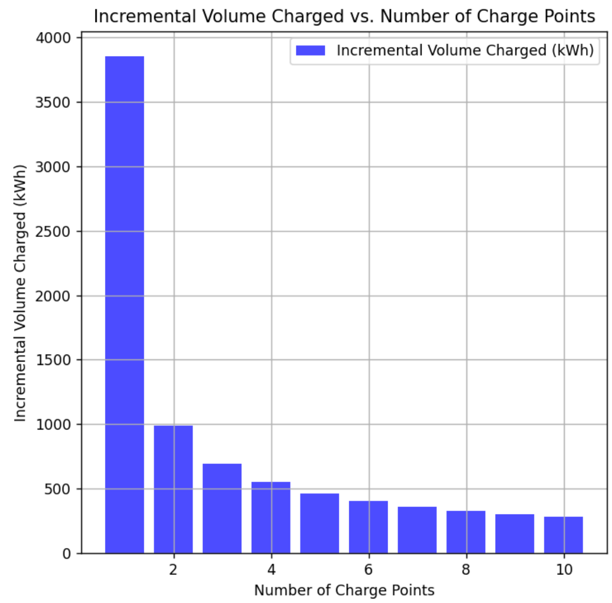

Figure 8 Additional volume per charge socket Location 1

From above mentioned figures, the additional volume for each subsequent charging point socket can be evaluated. This can be plotted as a bar chart stating the volume charged for the first charge socket installed, the additional volume for the second charge socket installed, etc.

From the data entries and the aforementioned formula $y = aX^b$ (Recall Section 2.2), the formula can be solved for a and b, where y equals the kWh charged, and X equals the number of sockets. Unfortunately there is limited literature available regarding the correctness of this formula and the application to this problem. The effect of number of charge points on cumulative volume charged is an optimisation problem on its own, and most studies on this matter are heavily focused on locating of charge points. The formula $y = aX^b$ does follow a clear and logical pattern, as is why it will be used in the optimisation model for determining added volume for each subsequent charging socket. The values of a and b are respectively, 2.914,59 and 0,403 for the locations 1 and 7 based on historical data. The formula for calculating the amount of kWh charged for a certain X can be defined as $y = 2914{,}59X^{0{,}403}$. The value for a is determined by the kWh charged when a single charging opportunity is present at a location. As such, this value is location dependent, and calculated based on the historical data of the chosen location. The model described in chapter 5 and 6 recalculates the value for a based on the historical data and the formula $y = aX^b$. The value for b (0,403) is a constant. It should be noted however, that this value is a determining factor in estimating the kWh charged at subsequent charging points, but that it is based on 2 data entries. This value for b can be different for different locations, based on charging demand at a location, however this value is always between 0 and 1 to make sure that demand is not infinite and decreases with each step of X. To retrieve the most accurate value for b, further research is necessary. Comparing historical data with data after a new charging point is placed could provide an insight into a more correct estimate of the value for b.

To estimate the value for *b* based on Location 1 and Location 7, a similar calculation is done for other locations. The results were values around 0.8 or even higher. These values imply an almost linear relationship between number of charging opportunities and kWh charged, which is not likely or logical to be the case. Consequently, for calculations in the model, the value of 0,403 is used to estimate the charging demand. The behaviour of adjusting this variable and recommendations on further research are given in chapter 6 and 7. To clarify the purpose of the value, the value for *b* will be called 'demand elasticity' in the remainder of the report

Another important factor in determining what type of charging point is optimal, is the utilisation of DC charging points. As previously discussed, (Stable) states that the utilisation of DC charging points is 18,1%, while that of Level 2 type chargers is 7%. However, when analysing the data of Company X, this utilisation is different. The table below shows the volume and time charged at Company X Almere de Strubbenweg, where a DC charger as well as Level 2 type chargers are present.

Type	**Hours**	**Volume**	**Ratio Hours**	**Ratio Volume/Hour**
4x AC	1.487,5	5.376,65	5,998	3,61
DC	62	1.681,76	5,998	27,075

Table 8 Ratio Utilisation and kWh/hour AC vs DC chargers

It can be concluded that the Level 2 type chargers have a higher utilisation rate than the DC chargers, however the DC charger delivers more kWh/hour. From these values we can derive the following in terms of volume charged at DC chargers compared to a Level 2 type charger:

$$Ratio\,\frac{Volume}{Hour}\,DC_{vs}AC = \frac{27{,}075}{3{,}61} = 7{,}5 \tag{1}$$

$$UtilizationRateDC_{vs}AC = \frac{1487{,}5/4}{62} = 5{,}998 \tag{2}$$

The DC utilisation rate is 6 times lower than the Level 2 type utilisation rate, and the Volume/Hour ratio is 7,5 times higher. Consequently, these ratios are used within the model. It is important to note that this is based on a single location as there is limited data available at Company X. Comparing the information from Stable and the data from Company X indicates that the utilisation rate can vary a lot. Further research is necessary to get a better understanding of the DC utilisation rate for different locations, but for this model the utilisation rate retrieved from historical data is used.

Next to this, the revenue created from HBE's should be considered. As discussed in section 2.2, the price of an HBE generally fluctuates between €10,- and €15,-. In the model, an average of €12,50 is used. The following formula for obtaining the general revenues from generated HBE's can be derived.

$$Revenue = \left(\frac{0.399 \cdot Volume_{ChargePoint}}{278} \cdot 12.50\right) - \left(\frac{2500}{NumberofChargePoints}\right) \tag{3}$$

Finally, a last important factor in determining the income from charging points is taking into account the growing EV-market. Currently, the compounded annual growth rate of the EV-market is 23,4% (Market Data Forecast, 2024). This factor is used in the model for determining the volume charged for a location, accounting for the growth (i.e. volume charged for next year).

5.3 Costs

The costs related to the charging points are divided between operational costs and depreciation costs. The columns that are of importance regarding costs are Column A and Column E. The depreciation costs are dependent on the investment costs and depreciation time of the charging points as well as the annuity factor (Recall 2.2) Next to the hardware costs for the charging points, the installment costs for the charging points also have to be included in the total costs. These can range from $500 to $3.000 or more (SinoSuperCharger) but for calculation purposes an amount of €649,- is used (WallDiscounter). The following table can be constructed for the hardware and installation costs for the different types of chargers:

Type	Hardware Cost	Additional Costs change
Level 2 Type Single	€1.404.98	€649
Level 2 Type Double	€3.064,-	€649
DC	€54.342,61	-36% by MIA (Milieu Investeringsaftrek, subsidy 36% from total equipment and installation cost)

Table 9 Prices for EV chargers from laadpuntexpert.nl (Level 2 type) and Rexel.nl (DC)

Because the lifetime of charging points is approximately 10 years, the above mentioned costs can be used in the general formula for yearly levelised investment costs (Schroeder, Traber, 2012) being the following 2 formulas:

$$\frac{investment\ cost}{year} = cost * annuity\ factor \tag{4}$$

$$annuity\ factor = \frac{(1+i)^n * i}{(1+i)^n - 1} \tag{5}$$

With *i* being the interest rate, and *n* the lifetime of the charging point. With an interest rate of 3.75% (DeNederlandscheBank, 2024), and 10 years being the lifetime of the charging point, the annuity factor is obtained being 0.1218. As stated in the model validation in section 4.2, the lifetime of charging points Company X uses is 8 instead of 10. This adjustment changes the annuity factor and consequent levelized cost per year as shown in table 8 in section 4.2.

The operational costs are dependent on multiple variables, being the subscription costs for the CPO and EMSP (in this case both being CPO/EMSP 1), and the costs for the charging sessions (dependent on kWh charged and the energy contract, as well as the start tariff). The subscription costs currently paid to CPO/EMSP 1 is €8,- per CP monthly and €4,- for each additional socket, and the costs per charging session is equal to €0.50 (excluding kWh costs). From conversations with Company X, the base electricity cost Company X pays per kWh is equal to €0.22 per kWh. With the current charging point volume charged the costs for the charging sessions for different locations of Company X can be calculated and are stated in Table 10:

Location	Charging Points	Sockets per CP	# of charge sessions	Cumulative Volume	Costs
Location 1	3	2x2 – 1x1	147	5.576,29	1.684,28
Location 2	7	6x2 – 1x1	2.505	61.830,10	15.815,12
Location 3	10	7x2 – 3x1	1.325	28.430,62	8.213,24
Location 8	2	2x2	119	2.763,92	955,56
Location 5	5	2x2 – 3x1	537	13.044,58	3.714,30
Location 9	2	2x2	829	13.719,21	3.720,73
Location 7	1	1x2	105	3854,15	1.044,41

Table 10 Annual costs charge points of 2023

5.4 Conclusion

Chapter 4 analyses the current situation of charging point usage at Company X. The revenues and costs for the charging points are illustrated. The effect of each subsequent charging opportunity is estimated through a comparison of historical data. The utilisation of DC charging points at Company X is compared to the average DC utilisation and the utilisation of Level 2 type chargers. The different characteristics discussed provide the basis of the solution from the mathematical model. As historical data at Company X is limited, further research is preferable to achieve more accurate and reliable parameter values. Assumptions are necessary for the model, but they need to be addressed when drawing conclusions from the results.

