

Msc thesis in Transport, infrastructure and logistics

Feasible charging infrastructure for battery electric trucks in Amsterdam

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September 2020



FEASIBLE CHARGING INFRASTRUCTURE FOR BATTERY ELECTRIC TRUCKS IN AMSTERDAM

MASTER THESIS

Version: September 11, 2020

in partial fulfilment of the requirements for the degree of

Master of Science

in Transport, Infrastructure & Logistics

at the Delft University of Technology,

to be defended publicly on Monday September 28, 2020 at 13:00-14:30.

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Keywords:

Amsterdam, Battery electric truck, Charging infrastructure, Charging method, and Zero emission zone

ABSTRACT

Freight transport and logistics in urban cities are recognized to contribute to a set of specific urban area problems (e.g. air, visual and noise pollution), and directly affecting the public health. The Dutch government wishes to implement medium size zero emission (ZE) zones for city logistics in 30-40 large cities, starting in 2025. The local government is given the responsibility to implement and enforce the ZE zone that requires a charging infrastructure. This research aims to support the local government with forming the plan of action by answering the research question (RQ): *"What are feasible charging infrastructures to supply the electricity demand for Amsterdam's battery electric trucks that travel in the municipality?"* The research focuses on Amsterdam and its city logistics battery electric trucks (BET) that use battery stored electricity to propel themselves. Charging infrastructure is defined as a network of charging stations that use a charging method to supply electricity to BET. Feasible is defined as something implementable with acceptable stakeholder resistance while complying with the view and goals of the local government. To be able to answer the RQ, this research evaluates BET, charging methods, stakeholders, and the transport and charging demand in Amsterdam.

A literature study, with academic and commercial sources, are used to evaluate the BET. It shows that the BET can be split into the truck types Single Unit (N2), Specialize (N2), and Single Trailer (N3). The current operating BET are scarce and mainly N2 diesel trucks that are converted into BET. Truck manufacturers are currently working on N2 and N3 BET, however these trucks are still in the pilot and testing phase. The evaluation of charging methods is also performed using a literature study. It looked at the main charging methods for BET which are plug-in, battery swap, catenary, third-rail, and wireless charging. Plug-in is most likely to be implemented in one of the first BET infrastructures due to its popularity with electric passenger cars. It charges a truck when they are at a standstill, called stationary charging. However, the most promising stationary charging method for charging infrastructure in Amsterdam is stationary catenary. The stationary catenary has high power, low visual and physical obstruction, and has a proven concept with public electric buses in Amsterdam. The most promising dynamic charging method (charging BET when it is on the move) is third-rail. It has a high chance to be market-ready before 2025, and positive technical characteristics, including medium spatial integration, low visual distraction, and low physical obstruction. A three-dimensional stakeholder analysis is used to evaluate the stakeholders. The analysis identifies and labels key players that play a big role in the successful implementation of feasible charging infrastructure as saviour or saboteur. Truck manufacturers and gas station operators are labeled saboteur. They have high interest, high power, and a negative/low attitude towards the implementation. Local government, grid operator, and carrier are labeled saviour, meaning they have high interest and high power, with a positive/high attitude towards the implementation. The interest of the local government is

to encourage the use of BET while keeping its societal and environmental impacts low. It is expected that the stance of the local government of Amsterdam is to be pro-active and open for different charging methods, while semi controlling the market and providing permits, grants, and tendering. A case study is conducted to evaluate the transport and charging demand in Amsterdam. The case study uses a spreadsheet calculation consisting of two equations to calculate the daily energy demand and the number of times the charging infrastructure is used. The input for the calculation is the Amsterdam transport characteristics from 2018 provided by the 'Centraal Bureau voor de Statistiek (CBS)' and the characteristics of BET. The case study shows that the companies located in Amsterdam had a total number of 685 N2 and 1.817 N3 trucks with a daily energy demand of 440 MWh. On a daily average the charging infrastructure is used 2700 times. In the case study a literature study is performed to look at the charging strategy, showing that the average charging moment is 80% at the depot and 20% along the road.

With these evaluations, a list of requirements is constructed. The requirements are split into constraints (to determine when the infrastructure is feasible) and objectives (to compare feasible charging infrastructures among each other). Using the evaluations and requirements, the RQ is answered by constructing feasible charging infrastructures for Amsterdam. It is concluded that a charging infrastructure with a dynamic charging method is not feasible for the municipality of Amsterdam. The preferred feasible charging infrastructure uses a stationary catenary with infrastructure ownership by a Charging Point Operator and a mix of carriers and shippers. It consists of 160 charging stations at the depots and 25 along the highway/roads. With the assumptions made in this research, the presented feasible charging infrastructure can supply the trucks registered in 2018 at the municipality of Amsterdam if they were BET. The required number of charging stations suggested in this research is significantly lower than the number found in a study by Topsector in 2019. This is primarily due to the different scope and assumptions. The result of this research is significantly lower due to the assumption of only opportunity charging, use of high power, a smaller geographical scope, absence of charging at a client, and the absence of external trucks coming from outside the municipality that will also require charging.

This thesis is to broaden the knowledge on BET charging infrastructure in Amsterdam for the municipality. Due to a lack of (detailed) information, assumptions were made in this research to simplify the studied situation. Further in-depth research is required when more information on BET and the charging methods become available. Therefore, the findings of this research should not be implemented one to one but should be used as a guide for the municipality to understand the order of magnitude, their options, and which direction should be explored. Based on the results of this research, recommendations can be given to the municipality. It is not advised for the municipality to implement a full-scale ZE zone (inside the highway ring of A10) in 2025, but rather implement the ZE zone in phases starting in the city center and expanding out throughout the years while giving time for BET technology development, stationary catenary technology development, and constructing the charging infrastructure. It is urged that the municipality of Amsterdam constructs a detailed plan of action that includes station-

ary catenary charging infrastructure and shares knowledge with other municipalities to have a national standardization. The plan of action should be based on forecasts for the years 2025-2030 showing the development of the technology, adaptation of BET with the influence of other ZE solutions, transportation movement in the ZE zone, and detailed information on what it takes to implement the charging infrastructure.

ACKNOWLEDGEMENTS

THIS master thesis is a partial fulfillment of the requirements for the degree of MSc Transport, Infrastructure, and Logistics at the Delft University of Technology (TU Delft). I would like to thank Lóri Tavasszy, the chair of the master thesis, for helping with finding a company for my research and providing useful feedback. Lóri Tavasszy also made sure I had great supervisors from the TU Delft, Bert Enserink and Arjan van Binsbergen. I am very grateful for Bert Enserink's and Arjan van Binsbergen's feedback and readiness to help.

The commissioner of this master thesis research was Districon B.V., which proved to be a great company to work with. Districon B.V. was helpful throughout the research, from finding a suitable topic and supervision to providing the guidance and facilities to finish the research. The passion and willingness to help of Wim de Goffau and Sanne Aelfers during the research was great, even through the challenging times of Covid-19. I would like to express my sincerest gratitude to Wim de Goffau and Sanne Aelfers and all those involved at Districon B.V., in particular Erwin Faber. I always felt welcomed and part of the Districon B.V. team throughout the research, thanks to Erwin Faber. As commissioners and supervisors both Wim and Sanne have been of great importance for the completion of this research. Their enthusiasm, expertise, and experience have been key and taught me a lot about city logistics and stakeholders, but also for instance about consultancy in general.

All in all, this thesis resulted in an enjoyable and educational experience which I will look back upon with fond memories. I hope the reader enjoys reading this research.

— Edwin Chung (September 2020)

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1

INTRODUCTION

THE introduction chapter for this master thesis research is divided into three sections. In section 1.1 the relevance and the topic of the research are explained. Followed by the problem introduction in section 1.2, including the research gap, research scope, research objective, and research questions. The final section 1.3 presents the approach and methodology of the research and how the report is constructed.

1.1. PROJECT CONTEXT

URBAN areas and cities face several issues such as increasing population, limited space, concerns on public health, climate change, noise pollution, and air pollution. At the local and national level, progress has been made to strengthen urban mobility planning with the guidance of Sustainable Urban Mobility Plans (SUMPs) and Sustainable Urban Logistics Plan (SULP). SUMPs is used for the complex task when contradictory demands are faced, such as restricting traffic in sensitive areas (e.g. city center) while not curbing the necessary movement of goods and people (Wefering et al., 2013). The SULP focuses on the optimization of urban freight logistics processes in order to decrease the related energy consumption and environmental impact (Ambrosino, 2015).

Freight transport and logistics in cities are recognized to contribute to a set of specific urban area problems (congestion, air pollution, and noise pollution), and directly affecting the lives of urban residents (Quak et al., 2016). The introduction of zero emission (ZE) zones is considered as one of the directions on how to reduce the negative impact from city logistics and making it more sustainable while maintaining an efficient urban freight transport system.

In the year 2025, the Dutch government wishes to implement medium size ZE zones for city logistics in 30-40 large cities, including Amsterdam (Rijksoverheid, 2019). The government has given the municipalities the responsibility to implement and enforce the ZE zone. The municipalities are planning to establish an action plan (including size

and location) for the introduction of ZE zone in their cities, including plans for charging infrastructure. The target dates may be delayed due to COVID-19, however, for this research, 2025 will be considered as the target date (NethEr, 2020).

Freight vehicles for city logistics can be split into delivery vans ($\leq 3,5$ tonnes) and trucks ($> 3,5$ tonnes). The city logistics is defined as either the last leg in a supply chain to a receiver located in a city or the first leg from the receiver in a city back to the shipper, which will be called last mile (Den Boer et al., 2017). ZE means locally zero polluting emission. A mean to achieve a locally zero polluting emission is electric propulsion, which can be split into indirect and direct electrification (Nicolaidis et al., 2017). Batteries and electric road systems (e.g. catenary system) are considered direct electrification. Hydrogen is considered indirect electrification, which can propel a vehicle using fuel cell technologies or can be used as fuel in an internal combustion engine. Alternative fuels such as liquefied natural gas (LNG) and biofuel are not categorized as a ZE solution, but are viewed as interim solution (Broos et al., 2019).

1.2. PROBLEM INTRODUCTION

THE Netherlands is one of the front runners in public charging infrastructure and electric vehicles (Wolbertus, 2020). In the past the primary focus was on electric passenger cars, which have successfully penetrated the market. With the introduction of the ZE zone an interest in electric trucks (e-trucks) has grown. The widespread penetration of e-trucks for city logistics depends on overcoming several large barriers (Nicolaidis et al., 2017): (1) the high investment cost (one-third consist of the cost of batteries (Tie & Tan, 2013)), (2) the limited range, (3) the long battery charging time, and (4) the lack of public charging infrastructure. The barriers lead to two 'chicken or egg' problems, which apply to the introduction of e-trucks and necessary charging infrastructure (Den Boer et al., 2013). The first chicken or egg problem relates to the costs versus demand for technology, with the assumption that higher demand eventually will reduce cost via economy of scale. The second chicken or egg problem relate to the availability of charging infrastructure versus the need of charging infrastructure.

RESEARCH GAP

To break the 'chicken or egg' cycle the municipality is willing to invest in charging infrastructure for e-trucks, leading to development of charging infrastructure and e-trucks technology, which reduces the cost and improve the characteristics. Municipalities are still left without comprehensive studies that aid with understanding what is required and feasible for an e-truck charging infrastructure for city logistics. Current literature lacks a clear overview of the wide range of methods to charge an e-truck, the influence of stakeholders, and requirements for a charging infrastructure, making it difficult to imagine a feasible charging infrastructure for e-trucks that takes the agenda of different stakeholders into account.

RESEARCH SCOPE

The focus of this thesis is on city logistic trucks that are powered by direct electrification (battery electric trucks), and charging infrastructures which can be implemented in Amsterdam starting in 2025. The research is written with the municipality of Amsterdam in mind and takes inspiration from and is build upon the knowledge from the report [Topsector Logistiek \(2019\)](#).

RESEARCH OBJECTIVE

The theoretical objective of this thesis aims to fill the gap mentioned above by systematically exploring the options for a feasible charging infrastructure used by battery electric trucks, that can be implemented starting in 2025 and is feasible in Amsterdam with a ZE zone. While taking into account the technology development, energy demand, and stakeholders. The practical objective of this thesis is to provide municipalities and other stakeholders a better understanding of the different options for a charging infrastructure. Thereby, assisting the stakeholder, mainly municipalities, to make better choices and take action to accomplish the ZE zone starting in 2025. This may not only stimulate entrepreneurs to invest in e-trucks, but it also ensures an organic charging infrastructure growth to match the supply with the (expected) demand.

RESEARCH QUESTION AND SUB-QUESTIONS

Based on the identified research gap, scope, theoretical objective, and practical objective, a research is proposed with the following **research question (RQ)**:

Research Question (RQ)

What are feasible charging infrastructures to supply the electricity demand for Amsterdam's battery electric trucks that travel in the municipality?

To derive at an answer for the RQ, this thesis will first provide answers to five **sub-questions (SQ)**, which are:

1. What types of battery electric trucks are available?
2. What type of charging method do battery electric trucks require?
3. What position do stakeholders take with the implementation of charging infrastructure?
4. What logistic and electric demand in Amsterdam does the charging infrastructure have to supply and at what type of location?
5. What are the requirements that make a charging infrastructure technological and socially feasible, considering the different charging methods, stakeholders' agenda, and current transport demand?

1.3. METHODOLOGY AND RESEARCH APPROACH

THIS sections presents the research approach, including the methods used, and the structure of the thesis report. The approach of this thesis is visualized in figure 1.1. The approach follows the five sub-questions and the research question, and includes expert validation and sensitivity analyses due to the high uncertainty of the future.

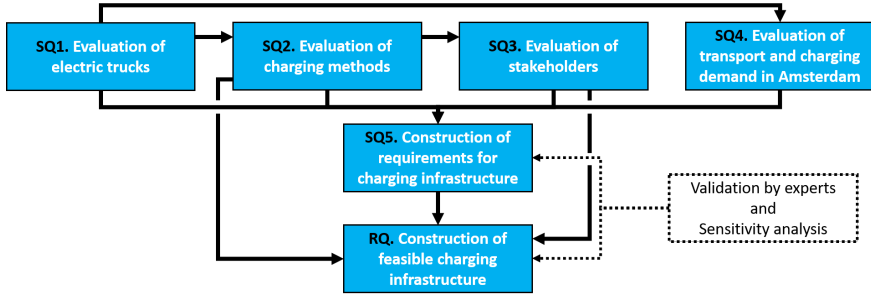


Figure 1.1: A visualisation of the research approach, based on the research question and sub-questions.

The first sub-question (SQ1) is answered in chapter 2 by evaluating battery electric trucks with a literature study. The literature study is on current operating and piloted battery electric trucks (BET). The information is gathered from academic and commercial sources. The literature study results in generalised characteristics for BET, including energy consumption and energy capacity. The findings on BET are used in SQ2, SQ4 and SQ5.

The second sub-question (SQ2) is answered in chapter 3 by evaluating the different charging methods. The evaluation is done with a literature study, with the knowledge on BET, from SQ1. The literature study is on current and previous pilots with different charging methods. The characteristics of different charging methods are gathered from academic and commercial sources, and compared with each other to derive preferred charging methods. The findings on the charging methods are inputs for SQ3, SQ5, and RQ

The third sub-question (SQ3) is answered in chapter 4 by evaluating stakeholders using a Three-Dimensional Stakeholder Analysis (Murray-Webster & Simon, 2006). The analysis is on the main stakeholders that are affected or affecting the implementation of the feasible charging infrastructure. The inputs for the analysis is based on previous studies (Wolbertus, 2020) Topsector Logistiek (2019) Quak et al. (2016) Rijkswaterstaat (2016) and the knowledge on charging methods from SQ2. The analysis results in labeling the stakeholders based on power, interest, and attitude. The roles of the stakeholders are also presented in this chapter, with a focus on the role of the local government. The findings on the stakeholders are inputs for SQ5 and the RQ, to compare different infrastructure ownership.

The fourth sub-question (SQ4) is answered in chapter 5 by evaluating the transport and charging demand in Amsterdam. The evaluation is conducted with a case study on the

municipality of Amsterdam. The case study consists of constructing and using a model to derive the average daily energy demand by BET and the number of daily charging moments by BET. The model consist of a spreadsheet calculation containing two equations. The input values for the spreadsheet calculation consist of data on the municipality of Amsterdam and constants of the BET characteristics. The data on the municipality are gathered from 'Centraal Bureau voor de Statistiek (CBS)' and consist of the number of registered trucks in municipality and their average annual traveled distance. The constants of BET used in the spreadsheet calculation are BET characteristics on energy consumption and energy capacity from the first sub-question (SQ1). The chapter will present the electricity demand and its location based on the transportation and charging strategy. The findings on the electricity demand are inputs for SQ5.

The fifth sub-question (SQ5) is answered in chapter 6 by constructing a road map and requirements to implement a feasible charging infrastructure in Amsterdam. The construction is based on the answers from the SQ 1-4, and the view and goals of the local government. In the chapter the requirements are split into constraints and objectives. The constraints are the requirements that a charging infrastructure has to comply with to be considered feasible in Amsterdam. Feasible is defined as something that is implementable with acceptable resistance while complying with the view and goals of the local government. The objectives are the requirements used to compare the feasible charging infrastructures. The infrastructure that optimizes the objectives the best is the preferred feasible charging infrastructure. The requirements are inputs for the RQ, to construct feasible charging infrastructure.

The research question (RQ) is answered in chapter 7 by constructing and comparing feasible charging infrastructures with different charging methods and infrastructure ownership. The construction uses the input from the charging methods from SQ2, stakeholder evaluation from SQ3, and the requirements from SQ5. The constraints are used to determine whether the charging infrastructure is feasible, and the objectives are used to compare the feasible charging infrastructures to determine the preferred feasible charging infrastructures for Amsterdam. The sensitivity analysis giving insight of the uncertainty of the future is also presented in this chapter.

The final chapter 8 presents the conclusion, discussion, recommendation for further studies, and recommendation for the municipality of Amsterdam.

2

EVALUATION OF E-TRUCKS

ELECTRIC trucks (e-trucks) for city logistics are the trucks that require the charging infrastructure and charging methods from 2025 onward. Before looking at charging methods and infrastructure it is important to answer the first sub-question “*What types of battery electric trucks are available?*”. This chapter is split into five sections to evaluate e-trucks and to give a better understanding of what is getting charged. The first section 2.1 discusses truck classification to understand the truck types considered in this thesis. Trucks can be further categorized based on their energy type. In the second section 2.2 these different energy types are presented. Battery electric trucks (BET) is one of the truck categorization based on the energy types and part of the scope of the research. The BET that are currently or soon available is presented in the third section 2.3. The final section 2.4 presents the conclusion of the e-truck evaluation.

2.1. TRUCK CLASSIFICATION

TRUCKS are used for relatively large freight transport, with both short and long hauls. They can be classified into four different truck types: Single Unit (bedrijfswagen), Specialize, Single Trailer (trekker met oplegger), and Multi trailer. This thesis will look at the former three as shown in figure 2.1. The truck types Single Unit and Specialize are part of European vehicle category N2, and Single Trailer are part of European vehicle category N3 (RDW, 2019). More on the vehicle classification and truck types can be found in appendix A

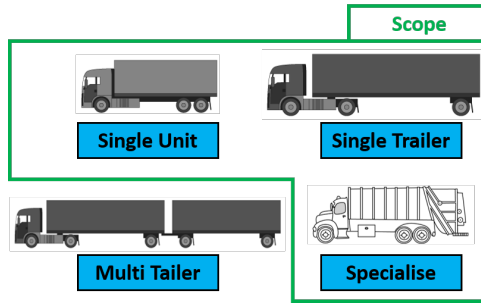


Figure 2.1: The four truck types based on the truck classification.

2.2. ENERGY TYPE

TRUCKS can be propelled using different types of energy as shown in figure 2.2. A commonly used energy type is conventional fuel, including diesel and gasoline. Due to their negative side effect on the climate, alternative types of energy have been researched, such as Bio-fuel, LNG, and electric. Bio-fuel and LNG are an interim solution to climate change and are not categorized as a solution for zero emission (ZE) (Broos et al., 2019). They are not of interest in this thesis.

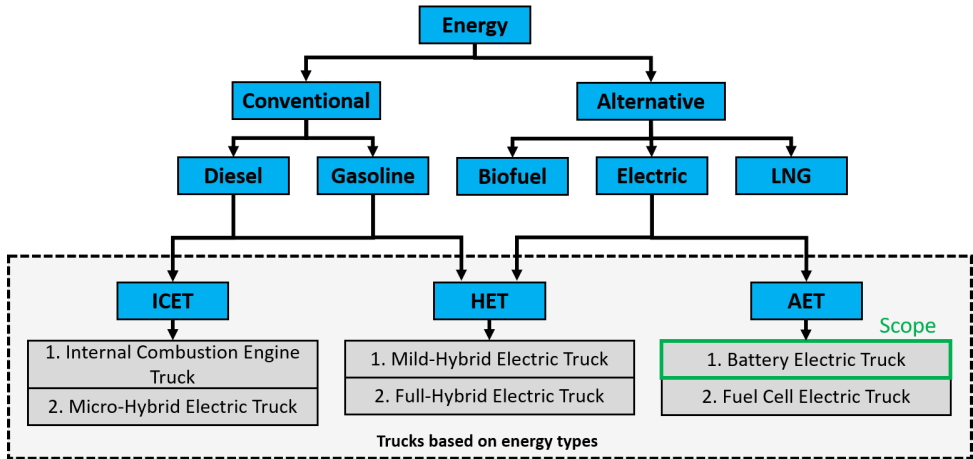


Figure 2.2: The classification of trucks based on energy types.

Considering the energy types, a truck can be classified into three groups: internal combustion engine truck (ICET), hybrid electric truck (HET), and all-electric truck (AET) (Tie & Tan, 2013). The groups can be further categorized as shown in figure 2.2. ICET is commonly used and propels a truck using a combustion chamber to transform chemical energy, such as diesel or gasoline, into heat and kinetic energy. HEV has two engines to propel a truck, an internal combustion motor, and an electric motor. In the past, electric vehicles had significantly limited technical advancement, primarily on the battery

Table 2.1: Market evaluation for the BET

| Market evaluation: BET | Single unit | Single Trailer | Specialize |
|-----------------------------|-------------|----------------|------------|
| GVW [tonnes] | 16-19 | 26-37 | 12-27 |
| Power [kW] | 165-350 | 210-480 | 330 |
| Torqu [Nm] | 1060-3500 | 970-9161 | 1060 |
| Battery capacity [kWh] | 150-300 | 165-720 | 120-200 |
| Energy consumption [kWh/km] | 0,75-1 | 1-1,8 | 0,6-1,7 |
| Range [km] | 180-300 | 100-800 | 120-180 |
| Warranty [year] | 8 | 8 | 8 |
| Service cost [€/month] | 350-600 | 350-600 | 350-600 |
| Dimensions (LxWxH) [m] | 12x2,55x4 | 16,5x2,55x4 | 12x2,55x4 |

range and limited charging infrastructure. To transition from ICET to AET, an intermediate step was made by building HET. They gave the user the possibility to drive electric, which is sustainable and environmentally friendly, but still provide the security to not be stranded when the battery ran out. AEV uses electric power and a motor to move. The AET can be further categorized into battery electric truck (BET) and fuel cell electric truck (FCET). These categorizations are based on different electricity storage types. Hydrogen is primarily used with FCET and batteries are used with BEV. The focus of this thesis will be on BET, which is also called an e-truck. More information on the battery energy storage unit can be found in appendix C.

