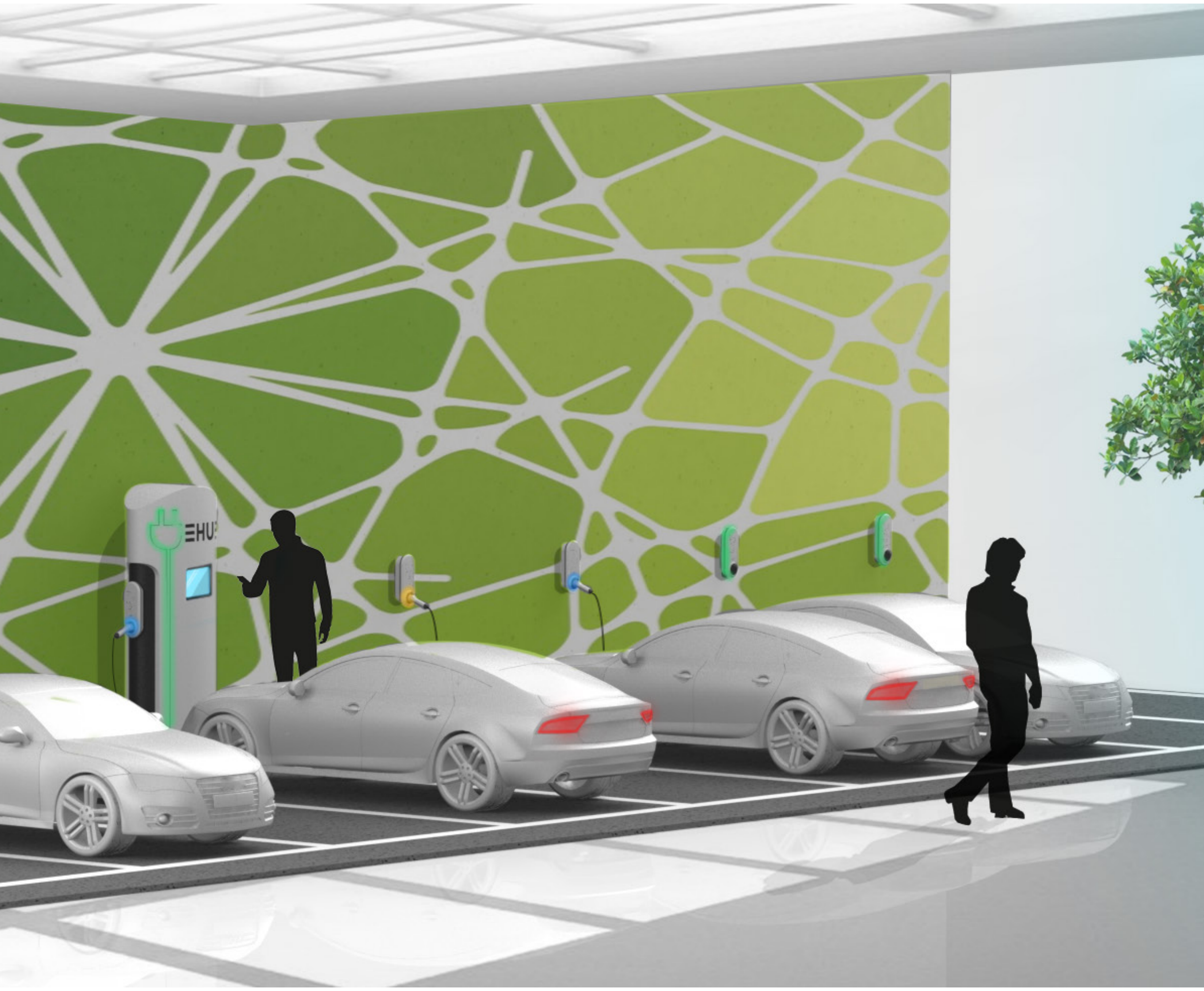
EHUB

A PROJECT FOR DUTCH-INCERT, BY JOHAN VAN DER SCHAAF



UNIVERSITEIT TWENTE.

EHUB

A PROJECT FOR DUTCH-INCERT, BY JOHAN VAN DER SCHAAF

UNIVERSITEIT TWENTE.

E-Hub, Charging Station of the Future

BACHELOR THESIS INDUSTRIAL DESIGN ENGINEERING

AUTHOR
Johan van der Schaaf
s1480049
j.m.vanderschaaf@student.utwente.nl

CLIENT
Dutch-INCERT
Delft University of Technology
Valorisation Centre Dutch-INCERT
2600 AA Delft
The Netherlands

PROJECT LEADER
B. Elders

UNIVERSITY
University of Twente
Drienerlolaan 5
7522NB Enschede

SUPERVISOR
dr. ir. G.M. Bonnema

EXAMINERS
ir. A.P. van den Beukel
dr. ir. G.M. Bonnema

DATE OF PUBLICATION
18-05-2017

DATE OF PRESENTATION
17-05-2017

PAGES REPORT
97

PAGES APPENDIX
16

Necessity is the mother of invention.