6. Solution analysis and implementation

This chapter describes the results from the model used to solve the optimisation problem. Section 6.1 describes the results, as well as different scenarios for certain parameters. Section 6.2 describes how the results and the model can be implemented in the company and how it can be used to monitor and evaluate the performance of the model and strategic decisions. The model is made in Python and solved with Gurobi 11.0.2

6.1 Results

The results from the model regarding different locations with aforementioned parameter values are defined in the table below. There are a couple of remarks to be made, and scenarios to be discussed.

Location	**CPO/EMSP**	**# of charging points**	**Type**	**Tariff**	**Revenue**	**Costs**	**Net revenue**
Location 1	CPO/EMSP 3	3	Level 2 Double	0,68	4.782,17	3.596,35	1.185,83
Location 8	CPO/EMSP 2	1	Level 2 Single	0,69	984,01	719,50	264,51
Location 9	CPO/EMSP 3	10	1x DC 9x Level 2 Double	0,95 – 0,68	30.357,28	20.054,58	10.302,69
Location 5	CPO/EMSP 3	9	Level 2 Double	0,68	17.886,96	11.905,08	5.981,88
Location 3	CPO/EMSP 3	10	1x DC 9x Level 2 Double	0,95 – 0,68	35.119,40	21.395,83	13.723,57

Table 11 Model solutions for several locations Company X

In the table above, the historical data (of 2023) is implemented in the model, and the results are shown. Clearly, the CPO/EMSP that provides the lowest costs for the charging points is CPO/EMSP 3. CPO/EMSP 2 is also chosen as CPO/EMSP once, as at location Arnhem the costs relating to the number of sessions are outweighed by the higher monthly costs for CPO/EMSP 3 (because the number of sessions are low). However, costs are not the only important factor for Company X in determining the choice for CPO/EMSP. User friendliness of a platform as well as development and innovation opportunities can also influence the choice for CPO/EMSP.

Next to the CPO/EMSP, a remark can be made regarding the tariff. The tariff chosen is almost always €0,68 for Level 2 type chargers, and €0,95 for DC chargers. This can be explained with the functioning of the price elasticity formula, which calculates the optimal tariff. If a price elasticity formula is used for calculating an optimal price, there is always a tipping point where increasing the price negatively influences the demand more than that the tariff positively increases the price. This tipping point is at €0,68 and €0,95 and is dependent on the base tariff and the price elasticity coefficient. At location Arnhem the tariff is €0,69, this can be explained by the relatively low kWh charged, and rounding of values in between calculations.

DC chargers are only profitable from a certain amount of kWh charged, but when that threshold has been met, a DC charger is more profitable than a Level 2 type charger. From above mentioned results, the threshold from when DC chargers are profitable can be determined as:

$$0{,}95kWh - costs_{DC} = 0{,}68kWh - costs_{L2} \quad (6)$$

Solving this formula with the predetermined costs for DC chargers and Level 2 type chargers results in a break-even kWh charged of 16.309,61. When a charging point charges more than 16.309,61 kWh yearly, a DC charging point is more profitable than a Level 2 type charger.

Recall in Section 3.1 the price elasticity of EV charging demand. From conversations with Unica, as well as sources on Github, this value could prove to be lower and different for each location. As the majority of EV drivers tend to not look at the charging price of EV-charging points this value could be near 0.1 (from 0.76 initially).

Next to the price elasticity, recall in chapter 4 that the demand elasticity (of 0.403) is based on a scarce dataset, with values of other locations being a lot higher. This has major influence on the total kWh charged (i.e. the cumulative revenue).

Furthermore, recall that the utilisation of DC chargers is estimated at 18.1% and the utilisation of Level 2 type chargers is 7% (Stable). However, the utilisation of the DC charger of Company X is 6 times lower than the utilisation of the Level 2 type chargers. Taking into account different utilisation rates for the DC chargers provides us with different results for the amount and composition of the different charge points and the cumulative net revenue.

These 3 parameters are iterated over different values to get an understanding of the behaviour of these parameters and how the model can be used under different circumstances (i.e. when research indicates different values for parameters). In the following 3 scenarios, the parameters and their behaviour, as well as other findings from the results are discussed.

Price Elasticity

As discussed, the price elasticity could prove to be a lot lower than used in the model. Moreover, the price elasticity can be different for each location, as it is dependent on the locational charging demand. To model the influence of changing price elasticity on the amount, composition and net revenue of the charging points the same locations as previously stated are analysed, and Figures 10,11 and 12 are defined. From the figures can be concluded, that higher price elasticity ensures lower net revenues for all locations.

Price elasticity	# of charging points	Type	Tariff	Revenue	Costs
0,1	8	Level 2 Double	0,90	13.712,29	8.856,76
0,4	5	Level 2 Double	0,9	7.865,82	5.366,67
0,76	3	Level 2 Double	0,68	4.782,17	3.596,34
0,9	2	Level 2 Double	0,63	3.679,14	2.644,12

Table 12 Location 1 Price elasticity effect on solution

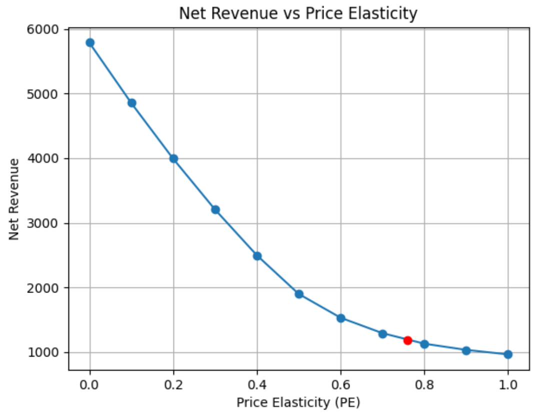

Figure 12 Location 1 Price Elasticity Behaviour

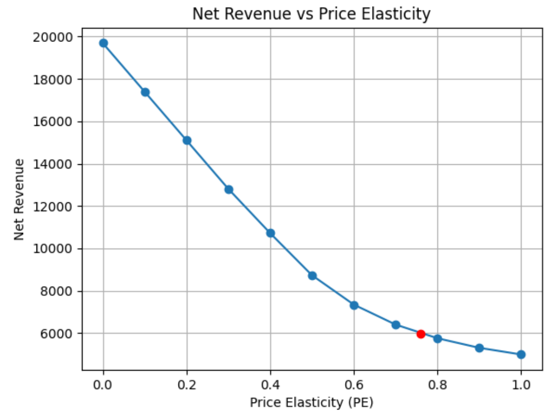

Figure 11 Location 5 Price Elasticity Behaviour

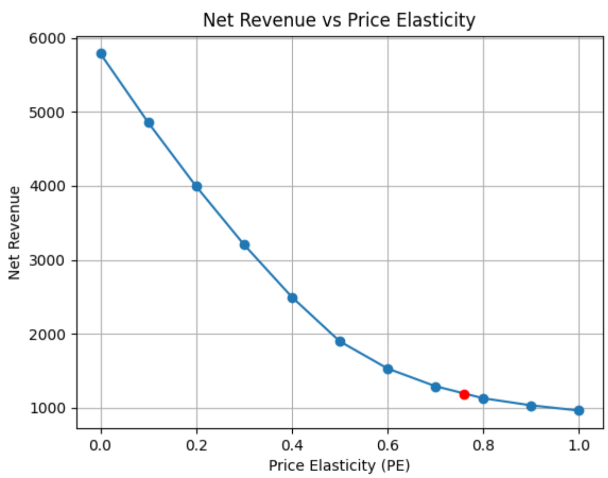

Figure 10 Location 3 Price Elasticity Behaviour

Demand elasticity

The demand elasticity is of importance in determining the number of charging points desired for a location. A higher value implies that charging demand is more linear, and a lower value implies that the additional charging demand falls off quickly. Similar to price elasticity, this value can be different for each location, based on the locational charging demand as well as the presence of possible alternatives. The Figures 13,14 and 15 are made to analyse the influence of the demand elasticity on aforementioned aspects.

Demand elasticity	# of charging points	Cumulative Volume charged	Type	Tariff	Revenue	Costs
0.2	1	4.161,64	Level 2 Double	0.68	2.904,48	1.611,86
0.403	3	6.852	Level 2 Double	0.68	4.782,17	3596,34
0.6	8	16.462,94	Level 2 Double	0.68	11.482,80	9.190,03
0.8	10	27.325,15	Level 2 Double	0.68	19.070,77	12.974,51
1.0	10	37.990,30	Level 2 Double	0.68	26.513,82	15.320,84

Table 13 Location 1 demand elasticity effect on model solution (Type is for all CP built, unless specified otherwise)