2.3. BATTERY ELECTRIC TRUCKS (BET)

THE original equipment manufacturers (OEMs) are the main stakeholders that currently and sparsely supply the Dutch market with ICEV trucks. DAF, Volvo, Mercedes-Benz, Scania, MAN, and Iveco are the largest among the OEMs for the Dutch market (Luman, 2015). Current operating BET are custom modified ICET converted to BET, by companies such as EMOSS, a non-OMEs. With their success and an increasing demand for BET, the market is moving towards the large OEMs, which are starting to invest in BET. Data of currently operational BET and BET in the pilot phase are show in table B.1 of appendix B.

2.4. INFLUENCE OF BET ON CHARGING INFRASTRUCTURE

TO sum up, the feasible charging infrastructure explored in this thesis is required to charge BET. It is an e-truck that uses a battery as an energy storage unit. The BET considered in this thesis consist of the following truck types: Single Unit, Single Trailer, and Specialize. Based on the characteristics of available BET (table B.1), a summary of their characteristics is derived, shown in table 2.1. Note that these values are for BET at their optimal state, which will decrease over time as BET as they are used. The truck types determine what type of charging method is needed, according to their energy consumption and capacity. How the different BET get charged will be explored in the next chapter 3.

3

EVALUATION OF CHARGING METHODS

IN this chapter, the second sub-question, "*What type of charging method do battery electric trucks require?*", will be answered. The answer is derived by evaluating different charging methods for the battery electric truck (BET) types described in chapter 2. The different charging methods are introduced and categorized in the first section 3.1. Each of the following sections 3.2-3.6 discuss a different charging method, including how the technology works, the required components, and system characteristics. The pros and cons of the charging methods are presented in appendix D. The final section 3.7 presents the conclusion for the charging method evaluation.

3.1. CHARGING METHOD CLASSIFICATION

USING BET results in a depletion of the battery pack. This requires BET to be (re)charged when the batteries are depleted. Several different charging methods exist and this thesis considers five of them, shown in figure 3.1. The charging methods can be categorized by the state of motion and the energy transfer method (Fisher et al., 2014), shown in figure 3.2.

The state of motion of BET divides the technologies into stationary or/and dynamic charging. Charging a BET while it is at a complete standstill is called stationary charging and charging while it is on the move is called dynamic charging. Dynamic charging means that the vehicle does not have to stop to recharge during a trip, requires a smaller battery size, and it eliminates range anxiety. It provides small charging boosts which can increase the life of lithium batteries compared to stationary charging (Omar et al., 2014).

The energy transfer method divides the technologies into conductive or inductive charging (Tie & Tan, 2013). Conductive charging transfers the power through a metal connection between charger and vehicle. Inductive charging is a charging method without a

contacting medium but the power is transferred magnetically. Inductive gives more flexibility and freedom due to the absence of physical and visual obstruction.

All the charging methods that will be discussed are connected to the electric grid to power the batteries. The electric grid produces an Alternating Current (AC) with 230 Volts. Noted is that a battery can only be (re)charged using Direct Current (DC) (see appendix C), thus requiring a converter.

Charging methods

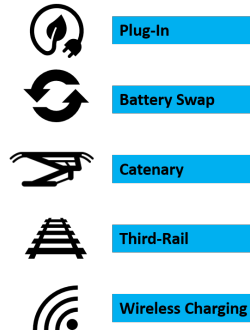


Figure 3.1: The five different charging methods considered in this report

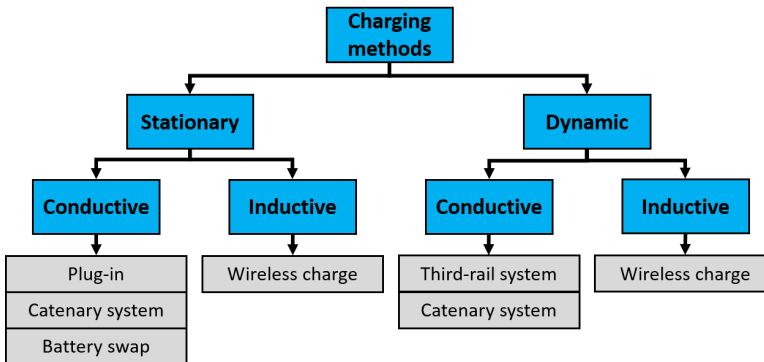


Figure 3.2: A visualisation of the different charging methods for BET. (Teoh et al., 2018) (Den Boer et al., 2013) (Rijkswaterstaat, 2016)

3.2. PLUG-IN

THE plug-in system is a well-known charging method when looking at electric passenger cars. This technology falls under the category stationary and conductive charging. A BET is charged by simply plugging it into a charging station, which is connected to the electric grid. The following parts will discuss the components and system characteristics for the plug-in charging method. The pros and cons for plug-in can be found in appendix D.1.

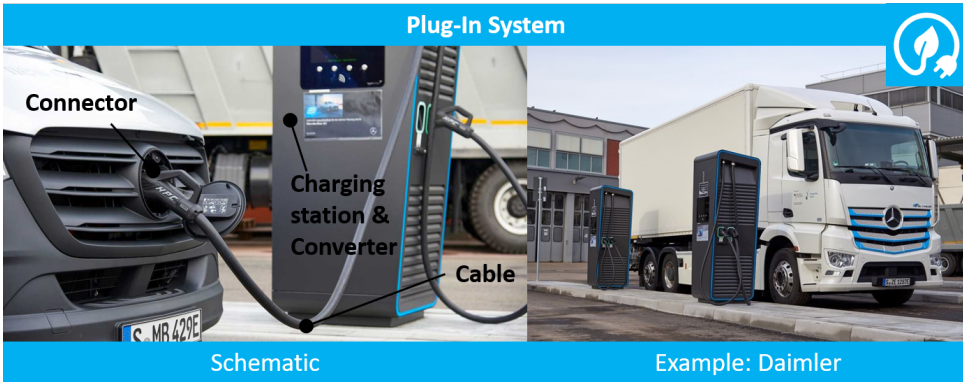


Figure 3.3: Schematic view of plug-in system. (Daimler, 2020)

PLUG-IN: COMPONENTS

Figure 3.3 illustrates a plug-in system for BET. The components for the plug-in system include a cable with a connector, a charging station, and a converter. Appendix E.1 discusses each component for the plug-in more in-depth. In short, the cable with a connector is used to connect BET with the charging station. The charging station supplies electric energy to the BET, sourced from the electric grid. A converter converts AC from the electric grid to DC for charging the batteries.

PLUG-IN: SYSTEM CHARACTERISTICS

There are examples of operating plug-in system for BET, such as in Rotterdam by BREYTER (EMOSS, 2017) and in Stuttgart by Daimler (Daimler, 2020). The new charging park in Stuttgart has a total output of 1 MW, distributed to two DC fast charging stations with 300 kW each for trucks, and three more charging stations with 150 kW output each for vans. It is predicted that in the future ultra-fast charging will become reality, with a power of 350-500 kW (Hall & Lutsey, 2019). It is assumed that 350 kW can become a reality before 2025. The system characteristics for the plug-in are displayed in table 3.1.

PLUG-IN: CONCLUSION

The plug-in system is a proven system for passenger cars, consisting of three main components: cable with a connector, a charging station, and a converter. With its system characteristics, it may be used for overnight charging and opportunity charging at a

Table 3.1: System characteristics of Plug-in (Tie & Tan, 2013) (Topsector Logistiek, 2019) (Hall & Lutsey, 2019)(Daimler, 2020)

| Characteristics | |
|--|------------------------|
| Power | 3,3-350 kW |
| Mode compatibility | All (Trucks, bus, car) |
| Visual distraction | medium |
| Physical obstruction | high |
| Efficiency | 97% |
| Weather | high |
| Moving parts | yes |
| Battery requirement | medium |
| Space requirement | low |
| Spatial integration | medium |
| Market ready 2025 | yes |
| Supporting country | Non specific |
| Automation | No |
| Example companies | Daimler and Tesla |
| Construction Cost | medium |
| Charging 80% of a 300 kWh battery | 42 min |

company site. It can be used by all modes. However, using such a system at a depot does have its downsides. The charging is not automatic and cables are hanging around, which is a trip hazard. Additionally, when parking in reverse at a depot, the charging station becomes an obstacle. The maximum charging power can be considered medium with a high of 350 kW. It would take 42 minutes to charge an empty 300 kWh to 80%, assuming linear charging.

3.3. BATTERY SWAP

THE concept of battery swap is relatively simple and falls in the category stationary and conductive charging. In the battery swap system, the BET is driven to a battery swapping station where its depleted battery is exchanged for a charged battery (Den Boer et al., 2013). The battery swapping station fully recharges the depleted battery, ready to be swapped into the next visiting BET. The following parts will discuss the components, and system characteristics for the battery swap charging method. The pros and cons can be found in appendix D.2.

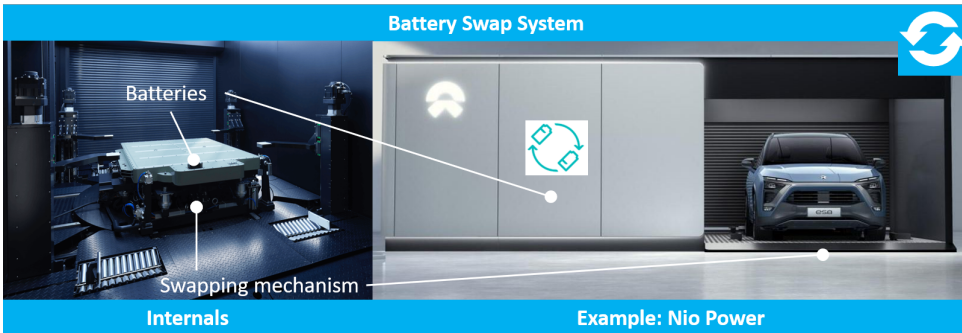


Figure 3.4: Schematic view of battery swap system.(NIO, n.d.)

BATTERY SWAP: COMPONENTS

The main components for a battery swap system is the swap station that consists of the underground swapping mechanism, charging system, stock of spare batteries, and cooling system. The battery of BET is located underneath the vehicles. The underground swapping mechanism removes the empty battery from a BET and swaps them for a charged one. The empty battery is stored in the stock of batteries and charged by the charging system. The cooling system regulates the temperate in the stock of batteries to prevent degrading of the battery. Figure 3.4 illustrates such a battery swap system.

BATTERY SWAP: SYSTEM CHARACTERISTICS

This concept has successful implementation with Automated Guided Vehicles, in a controlled environment at ports for transportation of containers (Vaggelas & Leotta, 2019). The battery swap system has been developed to be implemented for electric passenger vehicles by a company such as Better Place, Tesla, Ample, Nio Power, and BAIC BluePark. The system characteristics of the battery swap system are shown in table 3.2, based on the past and current battery swap companies. Appendix E.2 discusses the history of these companies with a battery swap.

BATTERY SWAP: CONCLUSION

With a battery swap, the battery in the BET is exchanged for a different charged battery at a swap station. The swap station consists of an underground swapping mechanism, charging system, stock of spare batteries, and cooling system. In the past, companies

Table 3.2: System characteristic of Battery Swap (Rijkswaterstaat, 2016)(Bloomberg News, n.d.) (Gaddy, Ben, 2018)(Den Boer et al., 2013) (NIO, n.d.)

| Characteristics | |
|--|---|
| Power/Charging speed | 3 minutes (faster than gas station) |
| Mode compatibility | All (depending on available battery) |
| Visual distraction | high |
| Physical obstruction | high |
| Efficiency | - |
| Weather | low |
| Moving parts | yes |
| Battery requirement | high |
| Space requirement | medium |
| Spatial integration | medium |
| Market ready 2025 | yes |
| Supporting country | China |
| Automation | yes |
| Example companies | Better Place, Tesla, Ample, Nio, and BAIC BluePark |
| Upfront cost | Low (purchasing/leasing vehicle and battery separate) |
| Construction cost | High (~1-3 million euro) |
| Charging 80% of a 300 kWh battery | - |

have tested this system but failed. Recently, companies in China have shown the success of the system with government support. Due to its characteristics, the system has a major advantage in charging speed and upfront capital cost. The charging speed is faster than conventional gas fueling and batteries can be leased or bought separately, lowering the vehicle cost. The drawbacks are the high investment cost for the spare batteries and the assurance of life expectancy of battery when the user does not lease the battery.

3.4. CATENARY

THE catenary system is a conductive charging system that can be used either dynamically or stationary. The BET is charged by connecting to an overhead conductive cable (catenary) with a pantograph. A similar system is found with trains.

CATENARY: COMPONENTS

The main components of the system are a feeder station, catenary, and a pantograph system. The feeder station, also known as a substation, consists of switching systems and a transformer that converts the alternate high voltage current of the grid to low direct current (typically 600–1,500 V) which flows into the catenary.

The catenary, also known as overhead line, conductive cable, or gantry, is placed overhead of the vehicle and is connected to the feeder stations. It provides contact to the vehicle's pantograph and assures the electricity to be transferred from the feeder station to the vehicle (Den Boer et al., 2013).

The pantograph is a mechanical linkage connected in a manner based on parallelograms and connects the BET to the catenary. There are two types of pantographs, as shown in figure 3.5. When a pantograph is mounted on the roof of the truck it is called a roof-mounted or off-board top-down pantograph. When the pantograph is mounted on the gantry or catenary it is called the gantry-mounted or on-board bottom-up pantograph.

3.4.1. STATIONARY CATENARY

With a stationary catenary system, the BET is charged when parked using an overhead catenary. Figure 3.5 shows a schematic overview of the system used for a bus, with a roof-mounted or gantry mounted pantograph. The catenary charging station is located along the planned trip route as a stop. During the stops, the bus can automatically connect to the overhead charging station with a pathogen and fast opportunity charge. A similar system can also be implemented for BET. The pros and cons for stationary catenary can be found in appendix D.3.



Figure 3.5: Schematic view of stationary catenary charging for bus (Siemens, 2015)(Heliox, 2018)(ABB, 2018)

Table 3.3: System characteristics of Stationary Catenary (Heliox, 2018)(SIEMENS, 2018)(ABB, 2018).

| Characteristics | |
|--|---------------------|
| Power | 50-600 kW |
| Mode compatibility | Trucks and bus |
| Visual distraction | medium |
| Physical obstruction | medium |
| Efficiency | 97% |
| Weather | medium |
| Moving parts | yes |
| Battery requirement | medium |
| Space requirement | low |
| Spatial integration | medium |
| Market ready 2025 | yes |
| Supporting country | Netherlands (buses) |
| Automation | yes |
| Example companies | Heliox |
| Construction Cost | medium |
| Charging 80% of a 300 kWh battery | 24 min |

STATIONARY CATENARY: SYSTEM CHARACTERISTICS

Multiple companies are developing these systems for buses. There are successful pilots of public transport buses that use the stationary catenary system, including in Schiphol and Eindhoven (Heliox, 2018). The system characteristics are shown in table 3.3, based on these pilots.

STATIONARY CATENARY: CONCLUSION

The stationary catenary charging method consists of a catenary, feeder station, and a pantograph system. Some public buses in the Netherlands have successfully implemented this system, and the system is promising for BET. The system can charge automatically with a wide range and high power (600 kW), taking only 24 minutes to charge an empty 300 kWh BET battery to 80% (assuming linear charging), enabling opportunity charging. The system is of most interest in transporting routes with similar characteristics as bus routes. With a constantly changing distribution route, this system would be less effective, unless the BET has a big enough battery and using these systems at the origin and/or destination. The system does have a medium vision and physical obstruction, but when using the system at a depot, this may be of low effect. The required space per charging station decreases when multiple charging stations are required at the same location. The main drawback of the system is that it can only be used by BET and buses, unable to charge vans and cars due to their height.

3.4.2. DYNAMIC CATENARY

Dynamic catenary is where a BET is charged while on the move with catenary installed over the road section and roof-mounted pantograph. It is similar to the DC operated bus trolley lines which have been in operation for decades, such as in Arnhem (Soop & Ydstedt, 2000) (Rafter, 1995). Since 2011, Siemens has been developing this charging method for BET, known as ehighway shown in figure 3.6, which is still in its pilot phase on public roads (Grünjes & Birkner, 2012). The pros and cons for dynamic catenary can be found in appendix D.3.

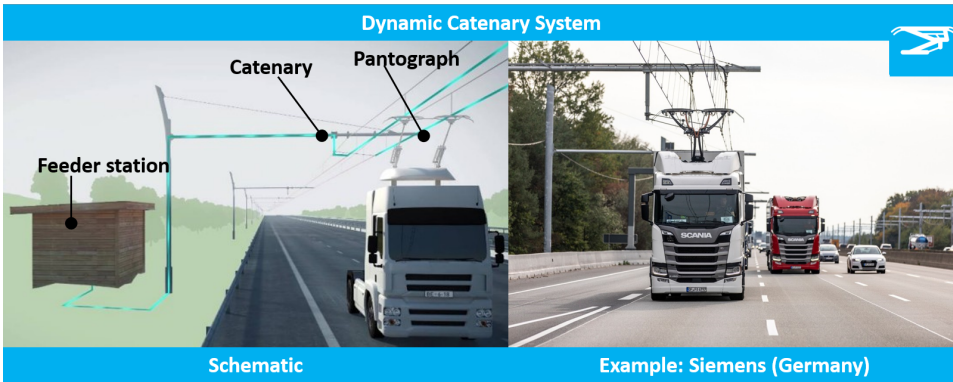


Figure 3.6: Schematic view of dynamic catenary charging for trucks (Siemens, 2015)(Scania, 2020)

DYNAMIC CATENARY: SYSTEM CHARACTERISTICS

As of 2016, several pilots on public roads for dynamic catenary have been performed. For BET, several successful pilots exist (Scania, 2019)(Gustavsson et al., 2019). The first dynamic catenary system on a public road was in Sweden, on the highway near Favle. Germany has 5 km of ehighway in both directions on the autobahn outside Frankfurt. In northern Italy, on A35 Brebemi highway, a stretch of 6 km ehighway is installed. In the USA, Siemens Mobility installed and tested a 3 km overhead contact line system for hybrid electric trucks near the U.S. ports of Los Angeles and Long Beach, two of the largest ports in the country. Looking at these pilots, the results of the system characteristics are shown in table 3.4.

DYNAMIC CATENARY: CONCLUSION

The dynamic catenary system consists of a catenary, feeder station, and a pantograph system. The system has been tested in multiple countries. It showed a lot of potentials, mainly on highways. The Swedish government has shown support and interest in implementing the charging method. The dynamic catenary enables smaller battery requirements for BET and can use experience and exiting infrastructure of trolley lines in urban areas. It can provide sufficient power, to power multiple BET dynamically. The drawback of this system is the high vision and physical obstruction, and limited modes use. Some cities already have a dynamic catenary network in the city center for public

Table 3.4: System characteristics of Dynamic Catenary. (Grünjes & Birkner, 2012)(Scania, 2019)(Gustavsson et al., 2019)

| Characteristics | |
|--|----------------|
| Power | 60-120 kW |
| Mode compatibility | Trucks and bus |
| Visual distraction | high |
| Physical obstruction | high |
| Efficiency | 97% |
| Weather | high |
| Moving parts | yes |
| Battery requirement | low |
| Space requirement | high |
| Spatial integration | high |
| Market ready 2025 | yes |
| Supporting country | Germany |
| Automation | yes |
| Example companies | Siemens |
| Construction Cost | High |
| Charging 80% of a 300 kWh battery | 120 min |

transport. If BET will use the existing network, the public transportation network may be disrupted.

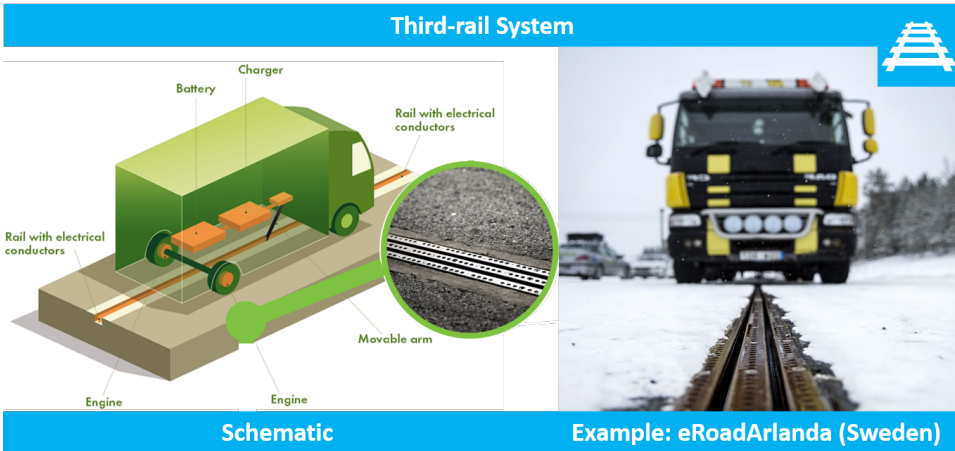


Figure 3.7: Schematic view of third-rail system (eRoadArlanda, 2016).

3.5. THIRD-RAIL SYSTEM

THE third-rail system falls under the category of dynamic conductive charging. It is thought that the system may also be used for stationary charging, however, no pilots or examples were found. Third rail, also known as live rail or conductor rail, is similar to catenary but the contact point is in the road surface in the form of a rail instead of an overhead conductive cable (Rijkswaterstaat, 2016). The pros and cons for third-rail can be found in appendix D.5.

THIRD-RAIL: COMPONENTS

The components of this system are the feeder station, conductor rail, and collector shoes. Figure 3.7 illustrates the third-rail system. More information on the components can be found in appendix E.3. In short, the feeder station provides transformed power to the conductor rail, sourcing from the electric grid. The conductor rail is placed on the road, connected to the feeder stations. It provides contact to the collector shoes and assures the electricity to be transferred from the feeder station to the BET. The collector shoes make contact with the conductor rail, connecting the BET to the power source.