\- PROVERB -

Preface

This thesis is written as part of the Bachelor Industrial Design Engineering at the University of Twente. The assignment is commissioned by the consortium Dutch-INCERT. Through this project, the consortium aims to bring a higher purpose to life: accelerating the transition to electric vehicles. My role in this project is to look at the system as a whole from a design-perspective. Through this project, I aim to create a basic framework for the E-Hub accompanied by a design for the physical infrastructure and thereby providing a substantial contribution for a future realization of the E-Hub.

The reason I decided to apply for this assignment was my interest for future-oriented projects that have a clear link with human behavior. During the project I have gained knowledge about the electrification topic on several levels, including environmental, social and technical areas. The studies I have conducted on these topics have increased my interest on this challenge and have inspired and motivated me to contribute to the project.

I would like to thank the project leader Bob Elders from Dutch-INCERT for his cooperation during this project. During the meetings, we have been discussing interim results on a weekly basis and Bob has provided me with important data and useful documents for the project. Furthermore, I would like to thank Sjoerd Moorman for his assistance at the start of the project and during the final weeks of the project for the vast amount of feedback, documentation and progressive discussions on the topic. I would also like to thank Maarten Bonnema, my supervisor from the University of Twente and expert on the topic, who has made this assignment known to university students and has provided me with feedback during the project, as well providing important documentation that has contributed to my thesis and the project in general.

Johan van der Schaaf
28 February 2017

Abstract

In the thesis 'E-Hub, Charging Station of the Future' a scalable and future-proof charging system is designed that is able to charge multiple cars from a central system and can be implemented in different contexts. During the design process, the conducted analyses and tests have led to several design consequences and proposals for the E-Hub. Several concrete solutions are provided, as well as multiple advises or proposals that provide a solution direction for the E-Hub.

A general analysis is provided on the most relevant topics regarding the charging infrastructure and mobility. Several stakeholders should be closely monitored and kept informed, such as distribution network operators and energy providers. Driving patterns will change due to the growing car sharing services and cost awareness of driving an electric vehicle will increase among users. Furthermore, several important standards and future technologies are analyzed that are relevant for the E-Hub. Connecting charging stations to smart grids and a future transition to inductive (wireless) charging prove to be relevant innovations in the future. Taking the changes on user-level as well as technological level into account will result in several design consequences, such as increased communication and interaction between users and charging infrastructure and the optional energy buffer that could reduce peak loads on the grid by using renewable energy.

A system architecture is created that defines the main subsystems of the E-Hub, which include the central console, the connection points, the user interface and an optional energy buffer. Furthermore, the Open Smart Charging Protocol and Open Charge Point Protocol are required to enable the E-Hub to communicate between different parties and enable smart charging. Together with the literature studies, several user tests have gained insights in the solution directions for the E-Hub. Based on these analyses, a set of solutions is created that can be combined to create a viable and operable system.

By presenting three different combinations of solutions, concepts are generated and visualized. The concepts are evaluated by looking at the concept decision criteria based on the key drivers of the E-Hub. Subsequently, the three concepts are combined to create a final concept that combines the most ideal solutions. Several important decisions made, include the decision to make the implementation of photo-voltaic panels as well as an energy buffer

location dependent. Furthermore, an intelligent pricing system will ensure that users provide accurate data to the E-Hub on their planned return time and the required battery level.

In the concept development phase, it is chosen to create a more specific solution for a smart parking system, which aims to make parking allocation of both electric and non-electric vehicles more efficient and removes the amount of connection points as a constraint for the availability of charging bays. An important design consequence is the need for a vehicle identification system, which can be accomplished by using SENSIT IR sensors. In order to make the system future-proof, a set of requirements is provided that defines the most important design choices that are necessary for a transition to inductive charging. Furthermore, based on additional research, it is chosen to use a three-phase power supply for all charging points. A proposal is presented for a user-friendly mobile application, as well as a set of instructions that can be implemented in connection points in a user-friendly way. At last, the physical design is presented that highlights the adaptability, visibility and availability of the system and gives a visual representation of all the design consequences that are necessary to create a viable and efficient charging solution.