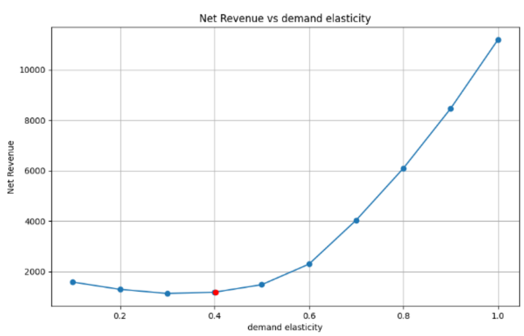

Figure 14 Location 1 demand elasticity

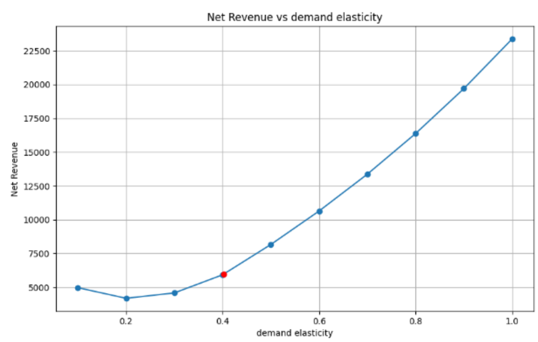

Figure 13 Location 5 demand elasticity

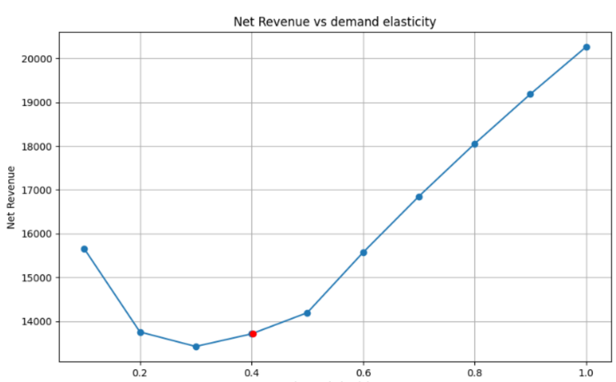

Figure 15 Location 3 demand elasticity

The plots of the different demand elasticity values follow an expected pattern, increasing the revenue when the values are higher. However, for really small values the net revenues are higher again. This may seem odd, but is simply explained through the calculation of the model. As the volume of the first charging point increases when the demand elasticity decreases, it becomes more profitable to build a DC charger. When only a single DC charger, that charges a higher tariff than Level 2 type chargers, is built, the resulting costs are lower and generated revenues higher than for higher values. Higher values have lower charging volumes for the first charging point, and they need multiple charging points in their optimal solution. Consequently, these higher values have higher costs and lower revenues.

DC Utilisation

As described, the utilisation of the DC charger at Company X is lower than the utilisation of the Level 2 type chargers at the same location. This is in contrast to the findings from Stable, where the DC charging utilisation is approximately 2.5 times higher than that of Level 2 type chargers. This utilisation is important in determining if (and how many) a DC charger at a location is desirable. As can be seen in the initial results, with the current utilisation of DC chargers, a DC charger is rarely built as it is only more profitable than a Level 2 type charger from a certain kWh threshold. When adjusting the DC charging utilisation however, different results can be seen. The effect of adjusting the DC charging utilisation on the amount and composition of CPs, the tariffs as well as the net revenue can be seen in Table 16 as well as Figures 16,17 and 18.

DC Utilisation	# of charging points	Type	Tariff	Revenue	Costs
1/6	3	Level 2 Double	0.68	4.782,17	3.596,34
¼	3	Level 2 Double	0.68	4.782,16	3.596,34
½	3	2xDC, 1xLevel 2 Double	0,95 – 0,68	21.774,60	16.278,98
¾	4	DC	0,95	46.744,01	31.709,66
1	6	DC	0,95	78.013,35	49.377,52
2.5	10	DC	0,95	255.549,77	110.935,13

Table 14 DC Utilisation effect on model solution

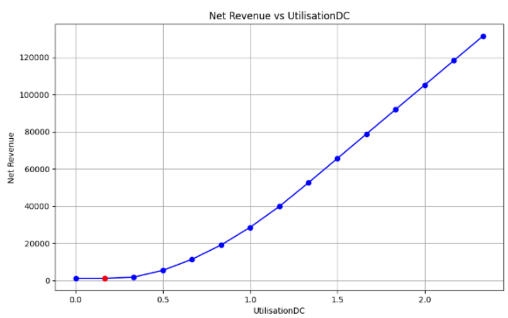

Figure 17 Location 1 DC Utilisation

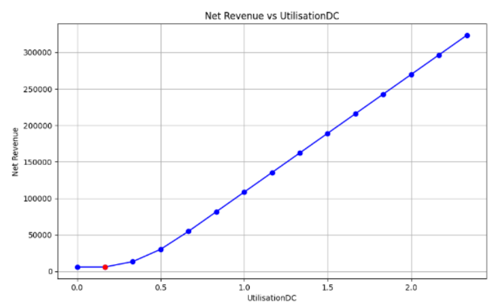

Figure 16 Location 5 DC Utilisation

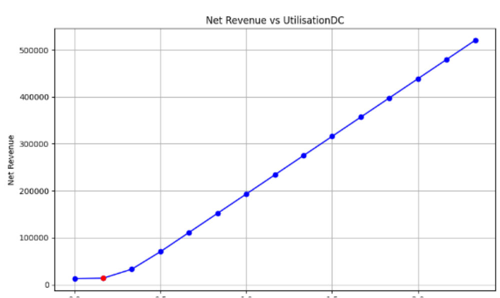

Figure 18 Location 3 DC Utilisation

HBEs

In the current model, the revenues generated through HBEs are incorporated in the revenue calculation per charging point. To check whether PV-installations at locations are desirable, it is interesting for Company X to see the current HBE revenue per location (i.e. for all charging points cumulatively) and compare this to the revenues generated by HBEs considering a PV-installation. In Table 17, for the above mentioned locations the revenues generated by HBEs with (E = 1) and without (E = 0,399) a PV-installation are shown.

Location	Cumulative Volume	Revenue HBE (E = 0,399)	Revenue HBE (E = 1)
Location 1	6.852,03	122,93	308,09
Location 8	1.395,04	25,03	62,73
Location 9	38.749,61	695,19	1.742,34
Location 5	25.629,09	459,80	1.152,38
Location 3	44.835,99	804,39	2.016,01

Table 15 Revenue comparison HBEs

Locations that have higher kWh charging demand are preferable for PV-installations. Moreover, it can be concluded that the costs for an HBE audit (i.e. ~ €2500,-) are recouped fairly easily when multiple locations are analysed.

Profit margin

Currently, the model adds a charging point to a location whenever the charging point is profitable (i.e. revenue is higher than costs). This means that when a charging point makes only a single euro of profit, it is already considered in the model and returned in the optimal solution. Companiescan argue that CPs should only be added when having a profit margin of at least x%. In Table 18 and 19, for Location 1 the difference in optimal solutions is sketched when a minimal profit margin is taken into account in the calculation of the optimal solution. This profit margin is determined by comparing the revenues and costs for each additional CP. In the tables below, the number of CPs and their corresponding revenues and costs are stated, when a CP is only added when its addition has a profit margin of more than x%.

Profit margin	# of charging points	Revenue	Costs
0%	3	4.782,17	3.596,34
10%	3	4.782,17	3.596,34
20%	2	3.754,63	2.696,14
25%	2	3.754,63	2.696,14

Table 16 Location 1 comparison profit margin

Profit margin	# of charging points	Revenue	Costs
0%	9	17.886,96	11.905,08
10%	9	17.886,96	11.905,08
20%	8	16.815,45	10.991,02
25%	7	15.665,28	10.052,16

Table 17 Location 5 comparison profit margin

CPO/EMSP

As previously described, the choice for CPO/EMSP may depend on more than only the costs associated with the CPO/EMSP. Consequently, in the table below the net revenue is shown when using a fixed CPO/EMSP. This is done by adding a constraint to the model that forces the model to use a before defined CPO/EMSP. The difference between the choices varies between locations, as the cost calculations are different for some CPO/EMSPs.

Locatie/CPO_EMSP	CPO/EMSP 2	CPO/EMSP 3	CPO/EMSP 4	CPO/EMSP 1
Location 3	13.009,91	**13.723,57**	13.129,56	12.450,29
Location 1	1.053,07	**1.185,83**	1.059,68	948,89
Location 5	5.627,08	**5.981,88**	5.469,24	5.263,03
Location 8	**264,51**	224,85	165,45	219,04
Location 9	9.503,21	**10.302,69**	9.708,70	8.908,34

Table 18 CPO/EMSP effect on net revenue

From the Table 20, it can be seen that between some CPO/EMSP choices there are marginal differences and some there are major differences. These comparisons can be used to substantiate decisions, or adjust decisions when outside factors (i.e. certain preferences) come into play.

Current scenario vs Model Scenario

Recall chapter 4, where the revenues and costs from the current situation at 7 different locations was determined. The model was used to analyse 5 of these locations and construct an optimal solution. Comparing the current scenario and scenario retrieved from the model provides information about the performance of the current decisions in regards to what is possible. Moreover, it emphasises the importance of changing business practices towards the decisions of the model when major profitability differences are observed. Before we can analyse the comparison in net revenue of the 2 scenarios, we need to determine the fixed costs of the charging points of the location. As described in Section 5.2, the fixed costs were different than initially described in chapter 4. The table below illustrates the total costs in the current scenario for the 5 locations analysed with the model.

Location	Operational costs	Fixed costs	Total costs
Location 3	8.213,24	4.726,46	12.939,70
Location 1	1.684,28	1.393,55	3.077,83
Location 5	3.714,30	1.997,41	5.711,71
Location 8	955,56	1.091,62	2.047,18
Location 9	3.720,73	1.091,62	4.812,35

Table 19 Cost overview current situation

Subtracting the total costs from the previously calculated revenues of the current situation calculates the net profit in the current scenario. Next, the net revenue of the current scenario can be compared to the net revenue of the model scenario. The difference in profitability is shown in the last column.