THIRD-RAIL: SYSTEM CHARACTERISTICS

The technology is implemented for trams and metros in several European cities, typically fully or almost fully segregated from outside environment. Sweden is the first to implement this system on public roads for BET (Rijkswaterstaat, 2016), with the demonstration project named Elways (elways, 2019). The Swedish government is making plans to implement the system nationwide (Boffey, 2018). It consists of 20,000 km road with a cost of 7,3 billion euros and will take 10 years. Table 3.5 shows the system characteristics of third-rail.

Table 3.5: Market evaluation of Third rail System (Bateman et al., 2018)(eRoadArlanda, 2016)(Boffey, 2018).

| Characteristics | |
|-----------------------------|---|
| Power | <i>[Not Found]</i> |
| Mode compatibility | All |
| Visual distraction | low |
| Physical obstruction | low |
| Efficiency | 97% |
| Weather | medium |
| Moving parts | yes |
| Battery requirement | low |
| Space requirement | high |
| Spatial integration | medium |
| Market ready 2025 | yes |
| Supporting country | Sweden |
| Automation | yes |
| Example companies | elways and eRoadArlanda |
| Construction Cost | High (1 km of rail cost 365.000 euro and build in 1 hour) |

THIRD-RAIL: CONCLUSION

The third-rail system is primarily implemented for conductive dynamic use. It consists of a feeder station, conductor rail, and collector shoes. How much power it can provide is not found. However, looking at the pilots, it can be concluded the system can sufficiently power multiple moving BET. The system would be able to power different modes of transport, including cars and vans. With the rail installed on the road, the obstruction is considered low. Third-rail shows the most potential for highway installation and using small batteries to travel between highway and destination. The drawbacks of installing rail in city roads are its vulnerability to weather and safety concerns.

3.6. WIRELESS CHARGING

THE wireless charging (WC) system is an inductive charging method that can be used for both stationary and dynamic charging. WC technology operates on the principle of magnetic inductance and magnetic resonance, similar to a transformer. Magnetic inductance is acquired by running an electric current through a primary coil (the source), which induces a magnetic field. When another coil (the receiver) is nearby and exposed to this magnetic field, an electric current is induced in this secondary coil, and wireless power transfer is achieved (Nicolaidis et al., 2017). To increase the efficiency at a long distance between the source and receiver, magnetic resonance is required. The magnetic resonance tunes the source and receiver coil so that they both magnetically resonate at the same frequency, and improve the wireless power transfer efficiency (Fisher et al., 2014).

WIRELESS CHARGING: COMPONENTS

Typical WC for BET consists of a road charging unit (the source or primary coil), the vehicle charging unit (the receiver or secondary coil), the communication system, and

the feeder station. The road charging unit is built into the ground (8 cm under the surface) and produces a magnetic field, using power provided by the feeder stations. A corresponding vehicle charging unit is mounted underneath the BET that picks up the magnetic field, inducing an AC, and transforming it into a stable DC power to charge the BET. The communication system provides real-time communication with charging units, mainly used with dynamic WC. The feeder station is an underground system that provides road charging unit with AC, sourcing from the electric grid.

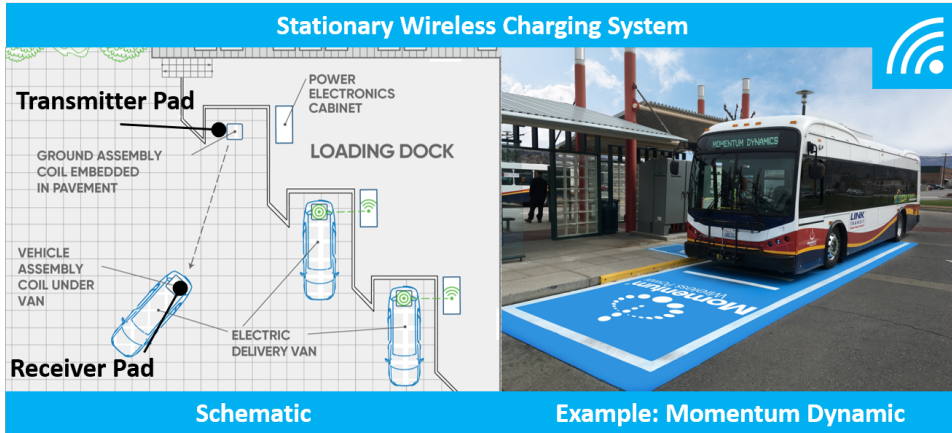


Figure 3.8: Schematic view of stationary wireless charging (Momentum Dynamics, 2018).

3.6.1. STATIONARY WIRELESS CHARGING

With stationary WC, the BET is simply parked over a road charging unit built under the road to charge using induction. This approach is useful for BET that charge at the depot, delivery points, in city centers, and along their routes. Figure 3.8 shows the system schematically. The pros and cons for stationary wireless charging can be found in appendix D.6.

STATIONARY WIRELESS CHARGING: SYSTEM CHARACTERISTICS

Stationary WC has been used in numerous other applications for over 25 years. This includes an entertainment system of airplanes in the back of each passenger for convenience and maintenance reasons (Kelley & Owens, 1989). Several companies and universities are researching stationary WC for BET. One pilot was found that successfully implemented stationary WC with buses on public roads in the USA (Momentum Dynamics, 2018). The system characteristics of the technology are shown in table 3.6.

STATIONARY WIRELESS CHARGING: CONCLUSION

The stationary WC charges a parked BET with induction using a road charging unit, a vehicle charging unit, a communication system, and a feeder station. The system can produce power of 300 kW, as shown in pilots in the USA. The underground characteristic results in low obstruction, minimal influence of weather, and it can power different types

Table 3.6: Evaluation of Stationary Wireless Charging System (Momentum Dynamics, 2018) (Witricity, 2018) (Fisher et al., 2014)

| Characteristics | |
|--|---|
| Power | 200-300 kW |
| Mode compatibility | All |
| Visual distraction | low |
| Physical obstruction | low |
| Efficiency | 85-93% |
| Weather | low |
| Moving parts | no |
| Battery requirement | medium |
| Space requirement | low |
| Spatial integration | low |
| Market ready 2025 | maybe |
| Supporting country | USA (Massachusetts, Indianapolis, and Washington) |
| Automation | yes |
| Example companies | Witricity and Momentum Dynamics |
| Construction Cost | medium |
| Charging 80% of a 300 kWh battery | 48 min |

of modes. The main drawback of the charging method is whether it will be market-ready in 2025. Addition to the low efficiency, and the induced magnetic fields.

3.6.2. DYNAMIC WIRELESS CHARGING

Dynamic WC involves induction charging while the BET is moving. This concept involves a string of road charging units built into the road. The infrastructure is completely passive underneath the road until a BET passes over a charging pad, and the BET is identified as a certified receiver of energy. When the BET is approved by the system, the energy transfer starts. The identification is done metre by metre, and every section turns on and off in milliseconds using the communication system. Since the infrastructure lies beneath the road, installing the technology in tunnels will not be a problem. For passenger cars, theoretical work has revealed that this technology is technically and economically feasible (Nicolaidis & Miles, 2015) (Nicolaidis et al., 2016). It is expected that the efficiency of this technology will reach up to 90% in the future (Nicolaidis et al., 2017). Figure 3.9 illustrates the dynamic WC. The pros and cons for dynamic wireless charging can be found in appendix D.7.

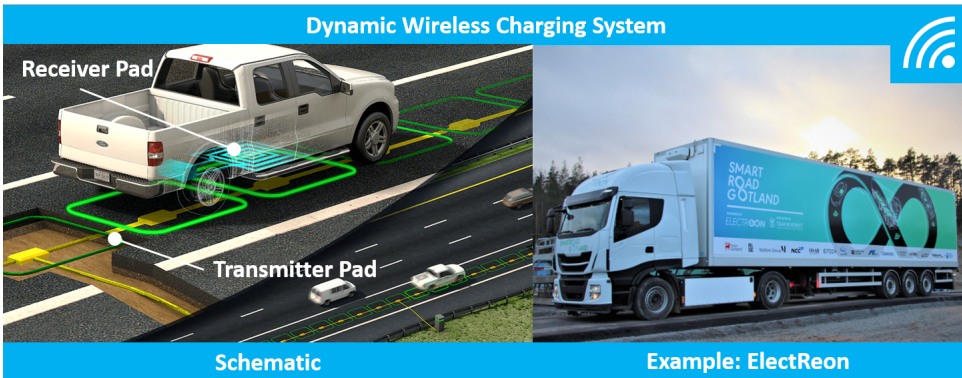


Figure 3.9: Schematic view of dynamic wireless charging (Edwards, n.d.) (electreon, 2020)

DYNAMIC WIRELESS CHARGING: SYSTEM CHARACTERISTICS

In 2016, only two pilot projects dynamic WC on public roads exist: in Belgium, and Spain (Rijkswaterstaat, 2016). They showed more development and innovations are required for this charging method. In 2020 the world's first wireless electric road charging an electric bus and truck became a reality in Sweden (electreon, 2020). The project is called Smartroad Gotland, appendix E.4 presents more information on the project. Looking at past tests the characteristics of the system are shown in table 3.7.

Table 3.7: Evaluation of Dynamic Wireless Charging System (Laporte et al., 2019) (Qualcomm Halo, 2017)

| Characteristics | |
|--|---|
| Power | 25-125 kW |
| Mode compatibility | All(Trucks, bus and car) |
| Visual distraction | low |
| Physical obstruction | low |
| Efficiency | 70-90% |
| Weather | low |
| Moving parts | no |
| Battery requirement | low |
| Space requirement | high |
| Spatial integration | low |
| Market ready 2025 | no |
| Supporting country | Sweden |
| Automation | yes |
| Example companies | Electreon AB, and Witricity |
| Lifespan | 40 years |
| Construction Cost | High (Project Smartroad Gotland cost 10 million euro, 1 km WC road takes 1 night of construction) |
| Charging 80% of a 300 kWh battery | 116 min |

DYNAMIC WIRELESS CHARGING: CONCLUSION








The dynamic WC charges a moving BET with induction, using multiple road charging units, a vehicle charging unit, a communication system, and a feeder station. By charging the BET while it is on the move, the power and efficiency drop. The system is still able to propel trucks on a road, as shown in Sweden, however, low efficiency is a drawback. Similar to the stationary WC, it has low obstruction and can power different types of modes. It is still a question whether the system will be market-ready and desirable before 2025, primarily due to the low efficiency. The system also has a negative public view on magnetic fields, even more with multiple road charging units.

3.7. INFLUENCE OF CHARGING METHODS ON INFRASTRUCTURE

FIGURE 3.10 shows a summary of the technical characteristics and the qualitative comparison for all the different charging methods that can be used to charge the different BET types (Single Unit, Single Trailer, and Specialize). It is derived by using the information discussed in this chapter. The charging methods are compared for each characteristic and given a color (green, red, or yellow). Green means the charging method is favorable for the charging infrastructure considering the particular characteristic, red means it is not favorable, and yellow means something in between.

This chapter adds to the RQ by looking at how the charging methods would influence a feasible charging infrastructure and which one is most promising or likely to be used in feasible charging infrastructure. These questions are discussed below. In short, the plug-in, stationary catenary, and third rail are most promising or likely to be used in a

feasible charging infrastructure.

| |  Plug-In |  Battery Swap |  Catenary Static |  Catenary Dynamic |  Third-Rail |  WC Static |  WC Dynamic |
|-----------------------------|---|--|---|--|--|---|--|
| Power [kW] | 3,3-350 | 3 minutes | 50-600 | 60-120 | - | 200-300 | 25-125 |
| Modal compatibility | All | All | No car | No car | All | All | All |
| Visual distraction | Medium | High | Medium | High | Low | Low | Low |
| Physical obstruction | High | High | Medium | High | Low | Low | Low |
| Efficiency [%] | 97 | - | 97 | 97 | 97 | 85-93 | 70-90 |
| Weather | High | Low | Medium | High | Medium | Low | Low |
| Moving parts | Yes | Yes | Yes | Yes | Yes | No | No |
| Battery requirement | Medium | High | Medium | Low | Low | Medium | Low |
| Space requirement | Low | Medium | Low | High | High | Low | High |
| Spatial integration | Medium | Medium | Medium | High | Medium | Low | Low |
| Construction cost | Medium | High | Medium | High | High | Medium | High |
| Market ready 2025 | Yes | Yes | Yes | Yes | Yes | Maybe | No |
| Supporting country | - | China | Netherlands | Germany | Sweden | USA | Sweden |
| Automatization | No | Yes | Yes | Yes | Yes | Yes | Yes |
| Example company | Tesla | Nio Power | Heliox | Siemens | elways | WiTricity | WiTricity |

Most Promising









| Characteristics | Description |  |  |  |  |  |  |  |
|-----------------------------|---|---|---|---|---|---|---|---|
| Power [kW] | The energy output by a charge station | | | | | | | |
| Modal compatibility | If a truck, bus, or/and car can use the charge station | | | | | | | |
| Visual distraction | Amount of distraction the station cause to BET and others | | | | | | | |
| Physical obstruction | Amount of obstruction the station cause to BET and others | | | | | | | |
| Efficiency [%] | The energy efficiency during energy transfer | | | | | | | |
| Weather | The sensitivity of the charge station to the weather | | | | | | | |
| Moving parts | Mechanical movements during the charging process | | | | | | | |
| Battery requirement | Requirement of large and/or high number of batteries | | | | | | | |
| Space requirement | The square meter necessary for the charge station | | | | | | | |
| Spatial integration | Amount of change to the surrounding due to the charge method | | | | | | | |
| Construction cost | Indicator of how expensive the charge station will be | | | | | | | |
| Market ready 2025 | Charge method implementable starting year 2025 | | | | | | | |
| Supporting country | A country with a succesful public pilot. | | | | | | | |
| Automatization | Direct human interaction with the station during charging | | | | | | | |
| Example company | A company that develop and offer the charge method | | | | | | | |
| Most Promising | The favourable charge method for a feasible charge infrastructure | | | | | | | |

Figure 3.10: Summary of the technical and qualitative characteristics of all the charging methods.


3.7.1. STATIONARY CHARGING METHODS


Stationary charging makes it possible for companies to install, own, and manage such a system at their location, e.g. depot. For governments it is important to know that stationary charging stations are a proven method, require less space, and largely have lower spatial integration and constructing cost, compared to dynamic charging. Resulting in an easier and faster feasible adaptation. The stationary charging methods include a plug-in, battery swap, stationary catenary, and stationary WC.

 The plug-in is most likely to be implemented in one of the first charging infrastructures. It has similar characteristics and social impact as conventional fuel stations. Compared to conventional fuel and catenary plug-in has a power of 350 kW, no automation, takes up slightly larger surface area and requires slightly more number of stations in charging infrastructure. Plug-in charging infrastructure is a base reference point to compare other charging methods.

 The battery swap is difficult to implement for only last mile city logistic in one city,


making it a less promising charging method. In addition to the high requirement of space and batteries for each battery swap station, which leads to a high construction cost per station.


 The most promising stationary charging method for feasible charging infrastructure in Amsterdam 2025, is a stationary catenary. The municipality of Amsterdam will be able to snowball their electric buses success case knowledge and construct a promising feasible charging infrastructure for BET. Similar to the plug-in, the stationary catenary has low space requirements, medium construction cost and spatial integration. But they are superior in the field of the required number of charging stations and safety, due to the automation, lower visual physical obstruction, and higher power.


 WC stationary shows great potential looking at the characteristics, but it is not market-ready for feasible charging infrastructure in 2025. It has a low societal impact and only requires space for parking of the vehicles. However, it is still unsure whether it is market-ready in 2025, and the low efficiency requires more demand on the grid when producing high power.

3.7.2. DYNAMIC CHARGING METHODS

Dynamic charging is effective when used on highways for long hauls across the country and most interesting for the national Dutch government. It enables BET to carry smaller batteries and extra stops for charging are no longer required, leading to lower social impact, primary inside the city. This makes the step from conventional trucks to BET easier, which is beneficial for smaller businesses and international transport. The dynamic charging methods include dynamic catenary, third-rail, and WC dynamic.

 The dynamic catenary has some negative technical and qualitative characteristics compared to the other dynamic charging methods, i.e. high spatial integration, visual distraction, physical obstruction, and sensitivity to weather. Therefore, dynamic catenary it is not considered a promising dynamic charging method for a BET charging infrastructure in this thesis.

 From all the dynamic charging methods, third-rail is the most promising. It has positive technical characteristics, including medium spatial integration, low visual distraction, and low physical obstruction, which makes it more socially acceptable. But most importantly, third-rail is market-ready in 2025 and successfully used in Amsterdam.

 Dynamic WC shows great potential when looking at the characteristics. It does not take up any physical space above ground, resulting in a low societal impact. However, it won't be market-ready in 2025 making it less promising for 2025.

4

EVALUATION OF STAKEHOLDERS

WITH electric vehicles being less noisy and more environmentally friendly compared to conventional vehicles, the general public perceives electric vehicles, including BET, positively (Quak et al., 2016). Different stakeholders have an important role in this process to ensure a large uptake and successful implementation of battery electric trucks (BET) with its charging infrastructure. Therefore, it is important to understand stakeholders and the charging strategy. This chapter looks at the sub-question: *"What position do stakeholders take with the implementation of charging infrastructure?"*. The chapter is split into three sections. The first section 4.1 explains the methodology, which is the Three-Dimensional Stakeholder Analysis (3dSA). The second section 4.2 presents the stakeholders which are included in the 3dSA. The results of the 3dSA are shown and discussed in the final section 4.3.

4.1. WHAT IS THREE-DIMENSIONAL STAKEHOLDER ANALYSIS?

A successful BET and charging infrastructure implementation and construction requires change, e.g. trip profile, charging/fueling moment, and vehicle type. The change has a large impact on society and the wider environment. Numerous stakeholders can affect or be affected by the outcome of the implementation. To manage change and risks, it is important to consider and understand stakeholders before acting (Demir et al., 2015). It is chosen to do a Three-Dimensional Stakeholder Analysis (3dSA). This gives higher transparency to a stakeholder's characteristics and agenda, and creates a stronger link to risk management.

The three dimensions that are important to know in a 3dSA, when initially considering stakeholders, are (Murray-Webster & Simon, 2006)(Demir et al., 2015):

1. **Power:** The ability and authority of the stakeholder to influence the implementation, either 'powerful' (+) or 'weak' (-). This can be due to their positional or resource power in the sector, or the credibility as a leader or expert.

2. **Interest:** The urgency by a stakeholder, positioned as 'active' (+) or 'passive' (-) in the implementation.
3. **Attitude:** The position of a stakeholder, whether they are 'backers' (+) or 'blockers' (-) of the implementation.

Drawing these three dimensions in a matrix divides the stakeholders into 8 different labels. The 8 labels are summarised in figure 4.1. To be able to label the different stakeholders it is important to understand each stakeholder, specifically their drivers and concerns. It ensures robust assumptions on the stakeholder and optimizing the stakeholder engagement strategy. The next section will discuss the different stakeholders, and label them accordingly.

4

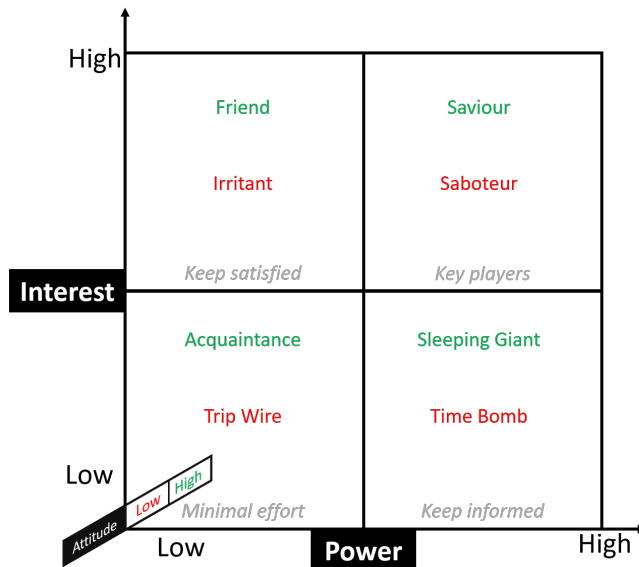




Figure 4.1: The eight different labels from the Three-Dimensional Stakeholder Analysis (Murray-Webster & Simon, 2006)(Demir et al., 2015).

4.2. WHO ARE THE STAKEHOLDERS?

THE stakeholders included in the 3dSA are shown in figure 4.2 and described below.

1.  **National Government:** Constructing the Dutch climate agreement and set the rules to lower the nation's greenhouse gas emissions.
2.  **Local Government:** Also known as a municipality, the ruling body of a group of residential areas, i.e. cities and villages, with the associated surrounding area. They are tasked with leading the implementation of ZE zones.

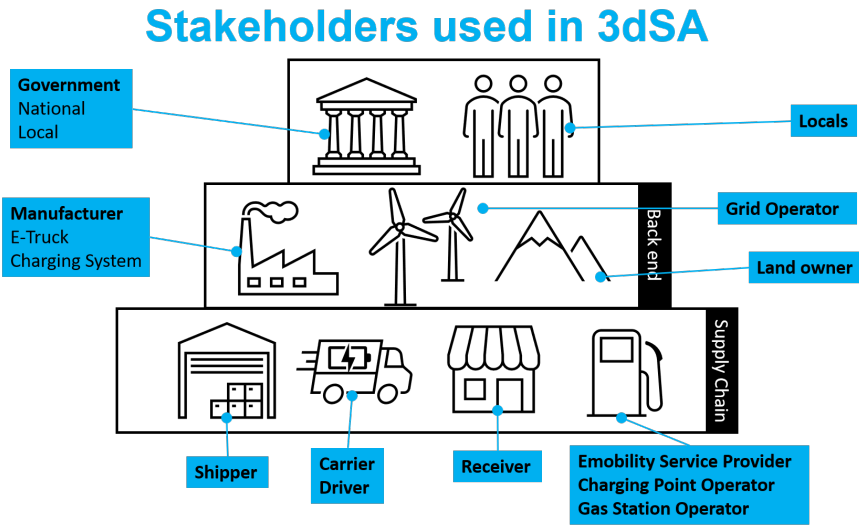














Figure 4.2: The stakeholders that are included in the 3dSA.

3.  **Locals:** Individual, group, or community likely to be affected by the BET and charging infrastructure implementation.
4.  **Truck Manufacturer (TM):** Developing and producing BET, also known as original equipment manufacturer (OEM) for trucks.
5.  **Charging Systems Manufacturer (CSM):** Developing and producing charging technology equipment, also known as original equipment manufacturer (OEM) for charging systems.
6.  **Grid Operator (GO):** Providing the transportation of energy in the form of electrical power using the fixed infrastructure. The electrical power is transmitted from generation plants over the electrical grid to regional or local electricity distribution operators.
7.  **Landowner:** Owning the real estate that the charging infrastructure requires.
8.  **Shipper:** Seller and sender of goods to a receiver.