Samenvatting

In het verslag 'E-Hub, Charging Station of the Future' wordt een schaalbaar en toekomstgerichte laadoplossing gepresenteerd welke het mogelijk maakt om meerdere elektrische auto's op te laden vanuit een centraal systeem en welke geïmplementeerd kan worden in verschillende omgevingen. Gedurende het ontwerpproces zijn verschillende afwegingen gemaakt op ontwerpgebied op basis van meerdere analyses, literatuuronderzoeken en gebruikerstesten. Er worden zowel enkele concrete oplossingen aangeboden, als enkele oplossingsrichtingen en adviezen voor de toekomstige E-Hub.

Er wordt een brede analyse gedaan over relevante onderwerpen gerelateerd aan het elektrisch laden van auto's en mobiliteit. Verschillende belanghebbenden spelen een grote rol op dit gebied en zullen geïnformeerd moeten worden, zoals de distributienetbeheerder en de energieleveranciers. Verder zullen auto deelservices in populariteit toenemen en zullen rijpatronen in de toekomst veranderen. Ook zullen mensen zich bewuster bezig gaan houden met de lage variabele kosten die horen bij het vervoer in een elektrische auto. Bepaalde standaarden en toekomstige innovaties die relevant zijn voor de E-Hub zijn geanalyseerd. Het verbinden van laadstations met intelligente energienetten en een toekomstige transitie naar inductief laden zullen in de toekomst een rol gaan spelen. Deze veranderingen brengen enkele ontwerpkeuzes met zich mee, zoals nieuwe interacties tussen gebruikers en laadstations en een optionele energiebuffer voor het gebruiken van hernieuwbare energie om pieken op het energienet te verkleinen.

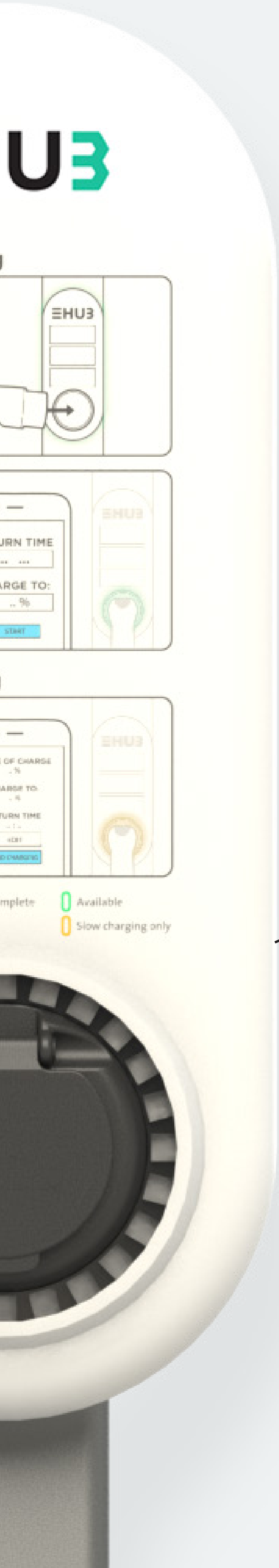
De architectuur van het systeem wordt gepresenteerd met enkele subsystemen, waartoe de centrale console, de connectiepunten, de gebruikersinterface en een optionele energiebuffer behoren. Het 'Open Smart Charging Protocol' en het 'Open Charge Point Protocol' zijn nodig om communicatie tussen de E-Hub en externe partijen mogelijk te maken en om de E-Hub te laten werken met slimme energienetten. Enkele gebruikerstests bieden verder inzicht in oplossingsrichtingen voor de E-Hub, samen met de gedane literatuuronderzoeken. Een morfologisch schema met deeloplossingen wordt aan de hand van deze resultaten gepresenteerd, welke gecombineerd tot verschillende concepten leiden.

De gecreëerde concepten worden geëvalueerd op basis van de belangrijkste drijfveren van de E-Hub. Vervolgens worden de drie concepten

gecombineerd om de meest ideale combinatie van deeloplossingen te vormen. Enkele belangrijke gemaakte keuzes zijn het locatie-afhankelijk maken van de zonnepanelen en de lokale energiebuffer. Verder zal een slim prijssysteem ervoor zorgen dat gebruikers bruikbare en nauwkeurige gegevens invullen over de geplande laadtijd en het benodigde laadpercentage.