Location	Net profit Current Scenario	Net profit Current Scenario (including HBE's)	Net profit Model Scenario	Difference in profit
Location 3	-4.694,82	-4.215,24	13.723,57	18.418,39
Location 1	-1.460,72	-1.391,16	1.185,83	2.646,55
Location 5	-1.928,78	-1.725,23	5.981,88	7.910,66
Location 8	-1.091,62	-1.072,51	264,51	1.356,13
Location 9	-833,78	-618,13	10.302,69	11.136,47

Table 20 Net revenue comparison current scenario and model scenario

The differences between the analysis of the current scenario and the net profit of the model scenario are significant. However, they can be explained firstly by the major difference in tariff (i.e. €0,29 and €0,68).

Secondly by the additional revenue creation from HBEs. Finally, the reduced costs from a different CPO/EMSP, as that has a significant influence on the costs.

6.2 Conclusion

Chapter 6 provides the solution analysis of 5 different locations, as well as an implementation and monitoring plan for use of the model. The parameters that have significant importance in determining the solution of the model are:

- Price Elasticity
- Demand elasticity
- DC Utilisation

Furthermore their impact on the net revenue is plotted. Finally, the current scenario and scenario retrieved from the model are compared to determine the gap in profitability.

The price elasticity determines the tariff chosen at the CPs. Currently the optimal tariff for Level 2 type chargers is approximately €0,68, and for DC CPs it is €0,95. As price elasticity is location dependent (on charging demand), these tariffs can vary. Locations with a lower price elasticity can use higher charging tariffs while maintaining same kWh volumes, while higher price elasticity ensures that lower tariffs are needed to be chosen for an optimal solution.

The demand elasticity is of importance in determining the additional volume of subsequent CPs. This value was calculated to be 0,403 (based on 2 locations in Hoogeveen). The value is used to determine the slope of the curve used for estimating cumulative volume of CPs at a location. Increasing the value decreases the slope and vice versa. However, for small values of the demand elasticity (<0.2) the estimated optimal net revenue increases as costs decline more heavily than revenues (due to less CPs that are deemed profitable). It is recommended to redetermine the demand elasticity by comparing a location when new CPs are built (i.e. the added kWh volume of additional CPs at an identical location).

The utilisation of DC chargers determines when they are more profitable than Level 2 type chargers. Currently this is from a kWh threshold of 16.309,61 kWh per year. However, this utilisation is based on historical data from 1 DC charger at Company X, while the utilisation retrieved from literature is significantly higher. Higher DC utilisations can increase net revenues significantly.

HBEs are a minor revenue source for the locations when charging is solely executed from the grid. PV-installations increase revenues from HBEs by ~150%, but as PV-installations are fairly expensive, each location should be evaluated individually to determine the profitability of installing a PV-installation. It can be concluded however, that performing an HBE audit at all locations of Company X (33), is profitable, as the revenues greatly outweigh the costs (~€2500)

From the analysed CPO/EMSPs, CPO/EMSP 3 is the most cost effective choice, however this can still not be the most optimal choice, dependent on Company X's preferences. Each CPO/EMSP should be evaluated individually to determine not only profitability, but also if it fits Company X's demands (i.e. ease of use of platform, expansion and future possibilities, etc.).

Evaluating the current scenario and the model scenario clearly shows the difference between possible and current net revenues. For some locations these are as high as ~€10.000,-. A remark to be made is that the costs in the current situation are expected to be slightly lower than used in the analysis, as CPO/EMSP 1 has a custom tailored cost profile for Company X (instead of the standard profile used in the calculations) and the CPs of Company X are expected to have slightly lower fixed costs than used in the calculations.

7. Conclusions and recommendations

In this thesis, an approach for modeling strategic decisions and their consequent effects within EV-charging was executed. Quantitative and qualitative data gathering provided information about the different parts of the EV-value chain and their behaviour. Quantitative data gathering was used for constructing the model, and showed the performance of the constructed model relative to the initial situation. Several locations were analysed, and the performance of different scenarios for parameters were compared. Section 7.1 answers the main research question and Section 7.2 discusses the limitations of the research. Section 7.3 provides recommendations to Company X, while Section 7.4 discusses the scientific contributions of this research. Finally, Section 7.5 explains what future research there is to be done.

7.1 Main research question

At the start of this research, Company X mentioned that a generalised model on their strategic decisions regarding EV-charging points was desired. As such, the goal of this research aims to find an answer to the main research question:

"How can a general model be defined for optimising strategic charging point decisions for maximising revenues?"

The research exposed the complex environment of EV-charging and the many different influential aspects for companies interested in housing charging points at their company locations. Due to the scope and limitations of this research, the research has been limited to an analysis of the performance of the current charging point network and comparing this to a best-case scenario, provided by a model based on historical data. The research leaves out certain preferences (by for example general management) for decisions, as those decisions need to be discussed individually and are not easily quantifiable within a model. The model provides a solely numerical analysis and recommendation, but analysing the performance of the model under certain 'set' decisions makes comparing important individual decisions straightforward. This research does not provide a single perfect solution that can be implemented for all locations, but gives an indication of how a model can be used effectively to analyse and evaluate decisions and provide future recommendations.

The research provided insight into the current performance of the charging point network, and showed that there are certain decisions that have a big impact on the revenue maximisation of the charging point network. These are the following:

Tariff:

- Currently the tariff is €0,29, while it generally ranges from €0,30 to €0,80. The tariff used in most 'expected revenue' calculations is €0,50. The optimisation model calculated an optimal tariff of €0,68 An increase in tariff from €0,29 to €0,68 would increase revenues by ~134%.

Number of CPs:

- Charging point utilisation is currently relatively low (also in terms of utilisation of Company X's CP compared to average utilisation). As such, the focus should first be increasing utilisation of CPs, before constructing additional CPs. CPs however, are already profitable with a low utilisation, and based on the analysed locations, (most of) the locations can increase their number of CPs to increase revenue.

CPO/EMSP:

- From the current model it can be concluded that CPO/EMSP 3 is the cheapest for managing the Charging Points and providing the CMS. As there are many more CPO/EMSPs in existence this conclusion is mainly to get a general indication of the costs, and to show that the current situation (i.e. CPO/EMSP 1) is, in terms of costs minimisation, not optimal.

Type of CP:

- Overall, Level 2 type chargers with double sockets are used most, as these are futureproof and they have the best revenue/cost ratio for the locations of Company X. DC Chargers can prove to be more profitable than Level 2 type chargers, but only from a certain kWh threshold (dependent on the cost and power of the DC charger)

Concluding, this research showed that a significant increase in revenue is possible, as well as cost reduction by considering different CPO/EMSPs. However, a generalized solution for all locations is not feasible. As many decisions and parameters depend on locational charging demand and behaviour, as well as other locational factors, a generalized model is difficult to define. Further research on the charging characteristics of specific locations is necessary.

7.2 Limitations

The research and its results are mostly based on historical data and literature research. The correctness of the historical data from the CPs can be questioned, as the effects of faulty charging points on the obtained data are not clear, and the described model uses this (possibly partly incorrect) data to provide a solution.

There is limited data available regarding DC charging points at Company X (only 1 DC charger in the portal). Consequently, the utilisation and kWh/hour ratio used can prove to be inaccurate.

Due to the scope of the research, not every aspect that is of importance in answering the problem statement could be taken into account. Currently the focus has been on providing a general analysis and comparison of the current CP network and the scenario from the model. This comparison neglects certain qualitative aspects of decision making that influence the answer to the problem statement.

The research was conducted at Company X, and several locations of Company X have been taken into account. The contact however, was mostly with a representative from Company X and from CPO/EMSP 1, whereas research other stakeholders (car dealerships / EV charging companies) could also be included in the research to prevent bias and increase sample size for historical data (i.e. improve the model).

For implementing the model on different datasets, there are a number of parameters that can or need to be adjusted accordingly. Apart from the previously stated demand elasticity, price elasticity (PE) and DC utilisation, also the number of sockets is important. The number of sockets corresponds to the number of charging sockets in the data set. For example, 2 charging points with 2 sockets and 1 charging point with a single socket corresponds to 5 sockets (i.e. 5 different charging 'opportunities' for customers). The number of sockets, the dataset and the demand elasticity determine the charging demand for when a single charging 'opportunity' is present.

Next to the number of sockets, the number of charging points the model runs can also be adjusted. The initial number of charging points ranges from x to 10, as for most locations, Company X does not have the parking capacity to install more charging points. Consequently, this value should be adjusted to the maximum amount of charging points that can possibly (or is desired) be built.

As for locations that have a PV-installation, and use the produced electricity directly in their charging points, the electricity margin can be adjusted. Currently this value is 0,399, as that is the amount of green electricity when charging from the grid. This value could increase when a margin of the electricity used in charging points is retrieved from the PV-installation and as such increase the revenues from HBEs.

The price per HBE is currently estimated at €12,50, but this fluctuates mostly between €10,- and €15,-. This price could fluctuate even more in the future, as is why the most recent and accurate price for HBEs should be retrieved from one of the brokers to run the model as accurately as possible. The parameter 'PHBE' can be adjusted as such.

In the model, the costs regarding CPO/EMSP, as well as the costs associated with certain types of charging points can be adjusted as more or different CPO/EMSP and charging point types are considered. As the EV-market keeps growing, new technological innovations as well as an expanding market share (in the Vehicle Industry) will keep reducing the price for charge points. The annual levelised costs for the charge points can be adjusted in the model as well.

7.3 Recommendations

The recommendations are discussed in two parts, recommendations for the implementation of the model and recommendations based on the results of the model as well as general recommendations.