9.  **Carrier:** Transporting the goods from shipper to the receiver, also known as logistic operator. They manage the flow of things between the point of origin and the point of consumption to meet the requirements of customers. They own or lease the BET and employ the drivers.
10.  **Driver:** Direct users of the BET and Charging infrastructure. Employed by the carrier and have the most interaction with the charging infrastructure network.
11.  **Receiver:** The buyer and end user of the goods that are shipped.
12.  **Emobility Service Provider (EMSP):** Offering BET charging service to BET drivers by helping to find charging stations, start charging events, and pay with various methods. They add value by enabling access to a variety of charging points around a geographic area by using the software.
13.  **Charging Point Operator (CPO):** Owning and operating a pool of charging points, consisting of the physical charging technology equipment. They provide charging possibilities for BET. Value is added by connecting smart charging devices to EMSPs.
14.  **Gas Station Operator (GSO):** Owning and operating conventional gas stations.

4.3. RESULT AND DISCUSSION OF THE THREE-DIMENSIONAL STAKEHOLDER ANALYSIS

THE input used for the 3dSA is primarily based on four reports. The first report by (Wolbertus, 2020) looked at the perspectives of stakeholders on charging infrastructure development for passenger cars. The second report by Topsector Logistiek (2019) looked at the charging infrastructure for city logistics EV. The last two reports by Quak et al. (2016) and Rijkswaterstaat (2016) conducted interviews with different stakeholders to understand their view on BET and charging infrastructure. The reports all share the idea that stakeholders are important for the success of BET and charging infrastructure implementation.

RESULT

Figure 4.3 shows the results of the 3dSA, where all stakeholders are labeled. TM has been in the transportation and logistics sector for a long time. With the senior position, they are powerful. In the past, they have received a lot of criticism from governments for their slow action concerning BET development, showing a blocking attitude. Currently, the

large TM has taken a more active interest in the development of BET. The factors that influence this are the success of electric cars and modified trucks, increasing demand for sustainability, innovative characteristics, and government criticism.



CSM, EMSP, and CPO are active stakeholders and backers for BET and charging infrastructure implementation. Their power is weak because they are new to the transportation sector.



The GSO have a senior position in the transportation sector. The implementation of BET and charging infrastructure competes with the internal combustion engine trucks (ICET) and gas stations, and are therefore a treat to GSO profit and business. The GSO are powerful, active, and blockers for the implementation.



The carriers are powerful and backers. They are backers because the ZE zone may be inevitable, and they cannot stay behind in innovation. They have a senior position by controlling the transportation in the city. Their interest depends on incentives because they find it hard to have a positive business case with BET, primarily the economic viability. The Dutch government has incentives to encourage carriers resulting in them being active. Besides financial incentives, carriers can also own the charging stations which gives them control over site access, charger type, placement, and timing. This control may be needed because charging infrastructure is one of the largest unknowns and sources of anxiety for fleets considering the near-term adoption of this technology. In the future, carriers may adopt a business model geared towards reducing transport movement into cities by creating or joining up urban networks (Den Boer et al., 2017). The business model may also consider increasing road safety while reducing noise and emission to gain a competitive edge.



The shippers and receivers are powerful, passive, and backers. They are backers because the ZE zone may be inevitable, and they cannot stay behind in innovation. They have a senior position, by financing and requesting transportation. Shippers choose a carrier primarily based on price and time. Green delivery is taken into account and has a large weight when this leads to a competitive advantage. A trend shows that shippers become demanding driven by timelines and convenience. The shippers' actions are of influence on the need and desires of receivers who are the end users and financiers.



Drivers are employed by the carrier. They are weak and passive because they do not benefit or gain anything from the change. Before experiencing BET, drivers did not have a strong opinion or interest on BET. However, after using BET for a couple of months drivers were positive and backer.



The GO are powerful, active, and backers. This is shown by the foundation ELaad, formed by the dutch grid operator, who has taken a pro-active role in supplying current for the electric cars plug-in systems.



National and local governments are powerful and backers. The national government wrote the climate agreement, but gave the local government the responsibility for the implementation of BET and charging infrastructure. This leads to the national government to have a passive role and the local government an active role. Local government has several views, with two of them being to mandate and implement green tendering for construction projects, and to bundle deliveries for facility logistics (Den Boer et al., 2017). The government’s view on promoting the supply and demand of large volumes of BET and charging infrastructure is by giving out incentives. Their view on urban planning is to separate the flow of traffic from dominant pedestrian and cyclist areas.



The locals are weak, passive, and backers. They are the public opinion on the implementation. This opinion can change from backer to blocker, and from weak to powerful, depending on how the implementation unfolds and whether individuals form groups or unions.



The landowners are powerful, passive, and backers. They own the real estate and determine whether the required modification to the land will happen.

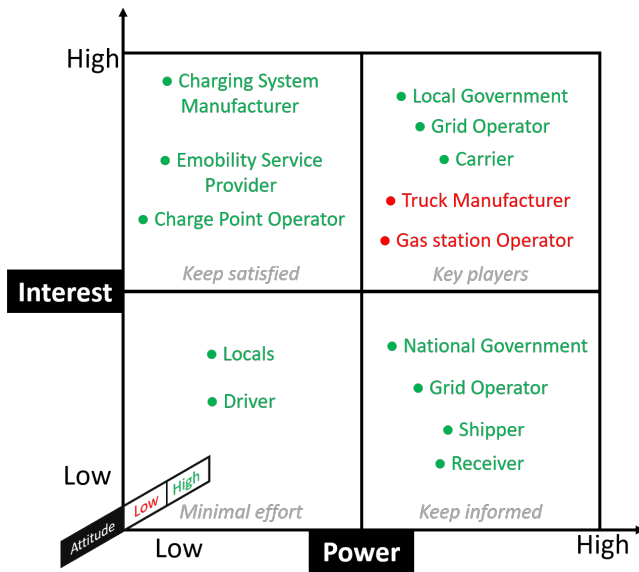


Figure 4.3: Visualisation of the 3dSA on the stakeholders.

DISCUSSION

Recommendation on which stakeholder is important to engage with, can be derived using figure 4.1 and 4.3. The carriers, grid operators, and local governments are stakeholders with the label saviour. These stakeholders need to be paid attention to and kept by

your side. The charging system manufacturers, Embobility service providers, charging point operators, drivers, and locals are stakeholders labeled as friends or acquaintances. They should only be kept informed. The gas station operators and truck manufacturers are labeled as saboteur, meaning they require to be engaged to disengage and to be cleaned up after. The last group includes the receivers, landowners, and national government, and are labeled as sleeping giants. They need to be engaged to awaken them.

The stakeholders with the labels saviour, friends, or acquaintance can be maintained passively. However, some stakeholders still need support from the government. Carriers require incentives and manufacturers require freedom to run tests. Similar to carriers, shippers and receivers also require an incentive to support the cause. Their primary view is to maximize profit and keep transportation low. The stakeholders labeled saboteur or sleeping giant requires a more urgent and active engagement to either disengage them or awake them. It may be possible for gas station operators to transfer to charging point operators, as they already have the experience and real estate.

4.4. INFLUENCE OF STAKEHOLDERS ON CHARGING INFRASTRUCTURE

This chapter adds to the RQ by looking at what role stakeholders can take for feasible charging infrastructure in 2025. This section looks at the overall role a local government can take and their expected stance, based on current practice. Followed by the expected overall stakeholder role for constructing charging stations, also based on current practice. However, governments can deviate from the expected role and affect feasible charging infrastructure differently. This will be further discussed in chapter 7.

4.4.1. OVERALL ROLE OF LOCAL GOVERNMENTS

There are several stances a local government can take. The two extreme stances are either, (1) the local government takes a pro-active stance, controls the market, does whatever it takes, and money is not an issue or (2) they are passive, do not intervene with the market, and want it as cheap and easy to implement as possible. Both sides have their pros and cons. Looking at current practices, the municipality of Amsterdam is somewhere in between the two, but leaning more towards the former. It is expected that the stance of the local government of Amsterdam that will influence charging infrastructure is:

- **Pro-active:** Shown in 2013 by the introduction of low emission zone and their clear plan of action for the future ([Gemeente Amsterdam, 2019](#)). The municipality is leading and encouraging the development and implementation of BET and charging stations.
- **Semi controlled market:** They encourage the market but try not to intervene. If charging stations or hubs around the border of the city are needed, municipals will provide the right permits, provide grants to encourage the development if needed, and lead the tendering. But they won't own, maintain, or build the charging infrastructure themselves.

- **Open for different charging methods:** As shown with the electric buses that partly travel in Amsterdam, using stationary catenary. The current dominating charging preference is corridor fast charging.
- **Providing permits, grants, and tendering:** This stance has led to passenger car charging stations growing like wild mushrooms around the city and surrounding area, and increasing the number of electric passenger and taxi cars usage.

4.4.2. STAKEHOLDERS' ROLE IN PUBLIC CHARGING STATIONS

The local government will put out tenders for multiple public charging stations part of the charging infrastructure for BET. CPO will submit different offers. The winning CPO will construct, own, operate and maintain the charging stations. Local government will monitor the CPO actions, assist them with permits and grants, and make real estate available with landowners if required. The CPO is required to consult and collaborate with the other CPO, CSM, TM, GO, and carrier to come up with standardisation and plan for a successful charging station. It is required to make public charging stations of interest.

4.4.3. STAKEHOLDERS ROLE IN PRIVATE CHARGING STATIONS

Private charging stations part of the charging infrastructure for BET will primarily be located at depots or clients. They will be primarily privately owned, constructed, operated, and maintained by carriers. Carriers primarily aim for a high profit margin without a long term vision, requiring grants by local governments to encourage them to invest in private charging infrastructure and BET. The shippers' and receivers' role will be to support carriers with the charging infrastructure, by financial reimbursement and operational support. It is of most importance that the carriers collaborate with grid operators to make sure enough energy is available for the charging stations.

5

EVALUATION OF TRANSPORT AND CHARGING DEMAND IN AMSTERDAM

As the last mile city logistic sector transitions from internal combustion engine (ICE) trucks to battery electric trucks (BET), a feasible charging infrastructure that supplies the BET with electricity is required. To be able to look and develop a feasible charging infrastructure, it is important to understand the electricity and transport demand first. This chapter answers the sub-question “*What logistic and electric demand in Amsterdam does the charging infrastructure have to supply and at what type of location?*”, by conducting a case study. The case study is based on data from the Amsterdam municipality in 2018, and it is assumed the demand will be the same in 2025. The geographical scope for this is illustrated in section 5.1. Section 5.2 presents the energy demand if city logistics would switch to BET. Section 5.3 discusses the BET charging strategy of different logistic segments in Amsterdam, which are used to determine the location of the demand.

5.1. GEOGRAPHIC SCOPE

THE case study looks at the trucks city logistics that are registered to companies inside the municipality of Amsterdam. Thus, the research area of the case study is the municipality of Amsterdam (Zip Code 4 level: 1011-1109), shown in figure 5.1.

5.2. CURRENT ENERGY DEMAND FOR CITY LOGISTICS

THE model to obtain the current energy demand by city logistics is illustrated in figure 5.2. The model consist of a input, output, spreadsheet calculation. The input for the models are the characteristics for the municipality of Amsterdam and for BET. The characteristics of BET used are energy consumption and battery capacity, taken from the

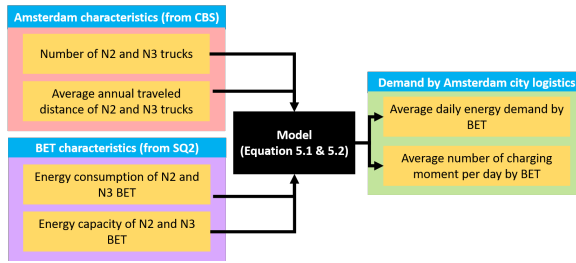


Figure 5.2: Visualisation of the case study approach.

Figure 5.3 illustrates how the CBS obtained these values.

CBS obtained the data starting with the RDW database consisting of vehicle registration for commercial vehicles, with the main user (who uses the vehicle most days) linked to a company. Leasing companies (owner of the vehicle) are often the main user of the vehicles and not the contracting party (the actual user of the vehicle). To allocate the number of vehicles to the actual users, information out of lease file by tax authorities and land use from the municipality are used. To distinguish the main users from companies and individuals, the Municipal Personal Records Database (GBA), General Companies Register (ABR), and basic database for self-employed persons by CBS are used. Also, the background characteristics of main users is extracted from these registers, such as industry and company size. The RDW and CBS register of mileage is used to map the distance traveled by the vehicles, and give an estimation of average annual traveled kilometres by a truck.

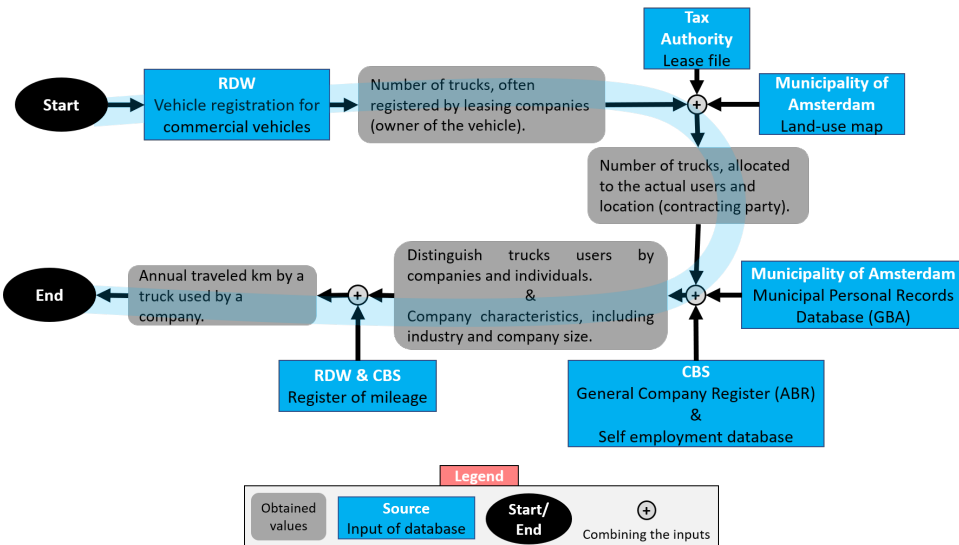


Figure 5.3: The steps CBS took to obtain the input values for this case study.

5.2.2. OBTAINED VALUES FROM DATABASES

The main values for each zip code, out the 2018 database, are the number of registered trucks and the average annual traveled distance per truck. These input values are obtained for the truck type Single Unit (N2) and Single Trailer (N3), as mentioned in chapter 2.1

NUMBER OF TRUCKS

The number of trucks registered at companies in Amsterdam are visualised in the map shown in figure 5.4. The location for the values is at the company/depot it is registered at. In 2018 there were 2.502 registered trucks in Amsterdam: 685 Single Units (n_{N2}), and 1.817 Single Trailers (n_{N3}). For all zip codes, the number of Single Trailer trucks is higher than the number of Single Units. The companies/depots located in the center (zip code: 1011-1019) and south-east (zip code: 1101) of Amsterdam have the most registered Single Units and Single Trailers. The Single Trailers also has a high number of registered trucks in the north-west (zip code: 1040-1047) of Amsterdam.

5

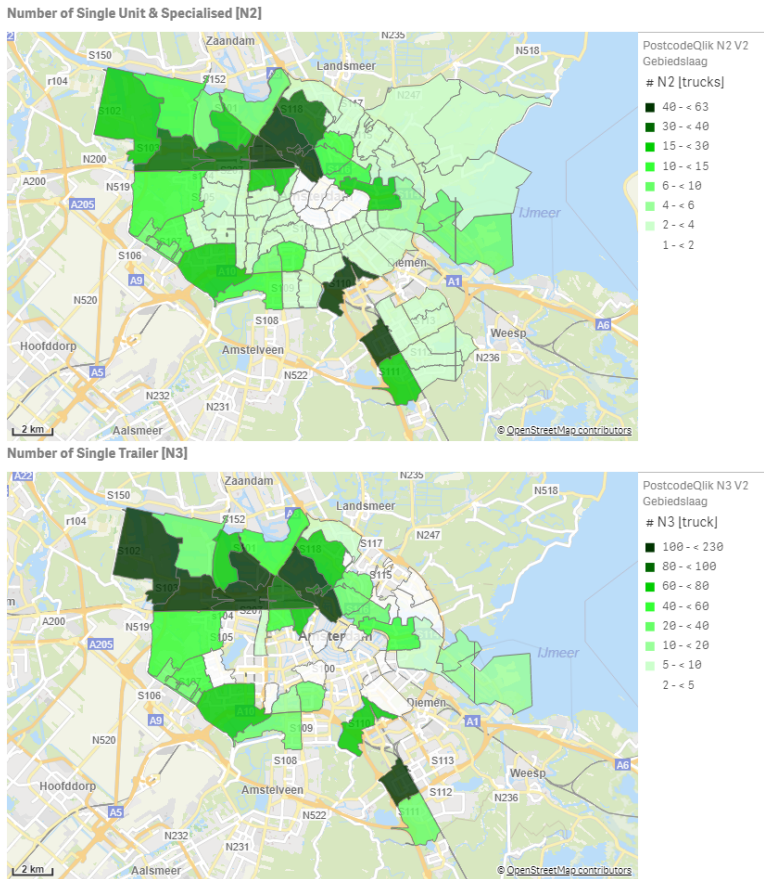


Figure 5.4: Visualisation of the number of trucks that are register to the location of a company.

AVERAGE ANNUAL TRAVELED DISTANCE PER TRUCK

The average annual traveled distance for each registered truck, Single Unit (d_{N2}^{annual}) and Single Trailer (d_{N3}^{annual}), in Amsterdam are visualised in the map shown in figure 5.5. Annually, on average, a N2 truck travels 16.541 km , and a N3 45.758 km. The location for the values is at the company/depot it is registered at. On average, Single Unit travel less distance than the Single Trailer. The trucks located in west Amsterdam (zip code: 1040-1047 and 1060-169) travel, on average, more kilometres per truck annually.

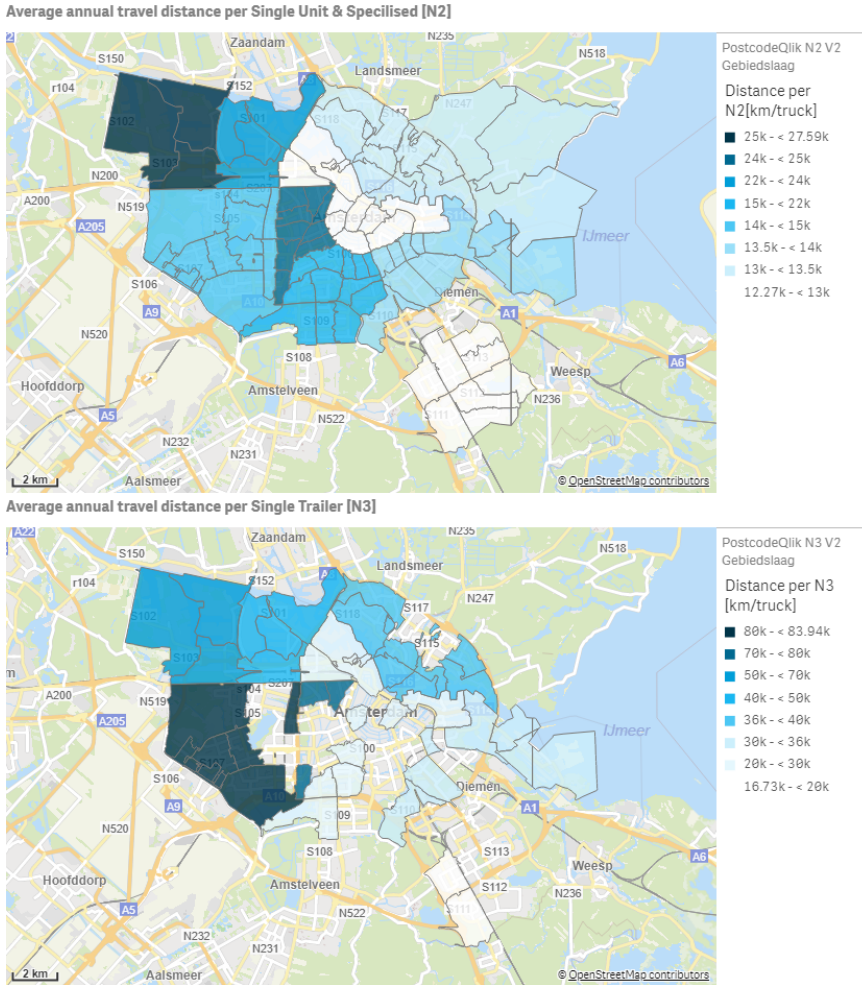


Figure 5.5: Visualisation of the average annual travel distance per registered truck in each zip code.

5.2.3. DEMAND BY CITY LOGISTICS IN AMSTERDAM

To construct a feasible charging infrastructure, it is important to know the average daily energy demand and the number of charging moments per day. These values from the case study are presented below, at the registered location. Noted that these values are only for internal trucks (registered in the municipality), and external trucks coming from outside of Amsterdam are not included. It is assumed that all the internal trucks will be BET with the implementation of ZE zone.

AVERAGE DAILY ENERGY DEMAND

Equation (5.1) shows how the total daily energy demand is calculated. The calculated energy demand is based on a couple of assumptions. The first assumption is that the energy demand only comes from the registered trucks in Amsterdam. Assuming they all are converted to BET in a instance without a transition period, while remaining the same truck type. This means the influence of other ZE fuel and vehicles type is absent. It is also assumed that the truck type Specialize has the same characteristics value as the Single Unit, because the CBS data did not make distinction between the two truck types. The final assumption is that the annual distance traveled is equally distributed over 365 days of the year, and the travel distance to the charging stations is neglected. With the knowledge that the presented values in table 2.1 are for BET that are in their prime, the highest presented energy consumption are used. For Single Unit and Specialize (c_{N2}) this is 1 kWh/km, and for Single Trailer (c_{N3}) this is 1,8 kWh/km. For the calculated demand, it is also assumed that the annual distance traveled is equally distributed over the 365 days of the year. It should be noted that the location for the values are at the registered company/depot. It is not the actual location of demand. To determine the actual location, the charging strategy has to be incorporated, as explained in the next section 5.3.

$$E_{total}^{daily} = \frac{d_{N2}^{annual} \cdot n_{N2} \cdot c_{N2} + d_{N3}^{annual} \cdot n_{N3} \cdot c_{N3}}{365} \quad (5.1)$$

with:

E_{total}^{daily} : Total daily energy demand [kWh]

d_{N2}^{annual} : Average annual traveled distance per Single Unit & Specialize [km]

d_{N3}^{annual} : Average annual traveled distance per Single Trailer [km]

n_{N2} : Number of registered Single Unit & Specialize

n_{N3} : Number of registered Single Trailer

c_{N2} : Energy consumption by Single Unit & Specialize [kWh/km]

c_{N3} : Energy consumption by Single Trailer [kWh/km]

The average daily energy demand for the truck in 2018 if they were BET are calculated and visualised in figure 5.6. It is clear that most energy demand is located in the west of Amsterdam (zip code: 1040-1047 & 1051-1069), primary in the north-west (zip code:

1040-1047). The total daily energy demand by the trucks is 441 MWh.