In de concept uitwerkingsfase is een slim parkeersysteem verder ontwikkeld om de allocatie van elektrische en niet-elektrische auto's op parkeerterreinen te optimaliseren. Verder zorgt dit slimme parkeersysteem ervoor dat het aantal vrije connectiepunten niet langer een beperking vormt voor de beschikbaarheid van laadpunten, door op een slimme manier connectiepunten te activeren en te deactiveren. Een belangrijke ontwerpkeuze hierbij is de toevoeging van een auto identificatie systeem, welke gerealiseerd kan worden met behulp van SENSIT IR sensoren. Om het systeem verder klaar voor de toekomst te maken, is een reeks eisen vastgesteld welke de meest belangrijke ontwerpafwegingen vastlegt voor de implementatie van inductief laden. Verder is er gekozen om gebruik te maken van een driefase spanning voor elk connectiepunt. Een voorstel voor een gebruiksvriendelijke mobiele applicatie wordt gepresenteerd evenals instructies welke op de connectiepunten kunnen worden weergegeven. Tot slot wordt het fysieke ontwerp voor de E-Hub gepresenteerd welke de aanpasbaarheid, de zichtbaarheid en beschikbaarheid van het systeem benadrukt. Het ontwerp visualiseert de verschillende ontwerpkeuzes die gemaakt zijn om een haalbaar en efficiënte laadoplossing te creëren.

Table of Contents



Charging point not activated

Introduction

Introduction

Dutch-INCERT

The client for this project is Dutch-INCERT. Dutch-INCERT is a consortium that is established by the three technical universities in Eindhoven, Delft and Twente and the Universities of Applied Sciences in Amsterdam, Rotterdam, Arnhem and Nijmegen. This consortium creates a platform that connects scientific as well as practical research and technological innovation with the transition to electric mobility in the Netherlands. Dutch-INCERT cooperates with innovative businesses and authorities that are leading in electric mobility. The goal is to strategically contribute to the development of necessary innovations and the transition to electric mobility in the Netherlands.

Goal

The external goal of the client is to accelerate the transition to electric vehicles. Around 2017-2018, five of the large original equipment manufacturers will release a competitively priced full-electric vehicle with an approximate range of 300 kilometers (Steinbuch, 2015). As a results, the sales of electric vehicles is expected to grow rapidly over the next years. The main problem is that the current charging infrastructure is insufficient to facilitate this growing number of electric vehicles in the coming years. More than two-thirds of the households in inner cities rely on public charging infrastructure and do not have access to a private parking place, carport or a garage (COB, 2009). This makes it hard to find a spot to charge their electric vehicle.

Regarding the E-Hub project, the goal is to create a scalable charging system that can be implemented at multiple locations, such as parking garages, residential parking areas or curbside parking spots. The starting point of the project is based on several predetermined requirements by Dutch-INCERT (FIGURE 1). The main focus point for this system is that it must consist out of a central console that distributes power over several connection points. Embedded in this system is an intelligent control system that ensures that every vehicle is charged at precisely the speed that is required to meet the needs of the consumer while ensuring a long battery life. Furthermore, the system should draw renewable power when this is readily available and adjust charging profiles to the amount of available capacity on the local energy grid.

CORE REQUIREMENTS FROM THE CLIENT

- Contains a central console that distributes power over several connection points
- Can be implemented in different contexts, such as residential areas, the workplace or the inner city
- Contains an intelligent control system that enables load balancing
- Adjusts charging profiles to user needs
- Adjusts charging profiles based on the amount of energy that can be drawn from the grid
- Makes use of renewable energy when this is readily available
- Is scalable while remaining cost-efficient
- Facilitates in both slow and fast charging, up to respecitvely 7 and 22 kW

FIGURE 1 > Requirements predetermined by client Dutch-INCERT

Scope and Boundaries

Due to the comprehensive nature of the project and its wide scope, the boundaries of the project should be clearly defined. The focus for this bachelor project will be put on the design of the physical infrastructure. This includes the design of the physical components, as well their relations to each other and the user. The relations and interactions between components within the system will be elaborated by creating an architecture on system-level. This architecture will define how data is transmitted and received within the system and which interfaces are necessary to enable this form of communication. Furthermore, the system will be elaborated on user-level by presenting the most efficient and user-friendly flow of interactions with the system. Recommendations on the means to receive user input and several visualizations of communication between the user and the system will be presented.