The model should be re-evaluated for each location Company X wants to implement the model. Historical data should be analysed further and knowledge about location specific behaviour of parameters should be used to adjust parameters accordingly. Keeping track of the historical data when adjusting decisions or changing CP infrastructure is also recommended to redetermine parameters and improve reliability.

Preferences regarding qualitative factors of a CPO/EMSP should be discusses first and a preselection should be made of eligible CPO/EMSPs. After receiving quotations from the eligible parties, the costs can be implemented in the model to obtain an optimal decision.

Implementing the model is recommended for locations where Company X has capacity for constructing additional CPs, as well as locations where cumulative kWh volume is high, as those locations have the most potential increase in profitability.

The tariff is one of the main revenue increasing factors, and it is recommended that the tariff is increased to €0,68 for all locations. The model can be used to determine optimal tariffs for specific locations, based on different price elasticities, which should be determined for each location specifically.

Including HBEs into the revenue streams of CPs is recommended, as the current kWh volume is already sufficient to attain profits. The costs for an HBE audit are easily outweighed when all locations are included. Another recommendation regarding HBEs is to investigate the kWh volumes of the CPs that are currently not in the portal. The costs related to measuring the kWh volumes of these CPs could be overshadowed by the revenue creation from the HBEs, especially when either the electricity margin from the grid (E=0,399) increases in the future, or when CPs use electricity from PV-installations.

Improving data registration on utilisation and volume charged at CPs. As data indicated, charge points are often used effectively only for a small portion of the time an EV is connected. Insights in how long EVs are connected without charging can assist decisions around type of tariffs for charge points (i.e. if a 'blocking' or 'time-based' tariff is more profitable than a kWh-based tariff).

7.4 Scientific contributions

Because of the specific nature of the problem, the scientific contributions are relatively limited. However, in current literature there is yet to be a generalisel model that encompasses these decisions. Most of the literature is heavily specific on one strategic decision or other variable, while this research focuses on considering multiple variables that describe a general model that can be adjusted for each company location and variable choices. This generalised model can be improved upon to make it more reliable and generalisable and increase its scientific contribution by implementing more and different data sets, as well as analysing the results when implementing certain decisions and adjusting the model accordingly.

7.5 Practical contribution

The practical contribution to the company is in the form of an advice for their optimal business practices. Firstly, it is clear that significant changes to their charging point practices are required, as the expectation is that the CPs achieve negative (or zero) net revenues. Next to the advice to the company (discussed in section 7.3) the practical contribution is in the form of the generalised model. Together with the generalised model and the discussion of how certain parameters and variables behave and can be adjusted according to different locations, the company can use this model to calculate optimal business practices for each of their locations, and evaluate their business practices (currently and in the future).

7.6 Future research

The EV-charging market is researched thoroughly but generalisations are difficult to make. It became clear during this research that multiple aspects of EV-charging are dependent on various factors, are location dependent and can vary widely. For this research, estimations or calculations were used to retrieve a generalised model, but for future research it is recommended that more accurate and complete data and calculations are used in the model, and be used to validate the results from the model. Research into customer and employee charging behaviour, as well as neighbouring charging opportunities are all eligible subjects for future research.

Next to this, future research can be done regarding the grid capacity of locations. As CPs have a major impact on the grid capacity of a location, and issues regarding grid capacity are present throughout the Netherlands, the exact impact of charging points (dependent on power and number of CPs) can be researched to establish how many CPs are available at a location.

Consequently, research can be done on optimising current CP utilisation. Both for the companies grid capacity utilisation as well as improving revenues on current charging points. This is mainly qualitative research on charging behaviour, but nonetheless important in determining and defining a step by step process to maximising profitability of CPs.