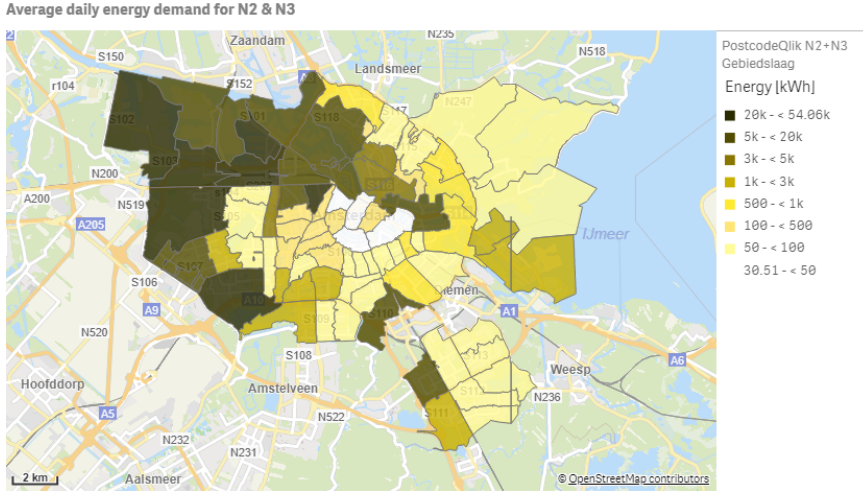


Figure 5.6: Visualisation of the average daily energy demand for 2018 Amsterdam, if the trucks (N2 & N3) were BET.

AVERAGE NUMBER OF CHARGING MOMENTS PER DAY

Equation (5.2) shows how the average number of charging moments per day is calculated. The constant for energy capacity for this research is based on the values presented in chapter 2.4, table 2.1. The assumptions and notes made for the average daily energy demand are also used here. Resulting in using the lowest energy capacity. For Single Unit and Specialize (e_{N2}) this is 150 kWh, and for Single Trailer (e_{N3}) this is 165 kWh.

$$N_{total}^{daily} = \frac{d_{N2}^{annual} \cdot n_{N2} \cdot c_{N2}}{365 \cdot e_{N2}} + \frac{d_{N3}^{annual} \cdot n_{N3} \cdot c_{N3}}{365 \cdot e_{N3}} \quad (5.2)$$

with:

N_{avg}^{daily} : Average number of charging moments per day

d_{N2}^{annual} : Average annual traveled distance per Single Unit & Specialize [km]

d_{N3}^{annual} : Average annual traveled distance per Single Trailer [km]

n_{N2} : Number of registered Single Unit & Specialize

n_{N3} : Number of registered Single Trailer

c_{N2} : Energy consumption by Single Unit & Specialize [kWh/km]

c_{N3} : Energy consumption by Single Trailer [kWh/km]

e_{N2} : Energy capacity of a Single Unit & Specialize [kWh]

e_{N3} : Energy capacity of a Single Trailer [kWh]

The average number of charging moments per day, in 2018, if the trucks were BET, are calculated and visualised in figure 5.7. On a daily average, the BET requires to use the charging infrastructure approximately 2.700 times a day.

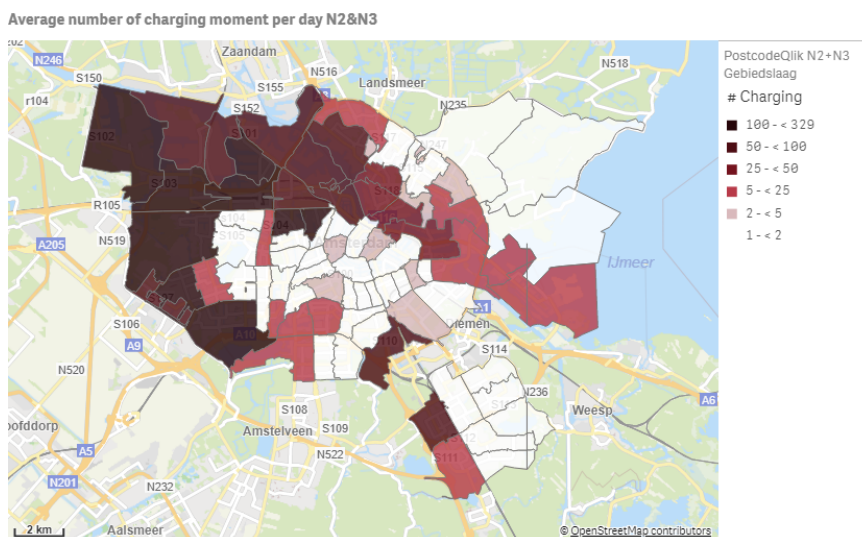


Figure 5.7: Visualisation of the average number of charging moment per day for 2018 Amsterdam, if the trucks (N2 & N3) were BET.

5.3. CHARGING STRATEGIES

BESIDES understanding where the stakeholder stands and who requires urgent engagement, it is also important to understand the behavior and strategy change when transitioning from ICE trucks to BET. The report (Topsector Logistiek, 2019) has looked at the charging strategies for the different BET users. Including the trip profile, which depends on travel distance, duration, and consumption. In this section, a small summary will be presented for the different charging strategies and use of charging stations, which will be later used in the report.

LOGISTICS SEGMENTS (BET USERS)

The BET users can be categorized into 8 logistics segments, who are responsible for the vast majority of logistical journeys in the city and most affected by the ZE-zones. The 8 logistic segments presented below are based on the segments suggested in Topsector Logistiek (2019) and additional information is taken from Den Boer et al. (2017).

1. **Waste Logistic:** Collecting sorted and residual waste from households and businesses in urban areas. On average, a daily trip of a waste logistic truck is 40 km, collecting 8-10 tonnes from 1200 households. They require a large specialized BET, with large electricity demand. The current trip profile contains multiple short trips with high density and shortstops.

2. **Construction Logistic:** Transporting construction materials to construction projects located in urban areas. This requires a large heavy BET, with large electricity demand. The current trip profile contains a limited number of trips and stops, however, they are relatively long.
3. **Parcels Logistic:** Delivering packages, letters (B2B and B2C), or high value express mail as single shipments. This segment is out of the scope of this report because of the primary use of vans for the last mile delivery and from depots to the receiver.
4. **Horeca Logistic:** Supplying hotels, restaurants, bars, and canteens, using depots located at the edge of large cities. The transportation uses large BET that can control the cargo climate, resulting in high electricity demand. The trip profile is long trips with multiple, but long stops. The receivers are in a dominant position in these markets, by determining the delivery time and frequency.
5. **Retail Food Logistic:** Transporting food related products to retailers such as supermarkets. The products can be split into groceries and fresh goods. The term groceries, in dutch "kruidenierswaren", used in this report are non-perishable goods and fresh goods are perishable goods e.g. bread, fruits, and vegetables. They are supplied using depots, where products are cross-docked. The supply chain is controlled by retailers and geared towards high volume, large scale, low-cost, and efficient operations. A supermarket is supplied minimally once a day with fresh goods, however, the non-perishable goods are not delivered every day. When only fresh goods are delivered, a single unit is used. For the transport of both fresh goods and non-perishable goods, a single trailer with high load factors is used. Per trip, a truck only carries the product for one store and travels on average of 75 km, with a maximum of 150 km. Thus the BET should be able to control the cargo climate, resulting in high electricity demand. The trip profile is multiple trips with few stops.
6. **Retail non-Food Logistic:** Transporting general cargo for non-food retailers. It uses a large BET. The trip profile is long trips (100-200 km) with few stops that are long.
7. **Service Logistic:** The transportation for the service of small repairs and installations. They use battery powered vans instead of trucks. Thus they are out of the scope of this report.
8. **Facility Logistics :** Delivering goods and services concerned with maintenance and operation to ensure the functionality of public and commercial buildings in cities. They use BET that have a large electricity demand. The trip profile is a long trip with multiple stops at business locations and incidental addresses.

CHARGING MOMENTS

Looking at BET and the report from [Topsector Logistiek \(2019\)](#), the preferred charging moments for each logistic segment is shown in figure 5.8 and their characteristics are shown in figure 5.9.

The waste segment, who does not charge at the client, is an exception due to the high density of short stops. With their long travel distance per trip (approx. 100km per trip), they require to charge along the road.

As construction segments frequently stop for longer periods at the same (large) constructing site, charging there will be a viable option. Trips to smaller or less frequently visited construction sites will require road charging due to the long distance and vehicle type.

The Horeca segment has long trips with long stops to known clients. Making it interesting to charge at the client if needed. However, the trips may be longer which requires them to charge along the road.

For the retail food segment, there are two types of trips. Both trips stop relatively long at the client. The short trips to the supermarket located near the depot will charge at the depot. Most of the fresh goods trips are of longer distance. For large clients, such as a supermarkets who are visited more frequently, have the required space, and the financial means to invest in a charging station, charging at the client becomes an interesting option. The delivery of fresh good trips to smaller clients who are visited less frequently will require roadside charging.

The majority of the charging moments for the retail non-food segment will be at the client. This is primarily due to the long trip distance (100-200 km), long stop duration at frequently visited clients, and large electricity demand due to the vehicle type. The client location for facility segment changes frequently, making charging at a client less likely. Additionally, the stop location is not always at a dock, but can be on the side of a curb.

Looking at the charging moments it is clear that most of the charging will take place at the depot. It is expected that this charging location is also the cheapest option. Most segments also show a portion of the charging moments that will take place along the road or at the client. Charging at a client requires the client to be a regular customer, to cooperate with the carrier, and also to be open to investing in the charging station. Thus, the portion of client charging is only a small percentage and neglected. All in all, it can be said that the charging moment, thus demand, of city logistics is 80% at the depot, and 20% along the road.

| Segment | Charging moment [%] | | | |
|-----------------|---------------------|------|-------|--------|
| | Home | Road | Depot | Client |
| Waste | 0 | 20 | 80 | 0 |
| Construction | 0 | 20 | 60 | 20 |
| Parcel | - | - | - | - |
| Horeca | 0 | 10 | 75 | 15 |
| Retail Food | 0 | 20 | 60 | 20 |
| Retail non-Food | 0 | 25 | 30 | 45 |
| Service | - | - | - | - |
| Facility | 0 | 10 | 85 | 5 |

Figure 5.8: BET charging strategy of the different logistic segments (Topsector Logistiek, 2019).

| Segment | BET type | Trips per day | | Stops per trip | |
|-----------------|----------------|---------------|----------|----------------|----------|
| | | # Trips | Distance | # Stops | Duration |
| Waste | Specialise | Multiple | Long | Multiple | Short |
| Construction | Single Trailer | Few | Long | Few | Long |
| Parcel | - | - | - | - | - |
| Horeca | Trailer & Unit | Few | Long | Multiple | Long |
| Retail Food | Single Unit | Few | Long | Few | Short |
| Retail non-Food | Single Trailer | Few | Long | Few | Long |
| Service | - | - | - | - | - |
| Facility | Single Unit | Few | Long | Multiple | Short |

Figure 5.9: Characteristics of each logistic segment (Den Boer et al., 2017) (Topsector Logistiek, 2019).

USE OF CHARGING STATION BY LOGISTIC SEGMENTS

There are two main ways logistic segments use the charging infrastructure to charge their BET:

- **Overnight charging:** uses low power to charge BET for a longer period, which is cheaper than opportunity charging. This is commonly done outside work hours, starting at 17:00-18:00.
- **Opportunity charging:** uses high power to quickly charge a BET as much as possible in a short amount of time, commonly during working hours when BET are parked or stopped.

To make the electric grid more robust, it is expected that smart charging will be a must in the future.

- **Smart charging** is an active strategy that efficiently manages the charging of BET, flattening the demand curve over time and preventing a high demand peak. This lowers the disruption on the electric grid and decreases the required investment in reinforcing the grid (Tamis et al., 2017)(Hilshey et al., 2012).

Overnight and opportunity charging with smart charging are explained more in-depth in appendix F. The main takeaway is that opportunity charging leads to less charging stations compared to the use of overnight charging, where one charging station will be used

by one BET each day on average. With the high powers that are possible with plug-in and catenary, it is assumed that the logistic segments will only use opportunity charging with smart charging. This means multiple BET can use one charging station in a day.

6

CONSTRUCTION OF REQUIREMENTS FOR CHARGING INFRASTRUCTURE

TO answer the RQ that aims to understand a feasible charging infrastructure, it is important to state the requirements that indicate when a charging infrastructure is feasible in the eyes of the local government. Feasible is defined as something that is implementable with acceptable resistance while complying with the view and goals of the local government. This chapter will use the results from the sub-questions 1-4 to derive requirements to answer the last sub-question: *“What are the requirements that make a charging infrastructure technological and socially feasible, considering the different charging methods, stakeholders’ agenda, and current transport demand?”*. In section 6.1 the use-case for the charging infrastructure and the road map for local government are described. Section 6.2 presents the requirements, based on the use-case, road map, and previous chapters. The requirements are split into four types of requirements: (1)functional constraints (FC), (2)non-functional constraint (NFC), (3)functional objectives (FO), and (4)non-functional objectives (NFO). The constraints are the requirements that a charging infrastructure has to comply with to be considered feasible and implementable in Amsterdam. The objectives are the requirements used to compare the feasible charging infrastructures. The infrastructure that optimizes the objectives the best is the preferred feasible charging infrastructure.

6.1. USE-CASE AND ROAD MAP

THE use-case is charging battery electric trucks (BET) using the charging infrastructure, in the year 2025. The BET is used by carriers for last mile city logistics, in the municipality of Amsterdam with a Zero Emission (ZE) zone inside the ring of A10. The charging infrastructure is a network of charging stations that recharge BET. The process steps for the use-case are shown in figure 6.1. To construct a feasible charging infrastructure that achieves these process steps, the local government will have to take a pro-active role, as mentioned in chapter 4.4, and follow the road map shown in figure 6.2. However,

the ownership of the charging infrastructure itself will be discussed in chapter 7.2.

Process for the use-case

The steps that will be taken in this use case to fulfil the function:

- Step 1. The charging infrastructure provides the BET with charging station locations.
- Step 2. The BET is parked at or driven near the charging station.
- Step 3. The charging station connects to the BET.
- Step 4. The BET specifies how much electricity is required.
- Step 5. The charging station identifies the BET.
- Step 6. The charging station checks the specification of the BET.
- Step 7. The charging station calculates how much electricity it can offer the BET.
- Step 8. The charging station offers to charge the BET, using the calculated electricity.
- Step 9. The BET accepts the offer.
- Step 10. The charging station recharges the battery of the BET.
- Step 11. The BET requests, or the charging station identifies, a charging stop.
- Step 12. The charging station stops charging the BET.
- Step 13. The BET disconnects from the charging station.
- Step 14. The BET leaves the charging location.
- Step 15. The charging station resets and updates the availability to the charging infrastructure.

Figure 6.1: The process of the interaction between BET and charging infrastructure for the use-case.

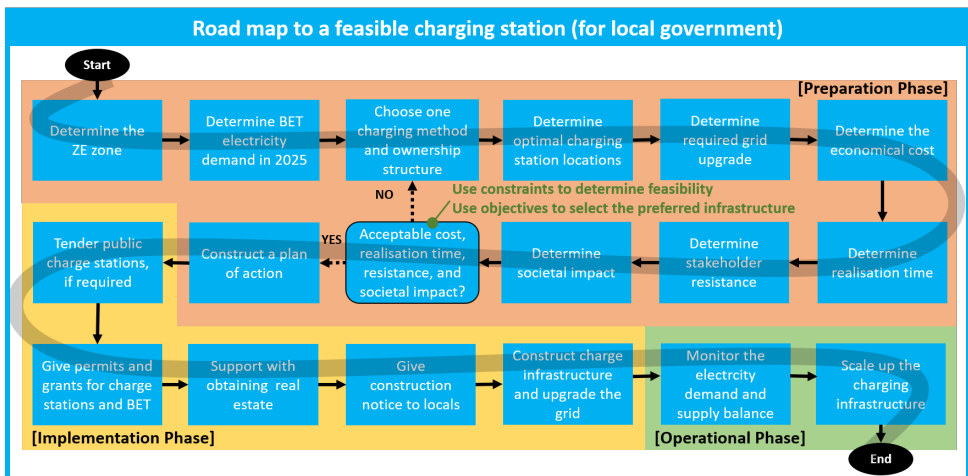


Figure 6.2: A road map for the local government to realize a feasible charging infrastructure.

6.2. REQUIREMENTS

THE requirements that are important for local government during the road map are split into four types (Robertson, 2001): (1) functional constraints (FC), (2) non-functional constraint (NFC), (3) functional objectives (FO), and (4) non-functional objectives (NFO).

- **Constraints:** mandatory for the charging infrastructure and have to comply with them to make it feasible and implementable in Amsterdam. Meaning constraints are binary and can never be part of a trade-off.
- **Objectives:** should be complied with by the charging infrastructure as much as possible. The objectives are the requirements used to compare the feasible charging infrastructures. The infrastructure that optimizes the objectives the best is the preferred feasible charging infrastructure.
- **Functional requirements:** things that the feasible charging infrastructure has to do, and it is the reason for its design.
- **Non-functional requirements:** the attributes or qualities that the feasible charging infrastructure has to have.

It should be noted that the requirements are constructed for local government, based on the knowledge from previous chapters, use-case, road map, and the view and goals of the local government. With the input and brainstorming with experts in the field (Senior consultant Wim de Goffau and consultant Sanne Aelfers at DISTRICON), the view and goals are validated and formulated as:

- **Societal impact:** Implementing an infrastructure on such a large scale requires stakeholder approval, mainly from the public. The societal impact has an impact during the construction, use, and formally also the decommissioning phase. The public resistance may be reduced by ensuring low visual pollution, safety, no decreasing traffic flow, and low disruption that affects the public.
- **Spatial planning:** Space in cities is scarce, primarily in city centers where also the truck movement should be at a minimum. Thus it is important to consider where to place the charging stations, how many, and how much space it takes up. The spatial planning is an aspect of societal impact.
- **Environmental impact:** The goal of implementing ZE is to lower the air pollution, and ensure sustainability. The infrastructure should aim for the same goals, by looking at the electricity that is used in the use phase.
- **Encourage BET:** The charging infrastructure requires to be attractive to encourage the use of BET and break the chicken and egg cycle. Attractiveness depends on factors such as available charging capacity, standardization, charging speed, waiting time, durability, realization time, scale-up possibility, and user tariffs. In addition to a clear set plan for the future, that gives companies knowledge on what they can expect from the local government.

- **Cost neutral:** From the point-of-view of a local government, a charging infrastructure should at least break even. Or at most not require constant investment and grants by the government to keep the infrastructure sustainable. This can be achieved by encouraging cooperation between stakeholders and share charging stations, outsourcing, or/and multiple modal uses.

The requirements for a charging infrastructure are presented in figure 6.3 and 6.4. The requirements are to support and give understanding to the local government on what is important for the implementation of a feasible charging infrastructure. Using these requirements, feasible charging infrastructure will be constructed in the next chapter to answer the research question.

Functional Constraints (FC)

The charging infrastructure must be able to....

- FC 1.keep track of available charging capacity at each charging station. (Availability)
- FC 2.communicate with ~2500 BET, including those from other European countries. (Communication)
- FC 3.(smart) charge ~2700 times a day. (Capacity)
- FC 4.supply available charging capacity that matches the BET electricity demand of ~440 MWh a day. (Capacity)

Non-Functional Constraints (NFC)

The charging infrastructure must....

- NFC 1.not disrupt the current traffic flow. (Societal)
- NFC 2.not disrupt the electric grid. (Societal)
- NFC 3.have a low/medium visual distraction, see figure 3.17. (Societal/Safety)
- NFC 4.have a low/medium physical obstruction, see figure 3.17. (Safety)
- NFC 5.prevent passersby to come in direct contact with the electricity. (Safety)
- NFC 6.have a low/medium space requirement inside cities, see figure 3.17. (Spacial)
- NFC 7.produce less CO₂, NOx, and PM₁₀, than current fuel provision infrastructure (i.e. tankers, energy requirement of gas stations). (Environmental)
- NFC 8. Focus on one charging method in short term. (Experience)
- NFC 9.have a charging method with a proven success case. (Experience)
- NFC 10.be realized before 2025. (Realization)
- NFC 11.have a set plan of action before 2021. (Realization)
- NFC 12.have road charging stations that are 24/7 publicly accessible. (Availability)
- NFC 13.have a 24/7 service maintenance for malfunctions. (Durability)
- NFC 14.have smart charging to lower the energy demand peaks . (Durability)

Figure 6.3: The main constraints, for local governments, to implement a feasible charging infrastructure.

| Functional Objectives (FO) | |
|--|--|
| <i>The charging infrastructure should...</i> | |
| FO 1. |physically obstruct stakeholders as little as possible. (<u>Societal</u>) |
| FO 2. |be able to charge a BET as fast as possible. (<u>Charging speed</u>) |
| FO 3. |be able to charge multiple transport modes (truck, bus, car). (<u>Modal use</u>) |
| FO 4. |use existing gas station locations. (<u>Location use</u>) |
| Non-Functional Objectives (NFO) | |
| <i>The charging infrastructure should...</i> | |
| NFO 1. |be realized without disrupting the public/surrounding. (<u>Societal</u>) |
| NFO 3. |have a low public resistance. (<u>Societal</u>) |
| NFO 5. |have low spatial impact inside the city center. (<u>Spacial</u>) |
| NFO 6. |have charging stations that require little space. (<u>Spacial</u>) |
| NFO 7. |use green electricity. (<u>Environmental</u>) |
| NFO 8. |be cost-neutral for the local government. (<u>Cost</u>) |
| NFO 9. |encourage cooperation for charging stations between stakeholders. (<u>Cost</u>) |
| NFO 10. |have charging stations with a short realization time. (<u>Realization</u>) |
| NFO 11. |prevent >2 BET waiting for the same charging location. (<u>Availability</u>) |
| NFO 12. |be able to scale up in the future. (<u>Future</u>) |

Figure 6.4: The main objectives, for local governments, to implement a feasible charging infrastructure.