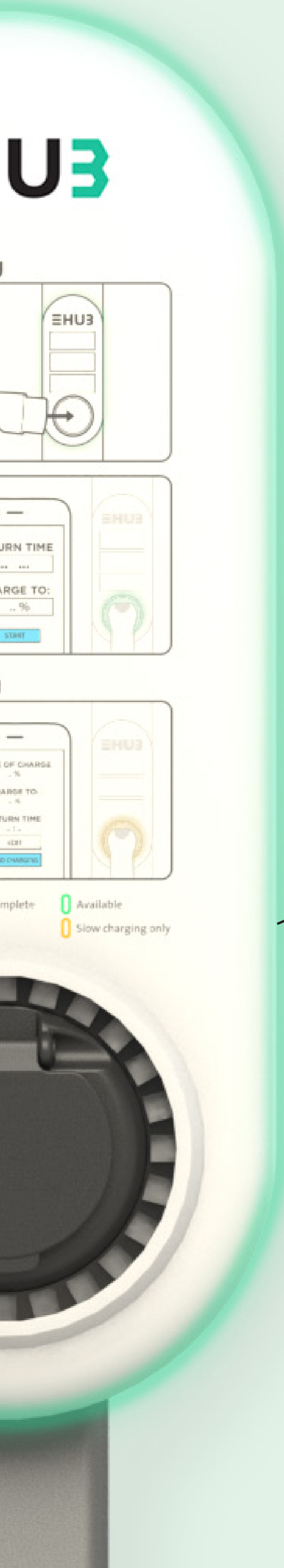
Strategy

For this project, an approach will be used that moves the design process through multiple diverging and converging cycles. Challenges are identified by conducting different types of research. Because of the wide scope of the project, the majority of the solutions will be elaborated to a certain degree of understanding that is relevant for the project from a design perspective. The most crucial factors that determine the success of the E-Hub will subsequently be elaborated into more detail in CHAPTER 5: CONCEPT DEVELOPMENT.

Structure

The structure of the report consists of the main stages of a typical design process. The succeeding chapters follow a chronological order, from the analysis phase up to the concept development phase. The concept development chapter is followed up by a general conclusion.

Furthermore, an explanation of several terms used throughout the report can be found at the end of the appendix, in SECTION E: GLOSSARY.



Charging point activated

2

Analysis

Analysis

In this phase, a broad analysis will be given on the relevant topics regarding the charging infrastructure. The analyses mainly consist of literature research, as well as several user interviews. The results from the analysis phase will be used to create requirements for the E-Hub and provide the general knowledge required to design the E-Hub system. Some topics addressed in this phase require a more specific research and will be further elaborated later.

Target Group

The current target group regarding the E-Hub typically belongs to the early-adopters market. Early adopters enjoy using new technologies and want to be the first to utilize them. Most Electric Vehicle (EV) owners are middle aged men, with a high education and income. They mostly own multiple vehicles and own an EV for the benefits of having free parking, reduced annual tax, no VAT and reduced fuel costs (Hjorthol, 2013). The target group is familiar with modern technology, such as computers, smartphones, wireless payment systems and graphical user interfaces.

Currently, the adoption of full-electric vehicles is still in the innovators phase (FIGURE 2). However, it is expected that in the future a tipping point will be reached that accelerates the adoption of EVs from the early adopters to the early majority. With the competitively priced full-electric vehicles entering the market around 2017-2018 (Steinbuch, 2015), this might happen sooner than initially expected. The shift will undoubtedly cause the target group to grow. People with a lower income may choose for an electric vehicle and as shared

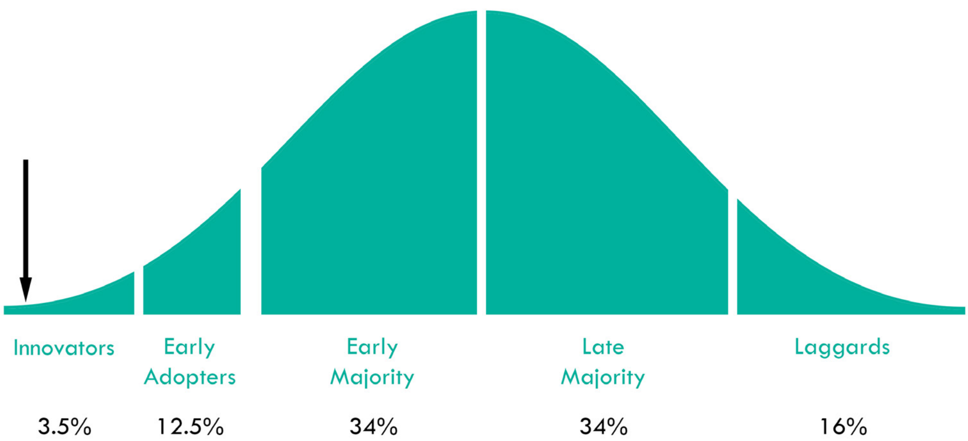


FIGURE 2 > Number of full electric vehicles on the road car systems become more common, younger people such as students might be able to drive EVs in the future. These future transitions should be considered in order to design a scalable and future-proof system.

Stakeholders

In FIGURE 3, the stakeholders are represented in a power-interest diagram that visualizes the most important stakeholders and their influence. The power-interest diagram displays the degree of interest and power for each stakeholder and clarifies their role regarding the E-Hub. Due to multiple upcoming innovations, the roles of several stakeholders will significantly change in the future. These changes are indicated by the gray arrows in the diagram. The most important stakeholders and their changing role will be further elaborated.

ENERGY PROVIDERS

The different energy providers supply energy to the charging infrastructure. These energy companies (e.g. Nuon, Essent, Eneco or E.ON) have collective agreements on who delivers energy to which charging station. These agreements allow consumers to charge their vehicles at any charging station, regardless of which energy company they are subscribed to.