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9. Appendices

Appendix A

CDR	Start_datetime	End_datetime	Duration	Volume	Charge_Po	Charge_	Charge_Poin	Charg	Cha	Pr	Tarif	Authen	Cor	Me	OE	Charge_Poin	Ser	Infra_Provid	Calcula	Evse	Con	Cus	Cus	Reimb	Reimbur	Re	Crea	Cust	Dri	Meter_Sta	Cpo_Cor	Emsp_Co	Whole	Wh	Re	Pub	Int	Co	Cpo	Ems	Cu	Token_Visual_Nur
4AD	2023-08-01T13:03:56	2023-08-01T15:26:36	02:22:40	9,363	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	2AB0817E				EVB-P21081524		GreenFlux	3,22	NL-(	2			2,72	R05000		2023-08-01T			2788398	NL-GFX	NL-TNM	3,9	21					EUR			NL38K1PNY3
419	2023-11-09T15:41:52	2023-11-10T08:01:26	16:19:34	3,456	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	AA607D7E				EVB-P21081524		GreenFlux	1,5	NL-(	2			1	R05000		2023-11-10T			3573335	NL-GFX	NL-TNM	1,82	21					EUR			NLGQJMJWK3
1C9	2023-09-23T09:06:15	2023-09-25T07:37:37	46:31:22	55,682	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	AA607D7E				EVB-P21081524		GreenFlux	16,65	NL-(	2			16,15	R05000		2023-09-25T			3203999	NL-GFX	NL-TNM	20,2	21					EUR			NLGQJMJWK3
EEF	2023-03-04T12:43:25	2023-03-07T13:37:55	72:54:30	9,456	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	5E+07				EVB-P20211550		GreenFlux	3,24	NL-(	1			2,74	R05000		2023-03-07T			2703922	NL-GFX	NL-TNM	3,92	21					EUR	EUR		NL4ZP3K96
5E5	2023-09-27T08:36:32	2023-09-27T11:27:50	02:51:18	13,784	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	14D6B9CA				EVB-P21081524		GreenFlux	4,5	NL-(	1			4	R05000		2023-09-27T			3786934	NL-GFX	NL-TNM	5,45	21					EUR			NL1R9KWGW2
B9E	2023-12-01T16:14:54	2023-12-02T08:39:40	16:24:46	8,389	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	AA607D7E				EVB-P20211550		GreenFlux	2,93	NL-(	2			2,43	R05000		2023-12-02T			3362742	NL-GFX	NL-TNM	3,55	21					EUR			NLGQJMJWK3
D51	2023-12-05T17:21:13	2023-12-06T09:08:20	15:47:07	9,091	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	AA607D7E				EVB-P21081524		GreenFlux	3,14	NL-(	1			2,64	R05000		2023-12-06T			4126647	NL-GFX	NL-TNM	3,8	21					EUR			NLGQJMJWK3
11C	2023-09-22T15:35:43	2023-09-22T17:03:52	01:28:09	11,765	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	14D6B9CA				EVB-P21081524		GreenFlux	3,91	NL-(	2			3,41	R05000		2023-09-22T			3192234	NL-GFX	NL-TNM	4,73	21					EUR			NL1R9KWGW2
EE1	2023-03-24T12:27:10	2023-03-24T13:50:27	01:23:17	9,756	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	04FB474A7E6B84				EVB-P21081524		GreenFlux	3,33	NL-(	1			2,83	R05000		2023-03-24T			2957351	NL-GFX	NL-TCE	4,03	21					EUR	EUR		NL-TCE-925169-5
875	2023-02-16T12:24:21	2023-02-17T09:12:19	20:47:58	56,453	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	B4784746				EVB-P21081524		GreenFlux	16,87	NL-(	2			16,37	R05000		2023-02-17T			2067139	NL-GFX	NL-TNM	20,4	21					EUR	EUR		NL4YJ26J2
74D	2023-05-26T12:02:09	2023-05-26T14:37:17	02:35:08	6,815	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	2AB0817E				EVB-P21081524		GreenFlux	2,48	NL-(	2			1,98	R05000		2023-05-26T			2294056	NL-GFX	NL-TNM	3	21					EUR	EUR		NL38K1PNY3
538	2023-12-20T16:57:07	2023-12-21T08:35:55	15:38:48	12,957	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	AA607D7E				EVB-P21081524		GreenFlux	4,26	NL-(	2			3,76	R05000		2023-12-21T			3848512	NL-GFX	NL-TNM	5,15	21					EUR			NLGQJMJWK3
84A	2023-11-30T15:45:33	2023-11-30T17:04:30	01:18:57	13,407	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	14D6B9CA				EVB-P20211550		GreenFlux	4,39	NL-(	2			3,89	R05000		2023-11-30T			3349335	NL-GFX	NL-TNM	5,31	21					EUR			NL1R9KWGW2
64F	2023-06-30T17:03:52	2023-07-04T12:38:43	91:34:51	1,521	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	5E+07				EVB-P20211550		GreenFlux	0,94	NL-(	2			0,44	R05000		2023-07-04T			2936337	NL-GFX	NL-TNM	1,14	21					EUR			NL4ZP3K96
A3B	2023-10-04T13:35:33	2023-10-04T13:42:55	00:07:22	1,108	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	14D6B9CA				EVB-P20211550		GreenFlux	0,82	NL-(	1			0,32	R05000		2023-10-04T			3283026	NL-GFX	NL-TNM	0,99	21					EUR			NL1R9KWGW2
028	2023-06-20T10:51:51	2023-06-20T14:03:26	03:11:35	5,744	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	5E+07				EVB-P20211550		GreenFlux	2,17	NL-(	1			1,67	R05000		2023-06-20T			2926978	NL-GFX	NL-TNM	2,63	21					EUR			NL4ZP3K96
820	2023-09-28T17:28:14	2023-09-30T09:34:50	40:06:36	1,312	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	AA607D7E				EVB-P21081524		GreenFlux	0,88	NL-(	1			0,38	R05000		2023-09-30T			3800718	NL-GFX	NL-TNM	1,06	21					EUR			NLGQJMJWK3
637	2023-11-18T09:42:26	2023-11-20T08:04:38	46:22:12	0,045	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	AA607D7E				EVB-P20211550		GreenFlux	0,51	NL-(	1			0,01	R05000		2023-11-20T			3560104	NL-GFX	NL-TNM	0,62	21					EUR			NLGQJMJWK3
EE9	2023-08-14T08:04:46	2023-08-16T08:03:25	47:58:39	5,08	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	AA607D7E				EVB-P20211550		GreenFlux	1,97	NL-(	1			1,47	R05000		2023-08-16T			3144620	NL-GFX	NL-TNM	2,38	21					EUR			NLGQJMJWK3
5C5	2023-08-03T17:14:41	2023-08-04T18:18:44	25:04:03	12,546	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	2AB0817E				EVB-P21081524		GreenFlux	4,14	NL-(	1			3,64	R05000		2023-08-04T			3377938	NL-GFX	NL-TNM	5,01	21					EUR			NL38K1PNY3
FAB	2023-02-03T15:20:34	2023-02-03T16:02:24	00:41:50	7,478	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	343C4F46				EVB-P21081524		GreenFlux	2,67	NL-(	1			2,17	R05000		2023-02-03T			2912046	NL-GFX	NL-TNM	3,23	21					EUR	EUR		NLEQKWJ78
3B4	2023-01-16T07:45:15	2023-01-16T11:29:33	03:44:18	12,116	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	E4EFF0C2				EVB-P21081524		GreenFlux	4,01	NL-(	1			3,51	R05000		2023-01-16T			2815023	NL-GFX	NL-TNM	4,85	21					EUR	EUR		NLMKJ92YZ0
FC1	2023-01-25T17:04:39	2023-01-26T10:01:40	16:57:01	16,264	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	5E+07				EVB-P20211550		GreenFlux	5,22	NL-(	2			4,72	R05000		2023-01-26T			2613427	NL-GFX	NL-TNM	6,32	21					EUR	EUR		NL4ZP3K96
DFE	2023-01-27T18:49:02	2023-01-27T20:34:21	01:45:19	12,559	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	94E536CE				EVB-P20211550		GreenFlux	4,14	NL-(	2			3,64	R05000		2023-01-27T			2629691	NL-GFX	NL-TNM	5,01	21					EUR	EUR		NL22K9XZ5
71A	2023-02-03T07:47:29	2023-02-03T11:25:39	03:38:10	2,521	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	5E+07				EVB-P20211550		GreenFlux	1,23	NL-(	1			0,73	R05000		2023-02-03T			2701399	NL-GFX	NL-TNM	1,49	21					EUR	EUR		NL4ZP3K96
47E	2023-02-03T16:22:06	2023-02-03T16:24:04	00:01:58	0,2	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	343C4F46				EVB-P21081524		GreenFlux	0	NL-(	1			0	R05000		2023-02-03T			2919524	NL-GFX	NL-TNM	0	21					EUR	EUR		NLEQKWJ78
5D9	2023-02-10T17:04:23	2023-02-10T17:04:29	00:00:06	0	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	5E+07				EVB-P20211550		GreenFlux	0	NL-(	2			0	R05000		2023-02-10T			2650653	NL-GFX	NL-TNM	0	21					EUR	EUR		NL4ZP3K96
AD3	2023-02-13T09:08:58	2023-02-13T16:59:19	07:50:21	81,018	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	343C4F46				EVB-P20211550		GreenFlux	24	NL-(	2			23,5	R05000		2023-02-13T			2659275	NL-GFX	NL-TNM	29	21					EUR	EUR		NLEQKWJ78
4DA	2023-02-17T13:27:51	2023-02-17T13:29:53	00:02:02	0,212	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	0420D48A707380				EVB-P21081524		GreenFlux	0,56	NL-(	1			0,06	R05000		2023-02-17T			2945383	NL-GFX	NL-DCS	0,68	21					EUR	EUR		NL-M-4005286-3
029	2023-03-24T11:45:36	2023-03-24T13:58:26	02:12:50	7,851	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	D4CE38CE				EVB-P20211550		GreenFlux	2,78	NL-(	2			2,28	R05000		2023-03-24T			2804684	NL-GFX	NL-TNM	3,36	21					EUR	EUR		NL8WG8G77
964	2023-04-04T16:28:06	2023-04-05T17:36:37	25:08:31	11,244	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	5E+07				EVB-P21081524		GreenFlux	3,76	NL-(	2			3,26	R05000		2023-04-05T			2188376	NL-GFX	NL-TNM	4,55	21					EUR	EUR		NL4ZP3K96
B7F	2023-05-11T10:01:56	2023-05-11T13:44:08	03:42:12	15,349	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	B4784746				EVB-P21081524		GreenFlux	4,95	NL-(	1			4,45	R05000		2023-05-11T			2990610	NL-GFX	NL-TNM	5,99	21					EUR	EUR		NL4YJ26J2
1FC	2023-05-20T12:01:44	2023-05-20T17:07:13	05:05:29	11,365	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	2AB0817E				EVB-P21081524		GreenFlux	3,8	NL-(	1			3,3	R05000		2023-05-20T			3042212	NL-GFX	NL-TNM	4,6	21					EUR	EUR		NL38K1PNY3
D3D	2023-06-06T13:19:08	2023-06-07T12:26:43	23:07:35	17,426	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	2AB0817E				EVB-P21081524		GreenFlux	5,55	NL-(	2			5,05	R05000		2023-06-07T			2332245	NL-GFX	NL-TNM	6,72	21					EUR	EUR		NL38K1PNY3
180	2023-06-07T14:57:59	2023-06-08T13:24:44	22:26:45	18,081	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	5E+07				EVB-P20211550		GreenFlux	5,74	NL-(	1			5,24	R05000		2023-06-08T			2888230	NL-GFX	NL-TNM	6,95	21					EUR	EUR		NL4ZP3K96
49F	2023-06-10T11:41:52	2023-06-10T15:54:05	04:12:13	10,328	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	2AB0817E				EVB-P21081524		GreenFlux	3,5	NL-(	2			3	R05000		2023-06-10T			2352665	NL-GFX	NL-TNM	4,24	21					EUR	EUR		NL38K1PNY3
827	2023-06-16T08:31:50	2023-06-16T17:29:45	08:57:55	18,881	Buitenvaa	7905 TA	Hoogeveen	NLD			A3	2AB0817E				EVB-P21081524		GreenFlux	5,98	NL-(	2			5,48	R05000		2023-06-16T			2380797	NL-GFX	NL-TNM	7,24	21					EUR			NL38K1PNY3