7

RESULTS: FEASIBLE CHARGING INFRASTRUCTURE

THE research question “*What are feasible charging infrastructures to supply the electricity demand for Amsterdam’s battery electric trucks that travel in the municipality with a zero emission zone?*” for the master thesis is answered in this chapter, followed by a conclusion and discussion in the next chapter. The research question is answered by constructing feasible charging infrastructures for different alternatives, using the results of the empirical research of each sub-questions as shown in section 7.1. The constructed feasible charging infrastructures based on the different charging method and ownership are presented in section 7.2. The infrastructures are compared to each other and the preferred charging infrastructure is derived in section 7.3. In the final section 7.4 sensitivity analyses are conducted for the preferred charging infrastructure.

7.1. KEY TAKEAWAY FROM THE SUB-QUESTION

THE constructed feasible charging infrastructure has to supply the electricity demand by the city logistic’s battery electric trucks (BET) located in the municipality of Amsterdam. The feasible charging infrastructure is constructed based on key takeaways from the sub-questions (SQ):

- **SQ 1 - Key takeaway from the evaluation on BET (chapter 2.4):** To first understand what is getting charged, the BET are evaluated by a literature study. Battery electric trucks are trucks that are powered by electricity, and store energy in batteries, which require (re)charging. They are split into truck type Single Unit (N2), Specialised (N2), and Single Trailer (N3). When the city logistics switch from conventional truck to BET, it is assumed the truck type will stay the same.
- **SQ 2 - Key takeaway from the evaluation on charging methods (chapter 3.7):** A literature study is used to evaluate the charging methods for BET. The most promising charging methods are stationary plug-in, stationary catenary, and dynamic third-rail. The plug-in and catenary charging stations have a power of 350

| | Charge methode | Infra ownership |
|---------------|---------------------|------------------|
| Alternative 1 | Stationary Plug-In | Local government |
| Alternative 2 | Stationary Plug-In | Carrier and CPO |
| Alternative 3 | Stationary Plug-In | Shipper and CPO |
| Alternative 4 | Stationary Catenary | Local government |
| Alternative 5 | Stationary Catenary | Carrier and CPO |
| Alternative 6 | Stationary Catenary | Shipper and CPO |
| Alternative 7 | Dynamic Third-Rail | Local government |
| Alternative 8 | Dynamic Third-Rail | CPO |

Figure 7.1: The different alternatives for the feasible charging infrastructure.

kW ($P_{plug-in}$) and 600 kW ($P_{catenary}$), respectively, with an effeicny of 97%. It is assumed that they are used for an average of 6 hours a day (t_{daily}).

- **SQ 3 - Key takeaway from the evaluation on stakeholders (chapter 4.3):** A Three-Dimensional Stakeholder Analysis is used to evaluate the position of stakeholders, with a focus on the local government. The local government has to play a large pro-active role for a successfully implementation of the charging infrastructure. However, they want to minimise the impacts, and therefore wish to use available space for roadside charging, e.g. existing fuel stations, that are not in the city center.
- **SQ 4 - Key takeaway from the evaluation on the electricity demand (chapter 5.2.3 & 5.3):** A case study is performed to evaluate the electricity demand by BET in Amsterdam. It is assumed the electric demand in year 2025 is the same as the demand by the registered trucks in year 2018. Looking at Amsterdam in 2018, it is found that the charging infrastructure requires to supply 2.502 BET who use the infrastructure 2.732 times a day, with the average daily demand of 440.538 kWh. With the suggested charging moments, it is assumed that stationary charging infrastructure requires to supply 80% (f_{depot}) and 20% (f_{road}) of the total electricity demand at the depot and along the road, respectively.
- **SQ 5 - Key takeaway from the feasibility requirements (chapter 6.2):** For the last SQ, requirements are constructed for the charging infrastructure using the empirical results of the previous SQ 1-4 and views of local government in mind. The requirements are split into constraints and objectives. The charging infrastructure will be feasible for local government, when it complies with the constraints as shown in figure 6.3. feasible is defined as something implementable with acceptable stakeholder resistance while complying with the view and goals of the local government. Feasible charging infrastructures are compared using the objectives as shown in figure 6.4, to determine the preferred infrastructure.

To answer the research question, feasible charging infrastructures are constructed for the municipality of Amsterdam. For the construction, the promising charging methods infrastructures and different infrastructure ownership will be considered, discussed, and compared. Therefore, 8 alternatives will considered, shown in figure 7.1.

7.2. CONSTRUCTING FEASIBLE CHARGING INFRASTRUCTURE

This section constructs feasible charging infrastructure for the 8 alternatives from figure 7.1. The first step in the construction is to determine if a charging infrastructure is feasible for each of the promising charging methods. This is determined using the constraints from figure 6.3. If the charging infrastructure is feasible, the next step is to determine the required number of charging stations and their location. The final step is to consider the different infrastructure ownership for the feasible charging infrastructure.

7.2.1. STATIONARY CHARGING METHOD

To comply with the requirement constraints and to supply the energy demand, the stationary charging infrastructure will either use the charging method plug-in or catenary (NFC 8). The infrastructure consists of depot and road charging stations, with a 24/7 service maintenance (NFC 13), and road charging stations that are accessible to the public (NFC 12). To minimize the impact on the traffic flow (NFC 1) and city center (NFC 6), the depot stations will be located at the locations of the registered companies, and the road charging stations will be located at the existing fuel stations on the Amsterdam highway. Using electricity instead of conventional fuel already decreases pollution significantly (NFC 7). With plans for obtaining green electricity along the highway, using green electricity for roadside stations will decrease the pollution even more. Both plug-in and catenary comply with the requirement constraints of visual distraction (NFC 3), physical obstruction (NFC 4), and electricity concern (NFC 5).

The number of required charging stations at each zip code is calculated for plug-in and catenary, using the equation 7.1. The results are shown in the next two paragraphs.

$$S_i = \left\lceil \frac{E_{total}^{daily} \cdot f_{depot}}{P_i \cdot t_{daily}} \right\rceil + \left\lceil \frac{E_{total}^{daily} \cdot f_{road}}{P_i \cdot t_{daily}} \right\rceil \quad \forall i = \text{plug-in or catenary} \quad (7.1)$$

with:

S_i : Number of required charging stations at each zip code

$E_{total,zipcode}^{daily}$: Total daily energy demand at each zip code [kWh]

f_{depot} : Fraction of the charging moments at depot

f_{road} : Fraction of the charging moments along the road

P_i : Power of the charging station [kW]

t_{daily} : Duration a charging station is used in a day [hour]

FEASIBLE CHARGING INFRASTRUCTURE WITH PLUG-IN

To comply with the functional constraints, a feasible plug-in charging infrastructure will require a total of 269 plug-in stations. The distribution for the 227 depot charging stations is shown in figure 7.3. The 42 road charging stations are distributed using figure 7.2: 6 on North A10, 9 on East A10, 7 on South A10, 4 on West A10, 5 on A5, 6 on A4, and

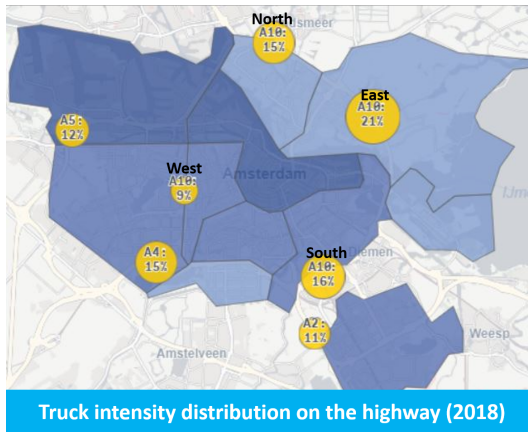


Figure 7.2: The distribution of the trucks on the highway of Amsterdam in 2018 (NDW, 2018).

5 on A2.

FEASIBLE CHARGING INFRASTRUCTURE WITH CATENARY

To comply with the functional constraints a feasible catenary charging infrastructure will require a total of 185 catenary stations. The distribution for the 160 depot charging stations is shown in figure 7.4. The 25 road charging stations are distributed, using figure 7.2: 4 on North A10, 5 on East A10, 4 on South A10, 2 on West A10, 3 on A5, 4 on A4, and 3 on A2.

7.2.2. DYNAMIC CHARGING METHOD

In general, the most promising dynamic charging method is dynamic third-rail due to the large drawbacks of the other two dynamic charging methods. The drawback of dynamic catenary is the visual and physical obstruction, and limited modes use. The drawback of dynamic wireless charging is the high uncertainty whether it is ready by 2025 and its low energy efficiency. For a charging infrastructure using third-rail to be feasible, it has to comply with requirement constraints, including the impact on traffic flow (NFC 1) and the city center (NFC 6). Third-rail would be located only on the Amsterdam highway, and not on city roads. For the Single Unit and Specialised (N2) BET, e.g. garbage truck, who may only travel inside the ring of A10 and do not drive on the highway, third-rail would be needed on city roads. Therefore, **third-rail charging infrastructure is not feasible for municipality Amsterdam**, and alternatives 7 & 8 do not comply.

7.2.3. INFRASTRUCTURE OWNERSHIP

The infrastructure ownership entails that the stakeholder will be responsible for constructing, maintaining, and operating the charging infrastructure. Different infrastructure ownership for the feasible charging infrastructure will be discussed with the objectives in mind.

Average required number of Plug-In charging stations at depot

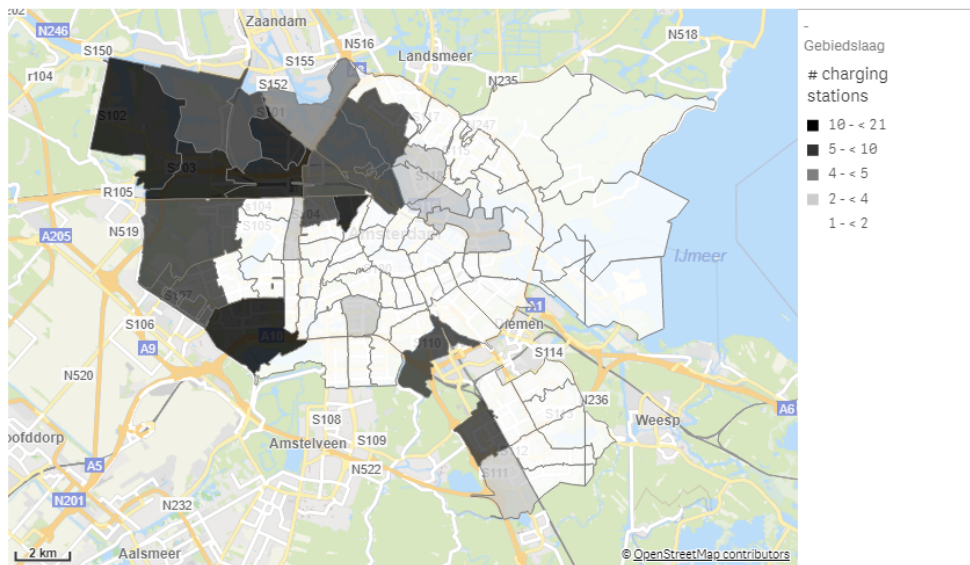


Figure 7.3: The required number of plug-in charging stations at depot per Amsterdam zip code, to supply 80% of the 2018 energy demand.

7

Average number of Catenary Static charging stations at depot

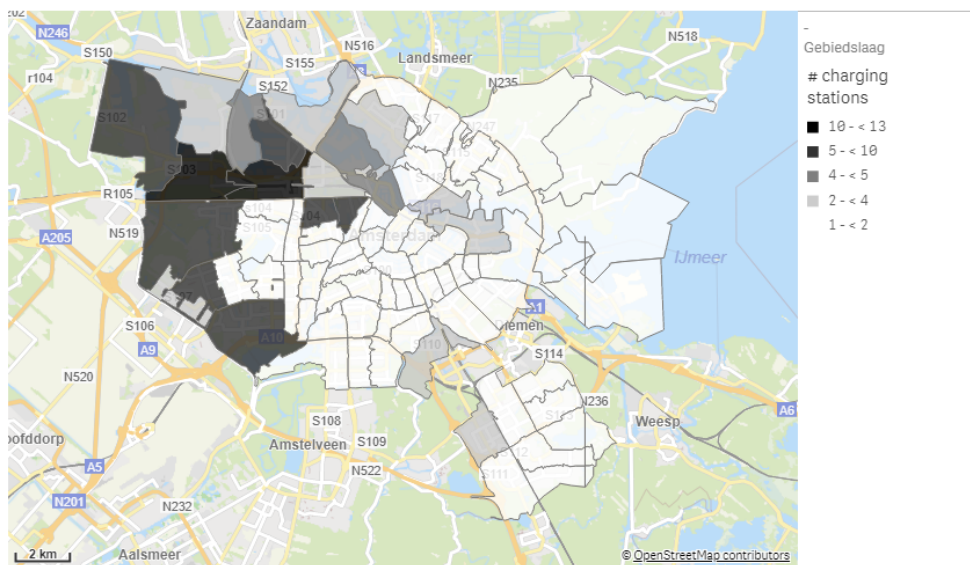


Figure 7.4: The required number of catenary charging stations at depot per Amsterdam zip code, to supply 80% of the 2018 energy demand.

LOCAL GOVERNMENT

A local government owning an infrastructure gives them the most control over the impact and implementation, and all charging stations will be publicly accessible. Owning a Plug-in charging infrastructure would be their safest bet. The technology has a lot of successful examples and has a lower R&D cost. However, the investment costs for both the stationary charging methods would still be high. It is easy for local governments to obtain space for the road charging station, as the space is owned by the government. However, as the local government does not own the space at companies, depot charging stations will lead to a higher cost. All in all, a cost-neutral (NFO 8) local government owned charging infrastructure may lead to a high user price.

CHARGING POINT OPERATOR AND CARRIER OR SHIPPER

The local government has the option to tender the ownership for publicly accessible road charging stations to Charging Point Operator (CPO). Similar to what has been done for electric passenger cars, as mentioned in chapter 4.4. As companies are willing to take more risks and invest in other charging methods to stand out, it will significantly lower the cost for local government, and enable market competition. It will also lower the user price and enable other options of charging methods, such as catenary. For the tendered road charging stations, the local government will take a supervisory role, provide grants for the construction phase, and aid with obtaining space.

The depot charging stations are located at the registered company. To lower the cost for the local government they can give ownership to carriers or shippers, and aid them with permits and grants. The stakeholder, either carrier or shipper, who owns the depot and its space, should have the ownership of the depot charging station. The other stakeholder should aid the depot charging station. Cooperation between carrier and shipper is important as they require each other to understand which BET and charging method to invest in. A carrier/shipper charging station will lead to a private or semi-private charging station, as they can also be shared with surrounding companies in the area, to lower the cost and required space.

7.3. COMPARING FEASIBLE CHARGING INFRASTRUCTURE

THE feasible charging infrastructures of plug-in and stationary catenary are compared with each other while considering different ownership. To compare and determine which of the alternatives provide the preferred feasible charging infrastructure, the objectives as shown in figure 6.4 are used.

Both charging methods are expected to be used on existing gas station locations but may require some grid upgrades (FO 4). The plug-in charging method can charge more modes than catenary (FO 3). However, catenary has a higher charging speed (FO 2), and enables less hinder to stakeholders (FO 1). For a single charging station, the space required for plug-in and catenary stations is roughly the same. For multiple charging stations the required space decreases for catenary stations compared to plug-in, making it easier to scale up (NFO 12) and have a lower spatial impact (NFO 5 & 6). This makes

catenary the preferred charging method for a feasible charging infrastructure.

The ownership of CPO and the mix of carrier and shippers is preferred over the local government, for the municipality of Amsterdam. This is due to the market competitiveness, which leads to lower investment costs for the local government, lower user prices, and broader options of charging methods.

All in all, the preferred feasible charging infrastructure is a mix of alternatives 5 and 6. It uses the stationary catenary charging method, with ownership of carrier or shipper and CPO.

7.4. SENSITIVITY ANALYSIS

SINCE there is still uncertainty in characteristic for the city logistics, charging methods and BET, it is valuable to know the change in outcome when their variables are varied. The variables of interest for the sensitivity analysis are:

- Number of trucks (city logistics)
- Charging power [kW] (for charging method)
- Energy consumption N2 [kWh/km] (for BET)
- Energy consumption N3 [kWh/km] (for BET)

The feasible catenary charging infrastructure is considered the base case with the results from section 7.2 as benchmark value. For the sensitivity analysis the same base case input values are used and only the variables of interest are changed each time. For number of trucks sensitivity analysis, the base case input is set at 100% (2475 trucks). The different percentages of number of trucks are rounded up, to obtain the number of charging stations. The rounding is to ensure that if a truck is registered at a zip code, at least one charging station is required at the zip code. The results of the sensitivity analysis are shown in figure 7.5.

The sensitivity analysis shows that low charging power of the charging method will influence the number of charging station the most, but levels off at higher power. Therefore, fast charging is a must but a charging speed of over 800 kW is not necessary. Overall, the energy consumption for N3, which is still relatively uncertain, will influence the number of charging station significantly. The sensitivity analysis for the number of trucks has similar results as for the N3 energy consumption. Meaning that the number of BET also influences the number of charging stations significantly. It shows that if the number of conventional trucks are replaced with BET in batches, the number of charging stations can also be constructed in batches.

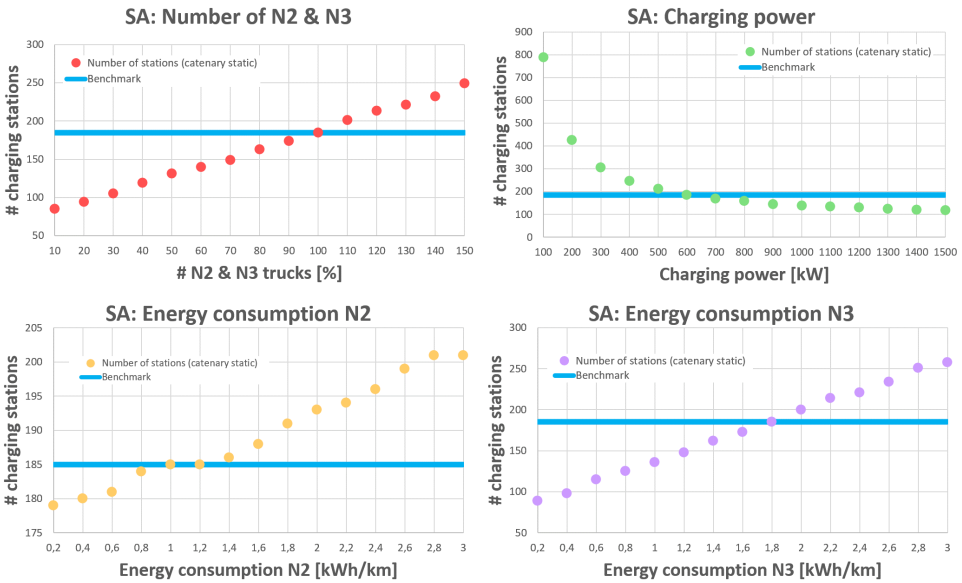


Figure 7.5: Graphical representation of the sensitivity analysis on the preferred charging infrastructure (stationary catenary) for the variables: number of trucks, charging power, energy consumption N2, and energy consumption N3.

8

CONCLUSION, DISCUSSION AND RECOMMENDATIONS

8.1. CONCLUSION

THE research question (RQ) of this research is “*What are feasible charging infrastructures to supply the electricity demand for Amsterdam’s battery electric trucks that travel in the municipality with a zero emission zone?*”. The objective of this research is to provide stakeholders, mainly the municipality of Amsterdam, with a better understanding of the different options for feasible charging infrastructure. The RQ is answered based on sub-questions (SQ) that evaluate the battery electric trucks (BET), the charging methods, the stakeholders, the energy demand, and the requirements for a charging infrastructure.

WHAT TYPES OF BATTERY ELECTRIC TRUCKS ARE AVAILABLE? (SQ 1)

A literature study is performed to evaluate battery electric trucks (BET) and answer SQ 1. The evaluation shows that BET are trucks that are powered by electricity and store the energy in batteries, which require (re)charging. Currently a handful of BET is operating on public roads. They are modified diesel trucks converted to a BET, and mainly fall under the European vehicle category called N2. Their success, and the increasing demand for BET, lead to an interest of original equipment manufacturers. Large original equipment manufacturers in the Dutch truck market all have successful pilots and are developing European vehicle category N2 and N3 BET for the near future. The technical development of BET has yet to mature, and primarily dependent on stakeholders that are not directly affected by the implementation of the ZE zone in Amsterdam.

WHAT TYPE OF CHARGING METHOD DO BATTERY ELECTRIC TRUCKS REQUIRE? (SQ 2)

A literature study is performed to evaluate charging methods for BET and answer SQ 2. The evaluation shows that the most promising stationary charging method (when a BET

is at a full stop) is stationary catenary. It uses overhead lines and pantographs to provide the highest power of all the charging methods to a fully stopped BET. This method is currently used for a couple of bus lines in the Netherlands, e.g. at Schiphol airport and several other cities including Amsterdam, Delft and Leiden. The most promising dynamic charging method (when a BET is moving) is third-rail. It uses a rail installed on the roads to provide power to a moving BET. The Swedish government has tested all the dynamic charging methods on their public road and shown most interest towards third-rail. The plug-in is the most known and popular charging method, due to the worldwide implementation with passenger cars. Plug-in may not be the most promising for BET, but is likely to be used in one of the first charging infrastructures, and should be used as a benchmark.

WHAT POSITION DO STAKEHOLDERS TAKE WITH THE IMPLEMENTATION OF CHARGING INFRASTRUCTURE? (SQ 3)

Using a Three-Dimensional Stakeholder Analysis, key players (labeled: saviour or saboteur) are identified and evaluated to answer SQ 3. The key players play a big role in a successful implementation of a feasible charging infrastructure. Local government, grid operator, and carrier are labeled saviour, meaning they have high interest and high power, with a positive/high attitude towards the implementation. Truck manufacturers and gas station operators are labeled saboteur. They also have high interest and high power but a negative/low attitude towards the implementation. It is concluded that the local government (labeled as a saviour), plays a big role and should be pro-active with the implementation, including semi-controlling the market, open for different charging methods, and by providing grants, permits, and tendering. Their interest is to encourage the use of BET, while keeping its societal and environmental impacts low, e.g. use of scarce space in inner city and visual pollution.