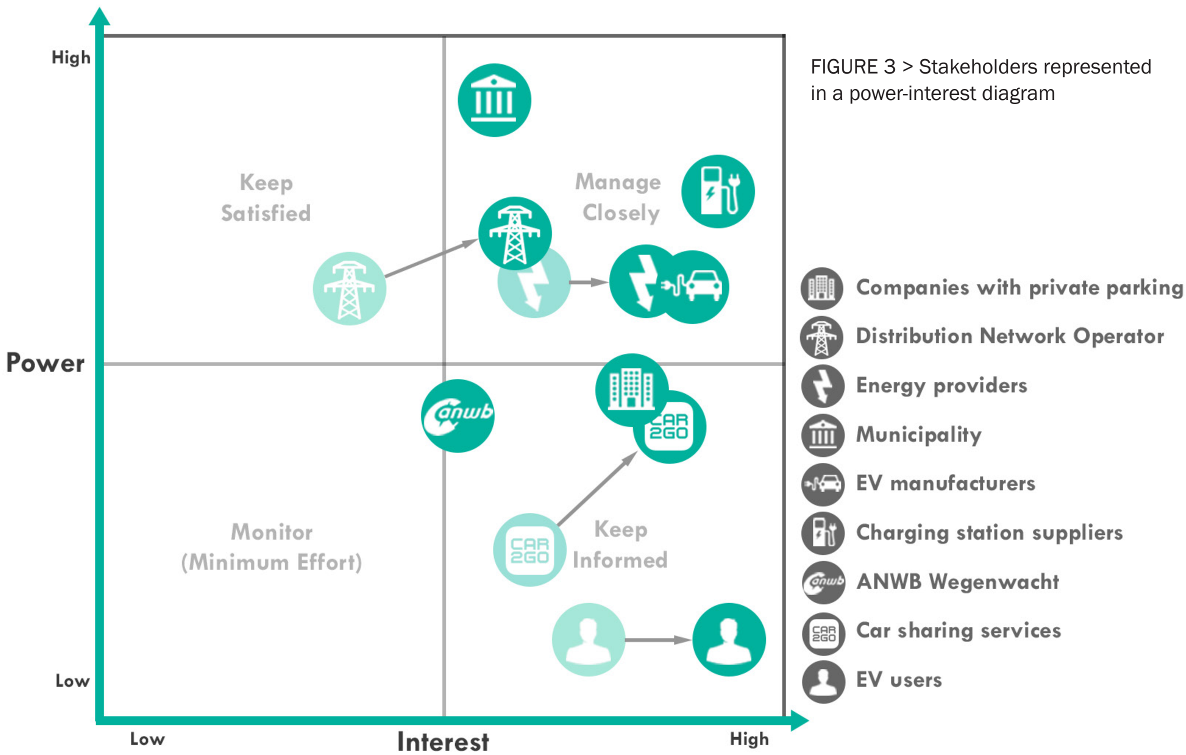


FIGURE 3 > Stakeholders represented in a power-interest diagram

Consumers are provided with a free charging card that makes charging possible at most charging stations. Some energy companies have their own charging card, others provide cards in collaboration with The New Motion, currently one of the largest providers of EV charging solutions in Europe.

FIGURE 3 shows that energy companies will have a bigger interest in charging solutions in the future. This can be explained by the increasing demand for energy due to increased EV sales. Furthermore, there is an increasing interest in coupling local production of renewable energy with charging stations (Codani et al., 2015), which alleviates the strain on the grid. Energy providers can help facilitate these solutions. Another explanation for this increasing interest is vehicle-to-grid (V2G) technology, where EVs can function as grid supply, serving the same functions as power generators as well as being grid loads (RMI, 2016). This will demand a new energy pricing structure, since there is no framework yet for energy that is being send back to the grid. More on V2G technology will be discussed in the section MARKET ANALYSIS II: EMERGING TECHNOLOGIES.

DISTRIBUTION NETWORK OPERATOR

Distribution Network Operators (DNOs) facilitate the transportation of electricity in a specific region and monitor energy demands and the available capacity on the grid. As EVs become a more common means of transportation, the demand for energy will increase and higher peak powers will be measured on the energy grid. Problems on the energy grid can be prevented through coordinated charging to minimize the power losses and maximize the main grid load factor (Clement-Nyns et al., 2010). In order to adjust charging profiles in a way that benefits the grid, communication systems are required between charging systems and the DNOs.