Table 21 Output data sheet CMS Portal

CDR_ID	Start_datetime	End_datetime	Durati	Volu	Charge_Point_	Charge	Charge_Po	Cha	Ta	Authentical	Charge_Point_	Infra_Pro	Calc	Evse_ID	C	Rei	Reimbur	Created	Meter_	Cpo_Co	Emsp_	Whol	Wh	Cpo	Token_Visual_Number
4ADC4115	2023-08-01T13:03:56	2023-08-01T15:26:36	02:22:40	9,363	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	2AB0817E	EVB-P21081524	GreenFlux	3,22	NL-GFX-EE	2	2,72	R05000	2023-08-01	2788398	NL-GFX	NL-TNM	3,9	21	EUR	NL38K1PNY3
41916EE23	2023-11-09T15:41:52	2023-11-10T08:01:26	16:19:34	3,456	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	AA607D7E	EVB-P21081524	GreenFlux	1,5	NL-GFX-EE	2	1	R05000	2023-11-10	3573335	NL-GFX	NL-TNM	1,82	21	EUR	NLGQJMJWK3
1C9BE5D8	2023-09-23T09:06:15	2023-09-25T07:37:37	46:31:22	55,682	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	AA607D7E	EVB-P21081524	GreenFlux	16,65	NL-GFX-EE	2	16,15	R05000	2023-09-25	3203999	NL-GFX	NL-TNM	20,15	21	EUR	NLGQJMJWK3
EEFD15D0	2023-03-04T12:43:25	2023-03-07T13:37:55	72:54:30	9,456	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	54084646	EVB-P20211550	GreenFlux	3,24	NL-GFX-EE	1	2,74	R05000	2023-03-07	2703922	NL-GFX	NL-TNM	3,92	21	EUR	NL4ZP3K96
5E5C17017	2023-09-27T08:36:32	2023-09-27T11:27:50	02:51:18	13,784	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	14D6B9CA	EVB-P21081524	GreenFlux	4,5	NL-GFX-EE	1	4	R05000	2023-09-27	3786934	NL-GFX	NL-TNM	5,45	21	EUR	NL1R9KWGW2
B9E7BF0EF	2023-12-01T16:14:54	2023-12-02T08:39:40	16:24:46	8,389	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	AA607D7E	EVB-P20211550	GreenFlux	2,93	NL-GFX-EE	2	2,43	R05000	2023-12-02	3362742	NL-GFX	NL-TNM	3,55	21	EUR	NLGQJMJWK3
D517B726	2023-12-05T17:21:13	2023-12-06T09:08:20	15:47:07	9,091	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	AA607D7E	EVB-P21081524	GreenFlux	3,14	NL-GFX-EE	1	2,64	R05000	2023-12-06	4126647	NL-GFX	NL-TNM	3,8	21	EUR	NLGQJMJWK3
11C15FE9F	2023-09-22T15:35:43	2023-09-22T17:03:52	01:28:09	11,765	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	14D6B9CA	EVB-P21081524	GreenFlux	3,91	NL-GFX-EE	2	3,41	R05000	2023-09-22	3192234	NL-GFX	NL-TNM	4,73	21	EUR	NL1R9KWGW2
EE159EA76	2023-03-24T12:27:10	2023-03-24T13:50:27	01:23:17	9,756	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	04FB474A7E6B	EVB-P21081524	GreenFlux	3,33	NL-GFX-EE	1	2,83	R05000	2023-03-24	2957351	NL-GFX	NL-TCE	4,03	21	EUR	NL-TCE-925169-5
8756490F2	2023-02-16T12:24:21	2023-02-17T09:12:19	20:47:58	56,453	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	B4784746	EVB-P21081524	GreenFlux	16,87	NL-GFX-EE	2	16,37	R05000	2023-02-17	2067139	NL-GFX	NL-TNM	20,41	21	EUR	NL4YJ26J2
74D8C6DF	2023-05-26T12:02:09	2023-05-26T14:37:17	02:35:08	6,815	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	2AB0817E	EVB-P21081524	GreenFlux	2,48	NL-GFX-EE	2	1,98	R05000	2023-05-26	2294056	NL-GFX	NL-TNM	3	21	EUR	NL38K1PNY3
53846F1C7	2023-12-20T16:57:07	2023-12-21T08:35:55	15:38:48	12,957	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	AA607D7E	EVB-P21081524	GreenFlux	4,26	NL-GFX-EE	2	3,76	R05000	2023-12-21	3848512	NL-GFX	NL-TNM	5,15	21	EUR	NLGQJMJWK3
84AE82DB	2023-11-30T15:45:33	2023-11-30T17:04:30	01:18:57	13,407	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	14D6B9CA	EVB-P20211550	GreenFlux	4,39	NL-GFX-EE	2	3,89	R05000	2023-11-30	3349335	NL-GFX	NL-TNM	5,31	21	EUR	NL1R9KWGW2
64FBFB1A	2023-06-30T17:03:52	2023-07-04T12:38:43	91:34:51	1,521	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	54084646	EVB-P20211550	GreenFlux	0,94	NL-GFX-EE	2	0,44	R05000	2023-07-04	2936337	NL-GFX	NL-TNM	1,14	21	EUR	NL4ZP3K96
A3B4BB24	2023-10-04T13:35:33	2023-10-04T13:42:55	00:07:22	1,108	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	14D6B9CA	EVB-P20211550	GreenFlux	0,82	NL-GFX-EE	1	0,32	R05000	2023-10-04	3283026	NL-GFX	NL-TNM	0,99	21	EUR	NL1R9KWGW2
028F1F1DE	2023-06-20T10:51:51	2023-06-20T14:03:26	03:11:35	5,744	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	54084646	EVB-P20211550	GreenFlux	2,17	NL-GFX-EE	1	1,67	R05000	2023-06-20	2926978	NL-GFX	NL-TNM	2,63	21	EUR	NL4ZP3K96
8209B3E62	2023-09-28T17:28:14	2023-09-30T09:34:50	40:06:36	1,312	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	AA607D7E	EVB-P21081524	GreenFlux	0,88	NL-GFX-EE	1	0,38	R05000	2023-09-30	3800718	NL-GFX	NL-TNM	1,06	21	EUR	NLGQJMJWK3
6373AD4C	2023-11-18T09:42:26	2023-11-20T08:04:38	46:22:12	0,045	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	AA607D7E	EVB-P20211550	GreenFlux	0,51	NL-GFX-EE	1	0,01	R05000	2023-11-20	3560104	NL-GFX	NL-TNM	0,62	21	EUR	NLGQJMJWK3
EE912760D	2023-08-14T08:04:46	2023-08-16T08:03:25	47:58:39	5,08	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	AA607D7E	EVB-P20211550	GreenFlux	1,97	NL-GFX-EE	1	1,47	R05000	2023-08-16	3144620	NL-GFX	NL-TNM	2,38	21	EUR	NLGQJMJWK3
5C55CA47	2023-08-03T17:14:41	2023-08-04T18:18:44	25:04:03	12,546	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	2AB0817E	EVB-P21081524	GreenFlux	4,14	NL-GFX-EE	1	3,64	R05000	2023-08-04	3377938	NL-GFX	NL-TNM	5,01	21	EUR	NL38K1PNY3
FAB54FB0	2023-02-03T15:20:34	2023-02-03T16:02:24	00:41:50	7,478	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	343C4F46	EVB-P21081524	GreenFlux	2,67	NL-GFX-EE	1	2,17	R05000	2023-02-03	2912046	NL-GFX	NL-TNM	3,23	21	EUR	NLEQKWJ78
3B46A3EA	2023-01-16T07:45:15	2023-01-16T11:29:33	03:44:18	12,116	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	E4EFF0C2	EVB-P21081524	GreenFlux	4,01	NL-GFX-EE	1	3,51	R05000	2023-01-16	2815023	NL-GFX	NL-TNM	4,85	21	EUR	NLMKJ92YZ0
FC1374080	2023-01-25T17:04:39	2023-01-26T10:01:40	16:57:01	16,264	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	54084646	EVB-P20211550	GreenFlux	5,22	NL-GFX-EE	2	4,72	R05000	2023-01-26	2613427	NL-GFX	NL-TNM	6,32	21	EUR	NL4ZP3K96
DFE37CFB	2023-01-27T18:49:02	2023-01-27T20:34:21	01:45:19	12,559	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	94E536CE	EVB-P20211550	GreenFlux	4,14	NL-GFX-EE	2	3,64	R05000	2023-01-27	2629691	NL-GFX	NL-TNM	5,01	21	EUR	NL22K9XZ5
71A97677E	2023-02-03T07:47:29	2023-02-03T11:25:39	03:38:10	2,521	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	54084646	EVB-P20211550	GreenFlux	1,23	NL-GFX-EE	1	0,73	R05000	2023-02-03	2701399	NL-GFX	NL-TNM	1,49	21	EUR	NL4ZP3K96
47E1B01F4	2023-02-03T16:22:06	2023-02-03T16:24:04	00:01:58	0,2	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	343C4F46	EVB-P21081524	GreenFlux	0	NL-GFX-EE	1	0	R05000	2023-02-03	2919524	NL-GFX	NL-TNM	0	21	EUR	NLEQKWJ78
5D985753	2023-02-10T17:04:23	2023-02-10T17:04:29	00:00:06	0	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	54084646	EVB-P20211550	GreenFlux	0	NL-GFX-EE	2	0	R05000	2023-02-10	2650653	NL-GFX	NL-TNM	0	21	EUR	NL4ZP3K96
AD3D645C	2023-02-13T09:08:58	2023-02-13T16:59:19	07:50:21	81,018	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	343C4F46	EVB-P20211550	GreenFlux	24	NL-GFX-EE	2	23,5	R05000	2023-02-13	2659275	NL-GFX	NL-TNM	29,04	21	EUR	NLEQKWJ78
4DA46CE4	2023-02-17T13:27:51	2023-02-17T13:29:53	00:02:02	0,212	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	0420D48A7073	EVB-P21081524	GreenFlux	0,56	NL-GFX-EE	1	0,06	R05000	2023-02-17	2945383	NL-GFX	NL-DCS	0,68	21	EUR	NL-M-4005286-3
029EC2BD	2023-03-24T11:45:36	2023-03-24T13:58:26	02:12:50	7,851	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	D4CE38CE	EVB-P20211550	GreenFlux	2,78	NL-GFX-EE	2	2,28	R05000	2023-03-24	2804684	NL-GFX	NL-TNM	3,36	21	EUR	NL8WG8G77
96414381A	2023-04-04T16:28:06	2023-04-05T17:36:37	25:08:31	11,244	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	54084646	EVB-P21081524	GreenFlux	3,76	NL-GFX-EE	2	3,26	R05000	2023-04-05	2188376	NL-GFX	NL-TNM	4,55	21	EUR	NL4ZP3K96
B7F854898	2023-05-11T10:01:56	2023-05-11T13:44:08	03:42:12	15,349	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	B4784746	EVB-P21081524	GreenFlux	4,95	NL-GFX-EE	1	4,45	R05000	2023-05-11	2990610	NL-GFX	NL-TNM	5,99	21	EUR	NL4YJ26J2
1FC8BF47	2023-05-20T12:01:44	2023-05-20T17:07:13	05:05:29	11,365	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	2AB0817E	EVB-P21081524	GreenFlux	3,8	NL-GFX-EE	1	3,3	R05000	2023-05-20	3042212	NL-GFX	NL-TNM	4,6	21	EUR	NL38K1PNY3
D3D49823	2023-06-06T13:19:08	2023-06-07T12:26:43	23:07:35	17,426	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	2AB0817E	EVB-P21081524	GreenFlux	5,55	NL-GFX-EE	2	5,05	R05000	2023-06-07	2332245	NL-GFX	NL-TNM	6,72	21	EUR	NL38K1PNY3
180DD85B	2023-06-07T14:57:59	2023-06-08T13:24:44	22:26:45	18,081	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	54084646	EVB-P20211550	GreenFlux	5,74	NL-GFX-EE	1	5,24	R05000	2023-06-08	2888230	NL-GFX	NL-TNM	6,95	21	EUR	NL4ZP3K96
49F0DE954	2023-06-10T11:41:52	2023-06-10T15:54:05	04:12:13	10,328	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	2AB0817E	EVB-P21081524	GreenFlux	3,5	NL-GFX-EE	2	3	R05000	2023-06-10	2352665	NL-GFX	NL-TNM	4,24	21	EUR	NL38K1PNY3
82702CCD	2023-06-16T08:31:50	2023-06-16T17:29:45	08:57:55	18,881	Buitenvaart 3003	7905 TA	Hoogeveen	NLD	A3	2AB0817E	EVB-P21081524	GreenFlux	5,98	NL-GFX-EE	2	5,48	R05000	2023-06-16	2380797	NL-GFX	NL-TNM	7,24	21	EUR	NL38K1PNY3