WHAT LOGISTIC AND ELECTRIC DEMAND IN AMSTERDAM DOES THE CHARGING INFRASTRUCTURE HAVE TO SUPPLY AND AT WHAT TYPE OF LOCATION? (SQ 4)

A case study is performed for the municipality of Amsterdam to evaluate its demand and the expected charging strategy. It is assumed the electric demand in year 2025 is the same as the demand by the registered trucks in year 2018. In 2018, the municipality of Amsterdam has a total of 2.502 registered trucks. If these trucks were BET with the same truck types, they would require a daily energy demand of about 440 MWh, with approximately 2700 charging moments a day. It is the same quantity of energy as currently annually consumed by 220 Amsterdam households. Peaks of energy demand are expected and require the use of smart charging. Looking at the charging strategy, the location of the charging moments can be assumed to be 80% at the depot/company and 20% along the road, with mainly opportunity charging.

WHAT ARE THE REQUIREMENTS THAT MAKE A CHARGING INFRASTRUCTURE TECHNOLOGICAL AND SOCIALLY FEASIBLE, CONSIDERING THE DIFFERENT CHARGING METHODS, STAKEHOLDERS' AGENDA, AND CURRENT TRANSPORT DEMAND? (SQ 5)

Using the results from the SQ 1-4, requirements are constructed, which are used to construct and compare feasible charging infrastructures. The requirements are split into constraints and objectives. The charging infrastructure will be feasible for local government when it complies with the constraints presented in figure 6.3. Feasible is defined as something that is implementable with acceptable resistance while complying with the view and goals of the local government. The main idea of the constraints is that a feasible charging infrastructure must be able to provide 440 MWh a day for the 2700 BET that will use the infrastructure at least once a day while preventing peaks on the electric grid. Additionally, the charging infrastructure must have a low disruption on the current urban ecosystem, all while being realized before 2025. The feasible charging infrastructures can be compared to determine the preferred infrastructure using the objectives presented in figure 6.4. Important objectives for feasible charging infrastructure are the charging speed to opportunity charge a BET and the total amount of space it requires.

WHAT ARE FEASIBLE CHARGING INFRASTRUCTURES TO SUPPLY THE ELECTRICITY DEMAND FOR AMSTERDAM'S BATTERY ELECTRIC TRUCKS THAT TRAVEL IN THE MUNICIPALITY WITH A ZERO EMISSION ZONE? (RQ)

The RQ is answered by forming feasible charging infrastructure for the municipality of Amsterdam, using the results from all SQ. Different charging methods and infrastructure ownership were looked at. The most promising dynamic charging method (third-rail) is not feasible for a charging infrastructure in the municipality of Amsterdam. The most promising dynamic charging method is third-rail. For third-rail to supply the energy demand it has to have charging infrastructure in the city center. However, space in the city center is scarce. This makes the most promising dynamic charging method not feasible for a charging infrastructure in the municipality of Amsterdam. **The preferred feasible charging infrastructure for the municipality of Amsterdam, with ZE zone inside the ring of A10, uses the stationary charging method called stationary catenary.** A total of 185 stationary catenary charging stations would be required to supply the energy demand of the trucks if they were BET of the same truck type. 160 of the stationary catenary charging stations should be located at the depot, and 25 along the road. **The ownership of the road charging stations should be tendered to Charging Point Operators. The ownership of depot charging stations should go to either the carrier of the shipper, depending on who owns the depot. The pro-active role of the local government is to tender, supervise, provide grants and permits, and aid with obtaining space.**

8.2. DISCUSSION

IN general, the presented preferred feasible charging infrastructure for Amsterdam should not be implemented one to one but used as a guide for the municipality to understand the order of magnitude, their options, and which direction should be explored. This was also the aim of the research, and for further research to build upon. The findings and

methodology of the research can be used for other municipalities. In this section the research is discussed based on the scope, assumptions for simplification, and the current availability of in-depth specifications and data.

IMPLEMENTATION AND ACCEPTANCE RATE OF ZE

The scope of the research is the year 2025, with the assumption that the zero emission (ZE) will be fully adopted by everyone in the city logistics in 2025. However, there is a real possibility that in reality the ZE will be fully enforced and adapted later than 2025. This gives the possibility for developing technology such as wireless charging, which would not be feasible before 2025, to become a feasible option.

THE CHANGE TO BET

The scope of the research is on battery electric trucks (BET). It is assumed that the city logistics trucks will all switch to BET (without transition period) and that other ZE fuel types or vehicles are not in the picture. However, (small) companies may not have the capability, interest, or confidence to switch to BET, which is 100% electric, resulting in avoiding the ZE zones, looking at other energy types (e.g. hybrid or hydrogen trucks), or/and other transport modes (e.g. distribution vans or electric cargo bikes). This changes the need and demand for electricity by trucks.

THE CHANGE IN TRUCK TYPES

One of the assumptions made in the research is that, when the ZE zone is implemented, the city logistics will behave the same. Meaning they will travel the same routes, use the same transport modes, and the truck type will remain the same. The only difference is that the diesel powered trucks are converted to BET. In reality, this may not be the case. It is still uncertain if trucks will be dominant in Amsterdam, and if so, which truck type, and what routes will be taken.

The local government prefers less (large) vehicle movement in the city. This can lead to hubs and depots (re)locating outside the city. They may use less large vehicles, Single Trailer (N3), to distribute their product in the city of Amsterdam, but use a higher number of smaller vehicles, e.g. distribution vans (N1) or single unit (N2). Furthermore, electric transport for smaller vehicles is also further developed than large vehicles. On the other hand, carriers contracted by the different shippers may combine the different products in one large vehicle at a hub or depot. Decreasing the number of movements in the city by using less (small) vehicles and longer but optimized routes.

CHARGING STATION USE AND DETOUR DISTANCE

For the calculations for the number of daily charging moments, it is assumed that the BET will only charge when the battery has a capacity that is too low for their next daily trip. Due to range anxiety, this may not be the case. Drivers may demand that their vehicles are charged every day if they use it daily, to have the certainty they can finish their daily trip comfortably. Additionally, the detour time and distance to go to the charging stations are not taken into account for the electricity demand due to unknown exact charging stations location and travel routes.

CHARGING STRATEGY AT CLIENTS

During the research on charging strategy, it was found that only a small percentage would charge at clients. It requires the client to be a regular customer, to cooperate with the carrier, and also invest in the system. Due to privacy reasons, the data used for this research lacked detailed information on the client, including their characteristics and location. Making it difficult to determine if the client is a regular customer, and can cooperate with the carrier to invest in a charging station. Therefore it is assumed that, in general, the charge moment for BET is at the depot or along the road. Charging at the client is neglected in this research. This does not mean client charging will not take place at all. Exceptions, such as large clients, e.g. Albert Heijn, may be interested to invest in charging areas at their location.

REGISTERED TRUCKS IN AMSTERDAM

As depot charging is the primary charging location, this would mean the trucks that are registered to companies in Amsterdam will have the bulk of the energy demand. These trucks are used in this research. In reality it is possible for trucks that are registered outside of Amsterdam to drive in the Amsterdam ZE zone. They may require charging too. It is expected this will be along the road, with only a small amount of energy demand. This research did not take these external trucks into account due to lack of data. However, it is important to consider them. Additionally, it is assumed that the trucks registered in Amsterdam will all travel in the ZE zone. Therefore, all registered trucks in Amsterdam require to be BET, even though they may also have trips outside of Amsterdam.

USE OF CHARGING STATION

The research assumes the possibility of high power charging of 350-600 kW, with the use of smart charging and only opportunity charging. Meaning multiple trucks can use a station in a day. Opportunity charging leads to less charging stations compared to the use of overnight charging, where one charging station will be used by one BET each day on average.

8

LACK OF DETAILED CHARACTERISES

In the construction of feasible charging infrastructure the actual cost and required space in square metres are not taken into consideration. Primarily due to the lack of information on the charging methods at the time. As the technology is progressing rapidly, information on cost and space for the charging methods should be available soon.

The energy consumption used in the research is based on pilots and BET that are not operational yet. From the sensitivity analyses it is clear that the effect of energy consumption by the BET, primarily N3 trucks, strongly influence the number of required charging stations. Thus, it is important to obtain the actual value of the energy consumption for operating BET.

FUTURE: 2018 TO 2025

The feasible charging infrastructure is based on the input values of the year 2018. In reality, the charging infrastructure will need to supply the demand of 2025, which is still

unknown. The research consist of sensitivity analyses that shows the influences of different uncertain input values.

TOPSECTOR LOGISTIEK REPORT

This thesis is inspired by, and builds further upon the report by [Topsector Logistiek \(2019\)](#). Both the Topsector report and this thesis have looked at the number of required charging stations for BET in Amsterdam. This thesis considers a feasible stationary catenary charging infrastructure for the municipally of Amsterdam. The energy demand is assumed to come from the 2.502 trucks, registered to the municipality of Amsterdam in 2018 with an average annual travel distance of 37.915 km, which are converted to BET. It is also assumed the BET will not charge at a client and they will only opportunity charge, which means that multiple BET can use a charging station in a day. This thesis concludes that a feasible charging infrastructure requires 160 (600 kW) charging stations at the depot and 25 (600 kW) along the road.

The Topsector report considers a stationary plug-in charging infrastructure for the Metropolitan Region Amsterdam. The energy demand is assumed to come from the 4.700 trucks, that have an average annual travel distance of 70.000 km and travel at least once in the ZE zone, which are converted to BET. It is also assumed the BET will primarily overnight charge, meaning only one BET can use a charging station in a day. The Topsector report concluded that the Metropolitan Region Amsterdam requires 1.157 (150 kW) charging stations at the depot, 10 (350 kW) along the road, and 183 (150 kW) at a client.

The results of both pieces of research are significantly different and difficult to compare. This is primarily due to the different scope and assumptions. The resulting number of charging stations needed, from this thesis, is significantly lower due to the assumption of only opportunity charging, use of high power, a smaller geographical scope, absence of charging at a client, and the absence of external trucks coming from outside the municipality that will also require charging.

RULE OF THUMB AND BACK OF THE ENVELOPE CALCULATION

To calculate the same values presented or a BET feasible charging infrastructure in this thesis, some rough back of the envelop calculations can be preformed using the rules of thumb, constants, and key takeaways listed below.

- *Charging power* higher than 800 kW does not significantly change the required charging stations.
- *Energy consumption* of the most dominant truck type impacts the number of charging stations the most.
- *BET* are still primarily in the pilot and testing phase. The average N2 BET have an energy consumption of 1 kWh/km and an energy capacity of 150 kWh, and the average N3 BET have an energy consumption of 1,8 kWh/km and an energy capacity of 165 kWh

- *Stationary catenary* is the most promising charging method for a charging infrastructure. The technology for BET is still in the pilot and testing phase, but it is already in use with some bus lines in Schiphol and Amsterdam. A stationary catenary charging stations has a charging power 600 kW, with an efficiency of 97%. In the thesis it is assumed a charging stations are used 6 hours a day.
- *Charging moment* of BET is 80% at depot and 20% along the road. Therefore the most energy demand is at the industrial areas, which are located north-west in the city of Amsterdam. The charging along the road can be based on the distribution of trucks intensity on the highways.
- *Energy demand* can be roughly calculated by taking the product of travelled distance and the BET energy consumption.
- *Number of charging moments* can be roughly calculated by dividing the energy demand by BET energy capacity.
- *Number of charging stations* can be roughly calculated by dividing the energy demand by the charging power and by the hours the charging stations are used.

8.3. RECOMMENDATIONS

BASED on the conclusion and discussion, recommendations are provided for further research and for the municipality of Amsterdam.

8.3.1. RECOMMENDATIONS FOR FURTHER RESEARCH

The recommendations for further research are based on the discussion. These recommendations are:

- Further research should look at feasible charging infrastructure if ZE is to be adopted later than 2025. With the rapid speed of innovation, other options may become available (e.g. wireless charging).
- Further research should take the influence of other ZE energy types and transport modes into account, including solutions that are available for last mile delivery. Including hydrogen but also electricity demand for other modes such as electric cargo bikes. Thus further research should combine the research of different ZE vehicle solutions for city logistics to understand the overall ZE energy infrastructure.
- Further research should look into how truck types will change when diesel trucks switch to BET.
- Further research should look into the influence of client charging.
- Further research should take external trucks that are not registered in Amsterdam, but will travel in the Amsterdam ZE, into account.
- Further research should consider the different uses of charging stations. Companies may want to use overnight charging over opportunity charging.

- With the availability of more detailed characteristics (e.g. cost and required space) of charge method, further research should take them into account to study if the stationary catenary charging infrastructure is still feasible and the preferred charging method.
- To implement the feasible charging infrastructure in the municipality of Amsterdam, a detailed plan of action is required. The plan requires further research to look at more specifications such as what type of charging stations should be installed and at which specific zip code 6 locations, additionally to where grid upgrade is required for the charging stations.
- Further research should forecast the input value to 2025 for a more realistic feasible charging infrastructure.

8.3.2. RECOMMENDATION FOR MUNICIPALITY AMSTERDAM

In short, the municipality is urged to construct a detailed plan of action that includes stationary catenary charging infrastructure and share knowledge with other municipalities to have a national standardisation. The current technology development of BET and charging methods are at still at the pilot phase. Moreover, the construction of the charging infrastructure still has to take place after the technology has matured. It seems too early to implement a full-scale ZE zone by 2025.

To realize a feasible charging infrastructure, a road map for Municipality Amsterdam is presented in figure 6.2 in chapter 6.1. The road map consists of three phases: preparation, implementation, and operation. With the ZE zone planned to take form within 5 years, the operational phase should be reached by then. The municipality is currently at a key point for a successful implementation of the feasible charging infrastructure. The municipality must complete the preparation phase by the end of 2020, which includes a clear plan of action for the construction of charging stations. This will give time for the implementation phase, which includes stakeholders investing in BET and constructing the charging stations.

Municipality Amsterdam should consider the preferred charging infrastructure, and gain more detailed and realistic knowledge for implementing stationary catenary charging infrastructure. This is accomplished by encouraging and supporting further research and trading knowledge with other municipalities. The first step for the municipality should be to form a collaborative team. The collaborative team should include representatives from carriers, shippers, grid operators, charge point operators, and the stakeholders that have worked on the stationary catenary charging stations for buses that are already in and around Amsterdam.

The collaborative team should provide the municipality with a forecast for 2025-2030. The forecast should consist of a technical, transportation, and implementation forecast. The technical forecast should show how the technical development of BET and charging stations will evolve and become available in the next couple of years. The forecast should be based on interviews with the manufacturers and academics that are research-

ing the technology and have insights on its trends, and based on the past development for passenger cars. The technical forecast should also look at the development and influences of other ZE solutions, including hydrogen trucks and electric cargo bikes. The transportation forecast should show the change and growth in the transportation market, including the number and type of trucks that will travel in the municipality in the upcoming years and the percentage of BET and the energy demand. The implementation forecast should consist of detailed information for implementing ZE zone and feasible charging infrastructure that take the technical and transportation forecast into account. Thus implementation forecast should include the total cost, zip code location, used square metres, grid upgrades, construction time, and type of charging stations used. It is expected that the technical availability will not come all at once but in phases, thus the ZE zone and charging infrastructure should also be implemented in phases, starting at the city center and slowly expanding out. Therefore the forecast should conclude with a plan that the municipality can follow to implement the ZE zone and charging infrastructure in phases throughout the years. Besides the forecast the collaborative team should also focus on the effects of the ZE zone on smaller companies who may have trouble adapting and investing in BET.

It is also advised to invest in the development of smart charging, which will be needed in the future with the increasing electricity demand. It will benefit the electric grid for charging in general, including BET and electric passenger cars. It is strongly advised for the municipality of Amsterdam to communicate with other municipalities to share knowledge and standardise a charging method across the nation.

UNCERTAINTY IN IMPLEMENTING ZE ZONE IN 2025

The municipality of Amsterdam wants to implement the full scale ZE zone inside the A10 highway ring by 2025. Based on the results of the thesis, implementing such a full size ZE zone at once in 2025 is too quick and not advised. In this thesis it is assumed the technological development of the piloted BET discussed in chapter 2 and the stationary catenary charging method, discussed in chapter 3, are matured and market ready before 2025. In reality this is still uncertain, and they are currently only in the pilot phase.

By implementing the ZE zone in 2025 the municipality tries to force the transition to BET in Amsterdam, having a direct effect on carriers, shippers, and receivers. However, it should be noted there are more dependencies and that the carriers, shippers, and receivers do not influence the technical development, and thus should not be forced into BET if the market is not ready. The truck manufacturers and charging system manufacturers who do have an influence on the technical development are still largely focused on the development for passenger cars and smaller city logistics vehicles.

After the charging method and BET are fully matured, the construction of the charging infrastructure still has to take place. The suggested 185 charging stations in this thesis is based on the number of trucks in 2018. It is likely that the number of trucks will increase in 2025, thus the required number of charging stations that have to be constructed will also increase.

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A

APPENDIX: VEHICLE CLASSIFICATION

USING the Federal Highway Administration (FHWA) vehicle classification, shown in figure A.1, vehicles can be categorized into different vehicle types (Randall, 2012). The FHWA classification consists of passenger transport (classes 1 to 4) and freight transport (classes 5 to 13). Freight transport can be divided into four types of trucks, which are in different classes based on the number of axes. The first truck type is the Single Unit (bedrijfswagen), known as box truck or cube truck, comprised of classes 5 to 7. These are trucks on a single frame, commonly used for short haul and conventional city distribution due to their relative smaller transport capacity. The second truck type is the Single Trailer (trekker met oplegger), known as tractor-trailer or semi-trailer, comprised of classes 8 to 10. This truck type consists of two units, one of which is a truck power unit. They are commonly used for long haul conventional distribution due to their trailer size capacity, or for transporting large volumes of product to one location. The third truck type is the Multi-Trailer, comprised of classes 11 to 13. This truck type consists of three or more units, one of which is a truck power unit. They are used for the same purpose as the Single Trailer, but can transport even a larger volume. The fourth truck type is called Specialize, which includes garbage trucks, construction trucks, flatbed trucks, and other Specialized trucks that aren't used for conventional distribution.

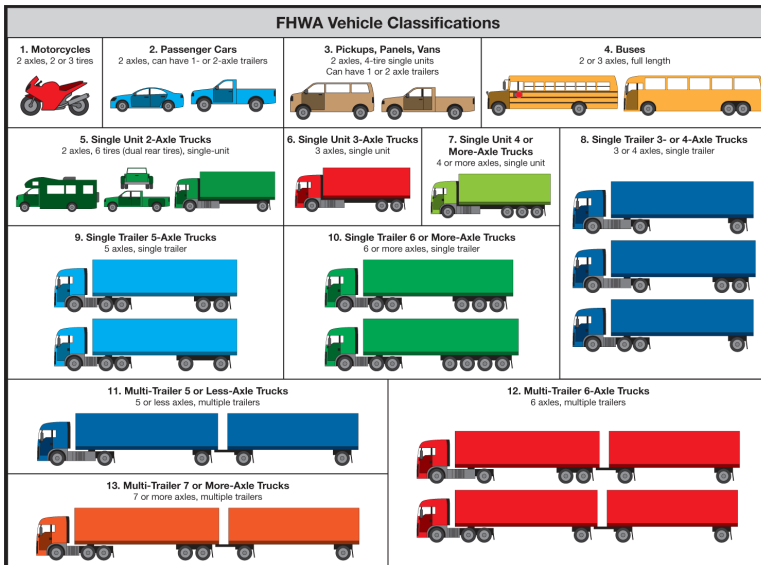


Figure A.1: FHWA 13-Category Scheme for Vehicle Classifications. (Randall, 2012)

B

APPENDIX: CHARACTERISTICS OF OPERATIONAL AND PILOTED BATTERY ELECTRIC TRUCKS

Data of BET that are currently operational, in the pilot phase or planned for the future is shown in table [B.1](#). The data includes the OEMs mentioned before, Tesla who has been a leading innovator in electric vehicles, and companies that have custom modified ICET to BET, such as EMOSS and e-force.

Table B.1: Suppliers of BET in operational, pilot, and planning phase. (DAF, n.d.) (Volvo, 2019) (Mercedes-benz, 2019) (Scania, 2020) (MAN, 2018) (Transport Topics, 2019) (EMOSS, 2017) (EForce, 2019) (Tesla, 2017) (Kroon, 2020)

| Company | GVW [ton] | Drive | Power [kW] | Battery Capacity [kWh] | Range [km] | Consumption [kWh/km] | Type | Status |
|--------------------------------|-----------|---------|------------|------------------------|------------|----------------------|----------------|-------------|
| DAF LF Electric | 19 | 4x2 | 195 | 222 | 220 | 1 | Single Unit | Pilot |
| DAF CF Electric | 37 | 4x2 | 210 | 170 | 100 | 1,7 | Single Trailer | Pilot |
| Volvo FL Electric | 16 | 4x2 | 165 | 300 | 300 | 1 | Single Unit | Pilot |
| Volvo FE Electric distribution | 27 | 6x2 | 330 | 200 | 200 | 1 | Single Unit | Pilot |
| Volvo FE Electric refuse | 27 | 6x2 | 330 | 200 | 120 | 1,67 | Specialized | Pilot |
| Mercedes-Benz eActros | 18/25 | 6x2 | 250 | 240 | 200 | 1,2 | Single Trailer | Pilot |
| Scania ASKO electric | 27 | 6x2/6x4 | 245 | 165 | 120 | 1,375 | Single Unit | Pilot |
| Man eTGM 18 | 18 | 6x2 | 350 | 150 | 200 | 0,75 | Single Unit | Operational |
| Man eTGM 26 | 26 | 4x2 | 350 | 240 | 200 | 1,2 | Single Trailer | Operational |
| Iveco Nikola Tre | 18/26 | 4x2/6x2 | 480 | 720 | 400 | 1,8 | Single Trailer | Planned |
| EMOSS BREYTER distribution | 19 | 4x2 | 200 | 200 | 180-240 | 0,8-1,5 | Single Unit | Operational |
| EMOSS CWS sanitair | 12 | | | 120 | 180-200 | 0,6 | Specialized | Operational |
| E-FORCE EF | 18/26 | 4x2 | 440 | 170/340 | 350-450 | 0,8-1,3 | Single Trailer | Operational |
| Tesla Semi | | | | 594-1000 | 475-800 | 1,25 | Single Trailer | Planned |

C

APPENDIX: BATTERY ENERGY STORAGE UNIT

As the focus of the thesis is on BET, the energy storage is the batteries. The storage device consists of one or more electrochemical cells that convert the stored chemical energy into electrical energy. Note that a battery can only be charged using direct current (DC). In the market, there are five types of batteries suitable for road transportation applications, which are lead-acid battery, nickel battery, ZEBRA battery, lithium battery, and metal-air battery (Tie & Tan, 2013). One of the promising energy storage devices for BET is a lithium battery, due to their lightweight, high specific energy, high specific power, high energy density, and no poisonous metals. The disadvantages of lithium batteries are its high production cost, high metal cost, and it requires a protection circuit to maintain safe operation. The other promising battery type are metal-air batteries. Such as lithium-air battery, which is still in the research state but has significantly higher energy density.