SUPPLIERS OF CHARGING STATIONS

Cooperation with current suppliers of charging stations is important to create a solid infrastructure. Together with current suppliers, the functioning of charging stations can be standardized and solid location implementation plans can be created. Currently, The New Motion is market leader in providing charging solutions and also FastNed is an influential stakeholders. While FastNed currently only facilitates fast-charging near highways, in the future FastNed will start implementing charging stations near city centers (Kane, 2016).

ANWB WEGENWACHT

The ANWB is a traveling association in The Netherlands. The ANWB provides public charging stations in inner cities and near highways. Furthermore, private charging stations are sold to individuals and businesses, as well as several important services, such as providing instructions and information on the location and costs of charging stations.

EV MANUFACTURERS

Different EV manufacturers cooperate closely with municipalities and energy companies to improve the charging infrastructure. For example, Nissan cooperated with the several project groups to create 'Smart Grids' to provide V2G systems (Hammerschmidt, 2016).

CAR SHARING SERVICES

Car sharing is a relatively new concept that has gained in interest over the last years. A distinction can be made between one-way car sharing and services that provide a peer-to-peer platform for individuals to rent their private car to other individuals. In the case of one-way car sharing, the cars are no longer owned by users, but by a fleet manager, who provides a fleet of cars throughout a certain area that are ready whenever the user needs them. Due to the high utilization rate of shared cars, the car-sharing system is an eco-friendly service. The short trips people generally make in shared cars makes it convenient for fleet-operators to use EVs instead of Internal Combustion Engine Vehicles (ICEVs). FIGURE 4 depicts the growth of the car sharing industry. Some important car-sharing systems in the Netherlands are Car2Go, WattCar, GreenWheels, SnappCar and MyWheels.

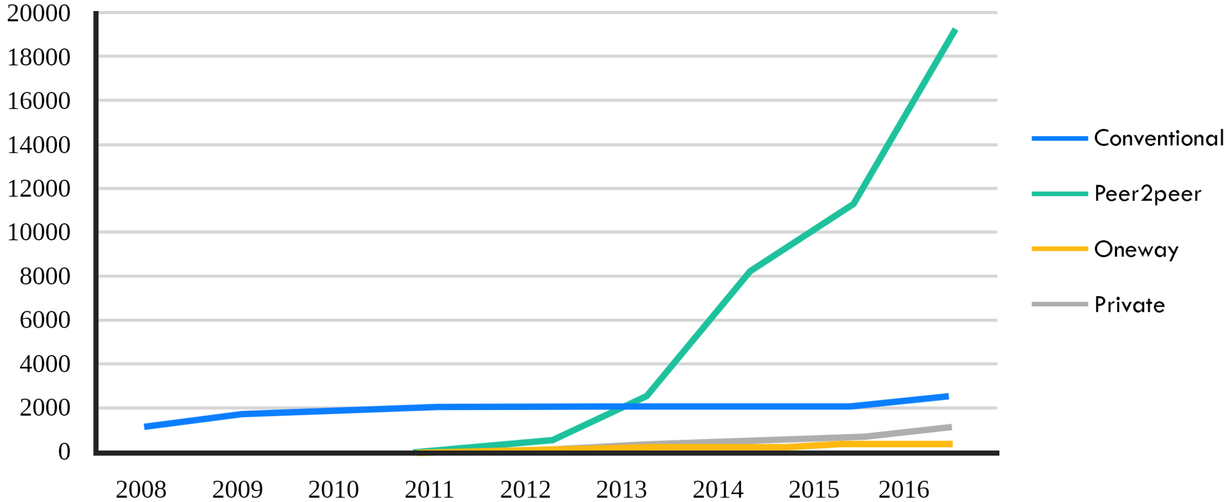


FIGURE 4 > Development of number of shared cars (CROW-KpVV, 2016)

Car sharing services are a growing trend. In 2011, Car2Go deployed 300 'on demand' EVs in Amsterdam. Besides these one-way car sharing services, several peer-to-peer networks have been set up in 2011, with SnappCar and MyWheels as the biggest players on the market. These systems allow users to rent their private cars. In this case, EVs as well as ICEVs are being used. In spring 2016, there were 25.128 shared cars in the Netherlands, a growth of 55% compared to 2015 (CROW-KpVV, 2016).

The potential of car-sharing services results from the inefficient use of privately owned cars. On average, privately owned cars travel approximately 37 kilometers a day (CBS, 2012) in the Netherlands. This lack of an intensive use of privately owned cars makes them an inefficient means of transportation. Especially in city centers, where parking places are scarce, privately owned cars take up a lot of valuable space.