Table 24 Partly cleansed data sheet CMS Portal

Column A CDR_ID	The ID related to the charge session
Column B Start_datetime	The date and time the car plugged into the charging point
Column C End_datetime	The date and time that the car unplugged from the charging point
Column D Duration	Duration of the charging session in hours, minutes and seconds
Column E Volume	The volume charged during the charge session (either in kWh or kW, dependent on the chosen export type)
Column F Charge_Point_Address	The street address and number where the charge point is situated
Column G Charge_Point_ZIP	The ZIP address where the charge point is situated
Column H Charge_Point_City	The city in which the charge point is situated
Column I Charge_Point_Country	The country in which the charge point is situated
Column J Tariff_Type	The tariff chosen for the related charge session
Column K Authentication_ID	The authentication ID related to the charge pass
Column L Charge_Point_ID	The ID of the charge point
Column M Infra_Provider_ID	The ID of the provider of the Infrastructure
Column N Calculated_Cost	Costs per kWh and additional setup costs
Column O Evse_ID	The ID of the specific EVSE
Column P Connector_ID	The ID of the connector, being either 1 or 2
Column Q Reimbursement_Cost	Costs per kWh
Column R Reimbursement_Tariff_Type	The reimbursement tariff chosen for related charge session
Column S Created	The date and time when the historical data of the charging session was created and stored in the portal
Column U Cpo_Contract_CountryParty	The country and party corresponding to the CPO contract of the charging session
Column V Emsp_Contract_CountryParty	The country and party corresponding to the EMSP contract of the charging session
Column W Wholesale_Cost_With_Vat	Calculated costs + Vat
Column X Wholesale_Vat_Rate	The VAT rate, always being 21%
Column Y Cpo_Currency	The curreny with which the CPO operates, always being EUR

Table 225 Column description output data sheet CMS Portal

Appendix B

```python
# set the possible number of charging point
N = 10
# set number of sockets in dataset
S = 17
# set margin green energy in energy contract
E = 0.399
# set number of charging points used for costs HBE audit calculation
C = 82
# set price per HBE
PHBE = 12.5
# Compound Annual Growth Rate EV Market Europe
CAGR = 1.234
# Price elasticity EV-charging demand
PE = 0.76
# Utilization rate DC chargers
UtilizationDC = (1/6)
# Speed of DC charger influence on ratio kWh/hour charged
PowerDC = 7.5
# power determining decreasing slope of power curve for multiple sockets
b_volume = 0.403
# initial volume and number of sessions of a single socket (based on historical data)
a_volume = total_volume / S**b_volume
a_sessions = total_rows / S**b_volume
```

Figure 19 Predefined Python Parameters

```python
# Define different base volumes for each type
base_volumes = {
    "Level2Single": a_volume * CAGR,
    "Level2Double": a_volume * (2 ** b_volume) * CAGR,
    "DC": a_volume * (2 ** b_volume) * PowerDC * UtilizationDC * CAGR,
}

base_sessions = {
    "Level2Single": int(a_sessions * CAGR),
    "Level2Double": int(a_sessions * (2 ** b_volume) * CAGR),
    "DC": int(a_sessions * (2 ** b_volume) * PowerDC * UtilizationDC * CAGR),
```

Figure 20 Python code for determining base volume/sessions for a specific type of CP

```python
# Add constraint to define the volume decrease factor based on the tariff
for t in types:
    if t == "DC":
        model.addConstr(
            volume_decrease_factor_DC == 1 - PE * (tariff_DC / base_tariff_DC - 1),
            name=f"volume_decrease_factor_constraint_DC"
        )
    else:
        model.addConstr(
            volume_decrease_factor == 1 - PE * (tariff / base_tariff - 1),
            name=f"volume_decrease_factor_constraint_"
        )
```

Figure 21 Python code for calculating VDF for Level 2 type and DC CPs independently

```python
# Volume formula for each type and CP
for t in types:
    for i in range(N):
        if i == 0:
            if t == "DC":
                # For the first CP, the volume is based on the base volume
                model.addConstr(
                    aux_volume[t, i] == base_volumes[t] * volume_decrease_factor_DC,
                    name=f"aux_volume_constraint_{t}_{i}"
                )

                model.addConstr(
                    aux_sessions[t, i] == base_sessions[t] * volume_decrease_factor_DC,
                    name=f"aux_session_constraint_{t}_{i}"
                )
            else:
                # For the first CP, the volume is based on the base volume
                model.addConstr(
                    aux_volume[t, i] == base_volumes[t] * volume_decrease_factor,
                    name=f"aux_volume_constraint_{t}_{i}"
                )

                model.addConstr(
                    aux_sessions[t, i] == base_sessions[t] * volume_decrease_factor,
                    name=f"aux_session_constraint_{t}_{i}"
                )
```

```
else:
    ab_volume = aux_volume[t, 0]
    ab_sessions = aux_sessions[t, 0]
    if t in ["Level2Double", "DC"]:
        # For subsequent CPs, calculate the maximum volume based on the previous CP's volume
        model.addConstr(
            aux_volume[t, i] == ab_volume * (((i+2) ** b_volume)-(i ** b_volume)),
            name=f"aux_volume_decrease_{t}_{i}"
        )

        model.addConstr(
            aux_sessions[t, i] == ab_sessions * (((i+2) ** b_volume)-(i ** b_volume)),
            name=f"aux_session_decrease_{t}_{i}"
        )
    else:
        ab_volume = aux_volume[t, 0]
        ab_sessions = aux_sessions[t, 0]
        # For subsequent CPs, calculate the maximum volume based on the previous CP's volume
        model.addConstr(
            aux_volume[t, i] == ab_volume * (((i + 1) ** b_volume) - (i ** b_volume)),
            name=f"aux_volume_decrease_{t}_{i}"
        )

        model.addConstr(
            aux_sessions[t, i] == ab_sessions * (((i+1) ** b_volume)-(i ** b_volume)),
            name=f"aux_session_decrease_{t}_{i}"
        )
```

Figure 22 Python code for determining volume and sessions for each type of CP installed as a certain number of CP

Appendix C

Implementation

The model in python is constructed such that historical data from a location can easily be used to evaluate the current business practice and determine a best practice scenario for that location. It should be noted that there are parameters in the model that need further research to be more accurate (preferably location specific research). The parameters stated in Section 6.1 have high locational variability, as is why they should be reconsidered for every location. The reconsidered values for these parameters can be easily implemented in the model, as all parameters are determined at the beginning of the model.

The model runs on a historical data set of a chosen location. A CSV file with the recorded data is necessary, and currently provided by the CMS Portal. The only prerequisite for this CSV file is that it contains a column with the volume of charge sessions (to calculate cumulative volume) and a column with the costs for the charge sessions (this is used to count only the rows that have costs > 0, to correct for faulty charge sessions). The path location of the CSV file is used to retrieve the data.

Monitoring

Monitoring the implementation of this model requires that the tariffs associated with certain locations and charge points are checked frequently, and updated when the model is used to evaluate a location and the optimal tariff turns out to be different than currently is the case. Moreover, the model is based on historical data of charge points, and charge points can be faulty. To achieve a most accurate result of the model, the historical data used should be clear of faulty charge points (or periods) and the monitoring of the execution of the model should include preventing and repairing faulty charge points as soon as possible.

Reliability

Reliability refers to the consistency of the measurement (Nicolas, 2023). The research performed is considered reliable when another person ends up with the same results when researching this problem and using the same steps taken in this research. The qualitative data gathered can differ substantially in the future, as developments change the economical and energy-related environments of Company X and charging points, and quantitative data can vary a lot as well due to strategic decision. However, when provided the exact same data as found in this research, then reliability can only be improved in a better argumentation for decisions, assumptions and qualitative data analysis (conclusions drawn from semi-structured interviews can vary and decrease reliability).

Validity

Validity can be divided into two categories, either external or internal validity. "External validity refers to the generalisability of findings from a study, or the extent to which conclusions can be applied across different populations or situations" (McDermott, 2011). The findings from the optimisation model in the research apply only to Company X, which makes it difficult to make generalisations regarding the findings of the research. The optimisation model however, could be used by others to evaluate and optimise their strategic charging point decisions, given that there is enough historical data to make the results of the model reliable.

Internal validity refers to the extent to which an experimenter can be confident that his or her findings result from experimental manipulations and even if he or she still remains uncertain as to how the mechanism might work in various settings or across diverse individuals (McDermott, 2011). The reference model and optimisation model are used to generate results, however to make the models function assumptions have to be made that may threaten the internal validity of the research. These assumptions are made such that the model simulates the real world as close as possible, but these could result in incorrect findings or drawing incorrect conclusions. The research aims to minimise assumptions or substantiate the assumptions where they are necessary.