When considering an appropriate battery for BET, several characteristics have to be taken into account. This includes battery capacity, energy stored in the battery, volume, and weight. They are measured in ampere-hours (Ah), watt-hours (Wh), liter (L), and kilogram (kg). Energy storage specifications for potential interesting batteries are shown in table C.1. The battery capacity is not constant or a fixed value. The nominal capacity of a battery is defined as the maximum Ah a fully charged battery can deliver under specified conditions. These conditions include the discharge voltage, discharge current or rate, and the battery temperature. To prolong the lifetime of a battery it is important to consider the cycle count of the battery and battery capacity. This can be done by using either the state of charge (SoC) or the depth of discharge (DoD) (Spiers, 2012). The latter is the fraction or percentage of the capacity which has been removed from the fully charged battery. The state of charge is the fraction or percentage of the capacity that is still available in the battery. Usually, when discussing the current state of the battery SoC is used, while DoD is often used when discussing the lifetime of the battery after

Table C.1: Characteristic of (potential) batteries

| Energy storage type | Specific energy [Wh/kg] | Energy density [Wh/L] | Speicfic power [W/kg] | Life cycle | Production cost [\$/kWh] |
|--------------------------|-------------------------|-----------------------|-----------------------|------------|--------------------------|
| Lithium battery | | | | | |
| Lithium-iron sulphide | 150 | - | 300 | 1000 | 110 |
| Lithium-iron phosphate | 120 | 220 | 2.000-4.500 | 2.000 | 350 |
| Lithium-ion polymer | 130-225 | 200-250 | 260-450 | 1.200 | 150 |
| Lithium-ion | 118-250 | 200-400 | 200-430 | 2.000 | 150 |
| Lithium-titanate | 80-100 | - | 4000 | 18.000 | 2.000 |
| Metal-air battery | | | | | |
| Aluminium-air | 220 | - | 60 | - | - |
| Zinc-air | 460 | 1400 | 80-140 | 200 | 90-120 |
| Zink-refuelable | 460 | - | - | - | - |
| Lithium-air | 1.800 | - | - | - | - |

repeated use. Both the scale for SoC and DoD are normally referred to as the nominal capacity (e.g. the capacity at the 10-hour rate). It is possible to find a DoD of more than 100% at a lower discharge current. This means that the battery can produce more than 100% of its nominal capacity at discharge rates lower than the nominal rate.


Recharging and discharging a battery will lead to a degradation of the battery. Cycling describes this repeating process, one cycle includes one discharge and one recharge. The cycle life is the number of cycles a battery can deliver over its life. Normally it is quoted as the number of discharge cycles to a specified DoD that a battery can deliver before its available capacity is reduced to a certain fraction of the initial capacity. To prolong the cycle life of a battery, the optimal user cycle is between 20-80%. Recharging it higher than 80% or discharging it lower than 20% can negatively impact the cycle life of a battery.

D

APPENDIX: PROS AND CONS OF THE CHARGING METHODS

D.1. PLUG-IN: PROS AND CONS

The evaluation of the plug-in charging method resulted in a list of pros and cons, as shown in figure D.1.




Plug-In

| Pros | Cons |
|--|--|
| Experience: Successful example of passenger cars. | Low power: The highest power is expected to be 350 kW before 2025. |
| Low investment cost: The investment cost for (slow) charging station are relatively low compared to battery cost. | Physical obstacle: The cord poses a trip hazard. The charging station is an obstacle when parking or leaving a depot, especially when parking in reverse. |
| Multiple modes: Trucks, buses, and cars can use plug-in charging. | Vulnerable to weather and vandalism |
| Existing standardization: Plug-in is standardized, enabling different companies to use the same system. | Changing behavior: It requires the user to remember to plug-in the BET when using slow charging. |
| Variety of charging power: Enables different charging strategies, grid balancing, and smart charging. | |
| Existing real estate: Plug-In can be implemented at existing gas stations when the ultra fast charging becomes a reality. | |

Figure D.1: The pros and cons for the plug-in charging method.

D.2. BATTERY SWAP: PROS AND CONS

The evaluation of the battery swap system resulted in a list of pros and cons, shown in figure D.2.



Battery Swap

| Pros | Cons |
|---|---|
| Fast charging time: Battery swap takes around three minutes, which is faster than refueling at a gas station. | No standardization: Batteries and their system in the BET require to be standardized across manufacturers. |
| Supporting government: As china shows interest in battery swap system, it helps standardization. It should be noted that half of the sold electric vehicles are sold in China. | Large surface area: A battery swap station for passenger cars takes up 3 parking spaces. It is expected that for BET these stations should be on the same scale; three truck parking spaces. |
| Low upfront capital cost: The batteries of BET can be bought separately or be leased. Users do not have to own the batteries but are charged for the batteries by their usage. | Assure life expectancy: Users that own their batteries and swap batteries should be assured a battery with comparable life expectancy regarding the original. |
| Technological improved batteries are easily be implemented and switched out. | No support of truck manufactures: They do not see a role for battery swapping or are unsure about the potential application. |
| Off board charging : The batteries are charged outside the vehicle. The user does not come in contact with the charging mechanism. It also enables grid balancing. | High investment cost: To ensure that fully charged batteries are always available, more batteries should be manufactured than the number of BET. A swap station for passenger car cost 3 million dollars, for BET it is expected to be higher. |
| Automation: With robotics, the system works automatically; the user only must drive to the right area and the system swaps the battery while the user is in the vehicle. | Complexity of the business model: This system has failed in the past, as shown by Tesla and the bankruptcy of Better Place. |

D

Figure D.2: The pros and cons for the battery swap charging method. (NIO, n.d.)(Vaggelas & Leotta, 2019)(Den Boer et al., 2013)

D.3. STATIONARY CATENARY : PROS AND CONS

The evaluation of the stationary catenary charging method resulted in a list of pros and cons, as shown in figure D.3.




Stationary Catenary

| Pros | Cons |
|---|---|
| <p>Bus characteristics: This system will be of most interest when routes have the same characteristics as a bus. Short hauls with fixed routes and stops, enabling opportunity charging.</p> | <p>Obstruction: It has a medium field of vision and physical obstruction. BET park in reverse when loading or unloading in a distribution center. The physical obstruction may form a problem. The obstruction can be reduced by using a stretched catenary, e.g. roof-mounted (Schiphol).</p> |
| <p>Safe: The users and others do not come near the high power that charges the BET.</p> | <p>Narrow modes use: Only Trucks and buses may use this system due to the height.</p> |
| <p>Proven concept: Pilots for buses in the Netherlands showed great success. Making it easier to innovate the system for BET.</p> | <p>Standardization: It requires truck manufacturers to standardize the pantograph system.</p> |
| <p>High power (600kW): Enables shorter charging time and opportunity charging.</p> | |
| <p>Space: Required space per charging station decreases when multiple charging stations are required at the same location.</p> | |

Figure D.3: The pros and cons for the catenary stationary charging method.

D.4. DYNAMIC CATENARY: PROS AND CONS

The evaluation of the dynamic catenary charging method resulted in a list of pros and cons, as shown in figure D.4.



Dynamic Catenary

| Pros | Cons |
|--|--|
| Continuous and relatively high power | Safety: Collision hazard with the overhead. But there is less risk for pedestrians and users. |
| Existing road: Dynamic Catenary for BET can be integrated with existing trolley line systems and road infrastructure. | Narrow modes use: Only Trucks and buses may use this system due to the height. |
| Small battery: The systems used to charge a battery or directly to power and propel the BET. Thus BET requires smaller batteries, for trips when not connected to the system. | Cost: Constructing the infrastructure for the system requires high investment costs. Additionally, when limited space is available, it is difficult to build. |
| Proven technology: The existing trolley lines shows that technology works and can be innovated for BET. | Obstruction: The high field of vision obstruction may lead to pushing back when implementing the system in the city. |

D

Figure D.4: The pros and cons for the catenary dynamic charging method.

D.5. THIRD-RAIL: PROS AND CONS

The evaluation of the plug-in charging method resulted in a list of pros and cons, as shown in figure D.5.




Third-Rail

| Pros | Cons |
|---|--|
| Low visual and physical obstruction: Low possibility for BET colliding with the system or visual distraction. | No standardization: The conduction rails and collector shoes require standardization across all modes. |
| Continuously charging: BET can use smaller batteries to travel and do not require to stop for charging. | Safety and maintenance: Over the years the system has advanced and improved its design, primarily on safety issues. Making it difficult for objects to come in contact with the power source. However, there is still a concerning factor of the possibility of touching high voltage, resulting in an electric shock hazard. |
| Multiple modes: Trucks, buses, and cars can use third-rail charging. | Frequent maintenance due to weather and objects obstructing the rail |
| Successful pilot and support: The Swedish government is one of the front runners in electric infrastructure for transport. They have tested multiple dynamic methods, including catenary and wireless charging, in an open environment. From these tests, they are making plans to invest and implement a third-rail system on highways for BET. | Difficult city implementation: Third-rail has potential when used on the highway. City implementation is difficult, due to more pedestrians, cyclists, crossovers, and litter that can come in contact with the rail. Additionally, constructing third-rail in a city is challenging due to the accessibility and obstruction from underground infrastructure especially in older cities. |
| High energy efficiency transfer | |
| Construction is relatively fast with low cost | |

Figure D.5: The pros and cons for the third-rail charging method (Bateman et al., 2018) (eRoadArlanda, 2016) (elways, 2019) (Rijkswaterstaat, 2016) (Boffey, 2018).

D.6. STATIONARY WIRELESS CHARGING: PROS AND CONS

The evaluation of the plug-in charging method resulted in a list of pros and cons, as shown in figure D.6.



Stationary Wireless Charging


| Pros | Cons |
|---|--|
| <p>Minimal influence of weather: The power transmits across water, ice, snow, mud, and gravel. Additionally, safe from vandalism and electrocutions hazards.</p> | <p>Safety concern: The generated magnetic field may still be harmful or perceived negative in the public eye. However, people within the vehicles are not exposed, and with the detection system, the system can avoid unnecessary magnetic field exposure.</p> |
| <p>No moving parts when charging, making it robust</p> | <p>Low efficiency but it is still able to produce high power</p> |
| <p>Low total cost of maintenance, operations, and parts, resulting in a low TCO</p> | |
| <p>Multiple modes: Trucks, buses, and cars can use stationary wireless charging.</p> | |
| <p>No obstruction: Better aesthetics for the public eye and no collision danger.</p> | |

D

Figure D.6: The pros and cons for the stationary wireless charging method.

D.7. DYNAMIC WIRELESS CHARGING: PROS AND CONS

The evaluation of the plug-in charging method resulted in a list of pros and cons, as shown in figure D.7.



| Dynamic Wireless Charging | |
|--|--|
| Pros | Cons |
| <p>Minimal influence of weather: The power transmits across water, ice, snow, mud, and gravel. Additionally, safe from vandalism and electrocutions hazards.</p> | <p>Safety concern: The generated magnetic field may still be harmful or perceived negative in the public eye. However, people within the vehicles are not exposed, and with the detection system, the system can avoid unnecessary magnetic field exposure.</p> |
| <p>No moving parts when charging, making it robust</p> | <p>Low efficiency but it is still able to produce high power</p> |
| <p>Low total cost of maintenance, operations, and parts, resulting in a low TCO</p> <p>Multiple modes: Trucks, buses, and cars can use stationary wireless charging.</p> <p>No obstruction: Better aesthetics for the public eye and no collision danger.</p> | <p>Relatively low power</p> <p>Infancy phase: Innovation is still required to bring it to the market. It is difficult to say whether the system will be ready before 2025. The biggest challenge is to scale up production from a laboratory scale to mass production.</p> |
| <p>Continuously charging: BET can use smaller batteries to travel and do not require to stop for charging.</p> | |
| <p>Large flexibility: regarding the area of use, business models, and future use for autonomous vehicles.</p> | |

Figure D.7: The pros and cons for the dynamic wireless charging method.

E

APPENDIX: ADDITIONAL INFORMATION ON CHARGING METHODS

E.1. PLUG-IN: COMPONENTS

The components for the plug-in system include a cable with a connector, a charging station, and a converter. The cable with a connector is used to connect the BET with the charging station. Since 2014, the European Union has required the provision of the connector called Combined Charging System (CSS) Combo 2, to promote a universal standard ([European Union, 2014](#)). The CSS Combo 2 supports all the different charging methods of AC and DC charging, with a maximum charging capacity of 43 kW and 350 kW, respectively.

The charging station supplies electric energy to the BET, sourcing from the electric grid. They can be divided into different power classes: residential slow, public slow, public fast, highway fast, and ultra fast charge, as shown in the table [E.1](#). The residential slow charging stations for overnight charging (typically 8 hours), are commonly found in households and residential areas. The public slow charging stations are found in everyday activity places, such as shopping malls, and company parking. At similar locations, the public fast charging station may also be located. Currently, the super fast charger is the most powerful plug-in charger that is in use, commonly found along the highway. It is predicted that in the future ultra-fast charging will become reality, with a power of 350-500 kW ([Hall & Lutsey, 2019](#)). It is assumed that 350 kW can become a reality before 2025.

A converter converts AC from the electric grid to DC for charging the batteries. The converter can be either on-board or off-board. On-board means that the BET has its own build-in charger with converter and charging activities are done inside the BET. This method is most suitable for slow charging stations. Off-board is where an external

charger is used to charge the BET, like the gas station concept, suitable for fast charging.

Table E.1: Plug-in charge station type (Tie & Tan, 2013) (Topsector Logistiek, 2019)

| Charge station type | Residential slow charge | Public slow charge | Public fast charge | Super fast charge | Ultra fast charge |
|---------------------------|-------------------------|--------------------|--------------------|-------------------|-------------------|
| Converter location | On-board | On-board | Off-board | Off-board | Off-board |
| Target area | Households | City area | City area | highway | Future |
| Power [kW] | 3,3-7 AC | 10-24 AC | 50 DC | 150-250 DC | 350 DC |
| Cost | | | | | |
| Hardware [€] | [Not Found] | 4.000 | 20.000 | 60.000 | 200.000 |
| Installation [€] | [Not Found] | 4.000 | 10.000 | 20.000 | 20.000 |
| Grid upgrade [€] | - | - | - | 10.000 | 10.000 |
| Transformer [€] | - | - | - | 50.000 | 50.000 |
| Service [€/year] | - | - | - | 6.000 | 12.000 |

E

E.2. BATTERY SWAP: HISTORY

Battery swap has successful implementation with Automated Guided Vehicles, in a controlled environment at ports for transportation of containers (Vaggelas & Leotta, 2019). The battery swap system has been developed to be implanted for electric passenger vehicles by a company such as Better Place, Tesla, Ample, Nio Power, and BAIC BluePark. In the past, both Better Place and Tesla piloted this concept for passenger cars but soon the project was shut down. Better place failed because of three reasons (Gaddy, Ben, 2018). Reason one, they could not acquire charging station locations. Reason two, the charging stations required huge cooling infrastructure to charge the batteries without degrading them, leading to a much higher price than planned (3 million dollars). Reason three, they lacked a supporting OEM partner that was willing to standardize their battery system.

Even though both Tesla and Better Place tried this concept unsuccessfully, the Chinese car-manufacturer and state-owned BAIC BluePark reportedly already has 187 battery-swap stations across 15 cities in China, to support 16.000 electric taxis (Bloomberg News, n.d.). They announced plans for 3.000 swap stations by the end of 2022. Nio, another Chinese company, has 125 battery swap stations. The Chinese government is supporting this concept and these companies by putting effort to establish common industry-wide standards that would allow drivers to swap out EV batteries in a matter of about three minutes. In the US this concept is picked up again by Ample who obtained a large investment from Shell.

E.3. THIRD-RAIL: COMPONENTS

The components of third-rail are the feeder station, conductor rail, and collector shoes. The former is similar to the catenary system, a station that provides, transforms, and

converts the grid power to power the conductor rail. The conductor is supplied with DC and placed on the road surface. The conductor rail can detect if a vehicle is moving. If a vehicle is not moving, the rail is not powered. When a vehicle is moving, a rail section of 50 m is powered. The conductor rail also detects how many vehicles are on the rail and calculates vehicle energy consumption. This enables the conductor rail to provide the vehicles the current accordingly and enable electricity cost to be debited per vehicle and user. The rail also has a build-in heating coil to prevent ice formation. Additionally, they are designed to eject or drain water, gravel, and another particles from the track. Maintenance may be required when too much debris comes in the rail. To limit the danger to other vehicles, cyclists, motorcycles, pedestrians, and animals, the power in the rail is located deep within the conduit and difficult to access. However, it can still form a safety concern in urban areas.

The collector shoes make contact with the conductor rail, connecting the BET with the power source. The collector shoes have a movable arm, able to detect the rail. It can automatically connect and disconnect with the rail, making overtaking a smooth process. Therefore, the vehicle is not required to be a position exactly above the rail to work.

E

E.4. WIRELESS CHARGING DYNAMIC: RECENT PILOT

The most recent pilot project using wireless charging dynamic is called Smartroad Gotland led by Electreon AB ([electreon, 2020](#)). The project had a total budget of 10 million euros, partly financed by the Swedish Transport Administration (Trafikverket). The installed dynamic WC road consists of 3 sections of 800 m in both directions, with a total length of 1,6 km. It is located on the 4,1 km route between the airport and town center of Visby on the idyllic island of Gotland, an eco-municipality in the middle of the Baltic Sea. During this project, embedding 1 km of copper coils (road charging unit) in the road took one night without interrupting daily life. During the test, receivers with 25 kW were used. Trucks had five receivers (125 kW) and the buses had three receivers (75 kW).

F

APPENDIX: USE OF CHARGING STATION BY LOGISTIC SEGMENTS

There are two main ways logistic segments use the charging stations to charge their BET; either overnight charging or opportunity charging.

- **Overnight charging:** uses low power to charge BET for a longer period. This is commonly done outside work hours, starting at 17:00-18:00.
- **Opportunity charging:** uses high power to quickly charge a BET as much as possible in a short amount of time, commonly during working hours when BET are parked or stopped.

Both charging uses have their pros and cons. With overnight charging most BET would start charging after working hours, resulting in a high number of low power charging. This would disrupt the electric grid with peak demand. However, the low power is more cost-efficient for users and the technology has already proven itself. Opportunity charging has similarities with charging at a gas station. However, it requires high power technology which has not been tested for that long and can also take a toll on the electric grid. To make the electric grid more robust, it is expected that smart charging will be a must in the future.

- **Smart charging** is an active strategy that efficiently manages the charging of EV, flattening the demand curve over time and preventing a high demand peak. This lowers the disruption on the electric grid and decreases the required investment in reinforcing the grid (Tamis et al., 2017)(Hilshey et al., 2012).

Overnight charging provides a lot of flexibility for smart charging because not all BET connected to the charging station after working hours have to be charged right away. Smart charging takes advantage of this and spreads the number of BET that require charging over the night, keeping the maximum electricity demand low. On top of that, the maximum electricity demand for BET charging can be higher during the night, as

other electricity demand, e.g. manufacturing and business, are lower. Figure F1, shows an example visualisation of how overnight charging may look, with and without smart charging in a region where BET is charged at a depot.

Smart charging for opportunity charging is a bit more challenging. As the BET requires charge immediately and is charged during the day, meaning the maximum electrify demand for BET charging is lower. One of the options to implement smart charging here is by installing container batteries (Alfen, n.d.), at fast charging stations. These large batteries are charged throughout the day, preferably when the maximum electricity demand is not too high. When a BET requires opportunity charging, they can use the large batteries for the high power and not disrupt the electric grid.

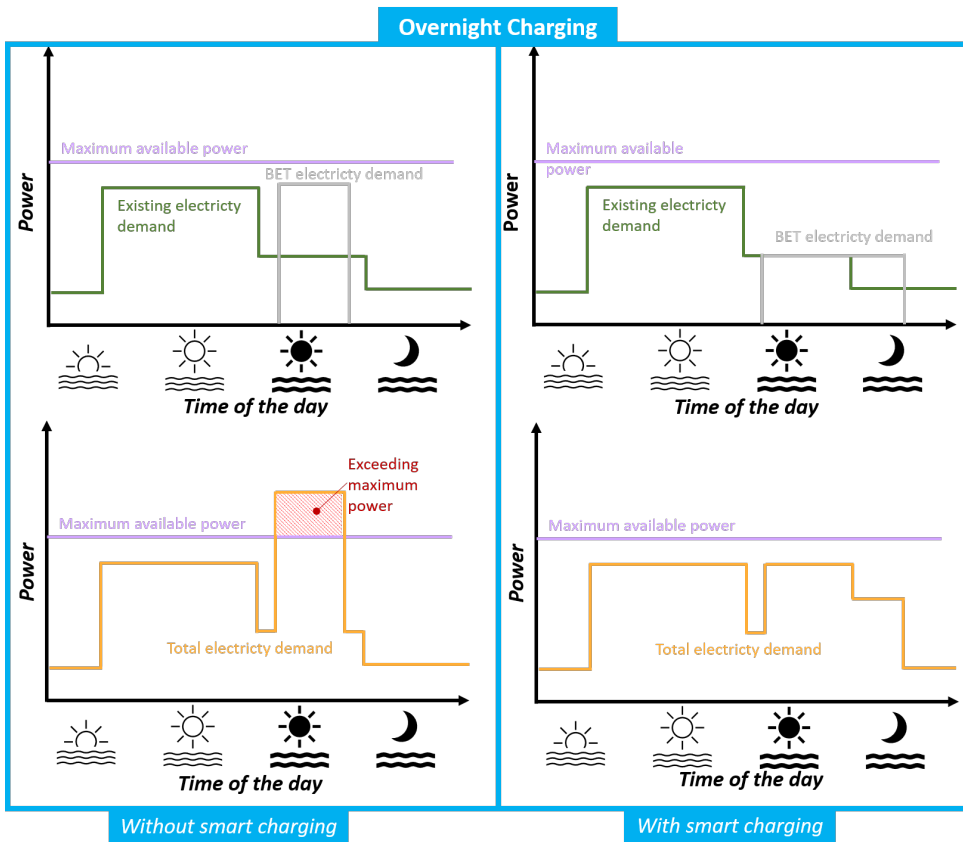


Figure F1: Example visualisation of how overnight charging with and without smart charging may look, where BET is charged at a depot.