The future of car sharing is an important aspect to consider with regard to the charging infrastructure. Consumer behavior will change on several levels, resulting in different charging needs. As explained in the previous section, car sharing will affect the amount of cars in city centers. Cars will be used more efficiently and individuals are less likely to purchase private cars. According to a study in Seattle, 18% of Car2Go members reconsidered the need of a private car, while another 16% reconsidered the need of a second private car (SDOT, 2014). As shown in the previous section, due to the short distances traveled in shared cars, it is favorable for fleet operators to make use of EVs. These EVs will be used with a much higher intensity, resulting in a greater mileage per vehicle per day and less time spent at charging stations. Shared cars are therefore likely to make use of multiple charging stations per day, with a relatively short time spent at the charging bay. Furthermore, car sharing is also based on the premise that users ignore the relatively high fixed cost of their privately owned car when they decide to drive by car. With shared cars, individuals tend to focus more on the low variable costs associated with the single trips, resulting in a further decrease in overall travel mileage (Katzev, 2003). This transparency of the cost of a car leads to a more economically smart use of the car. Individuals will often take better advantage of alternative transportation as well, such as public transport, using the bicycle more often, or combining several trips into one (Katzev, 2003).

DRIVERS OF EVs

The drivers of EVs include people that have their own electric vehicle, as well as people using publicly available vehicles. Since electric mobility is still in its 'early adopters' phase, drivers are still willing to adapt to changes and are able to handle a new type of infrastructure.

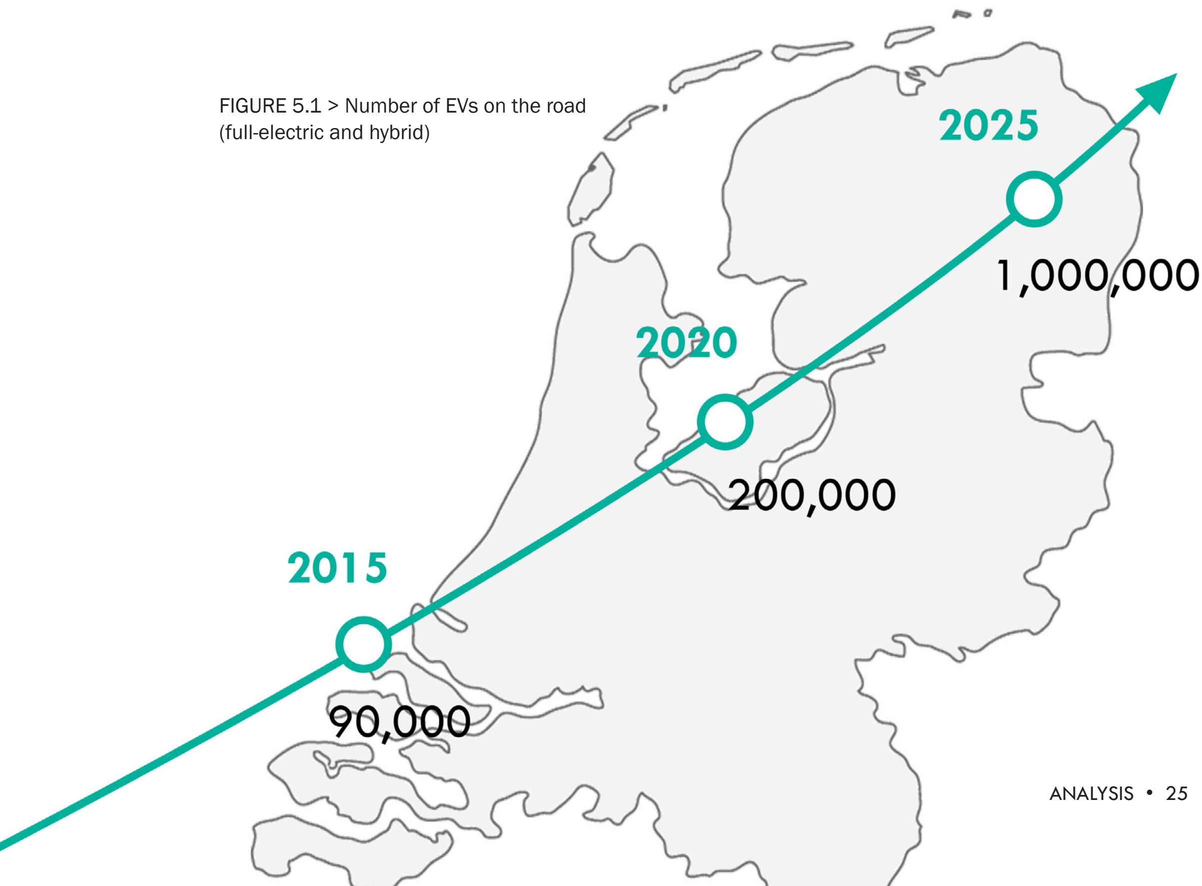
Problem Analysis

A literature study has resulted in several insights and observations that clarify the challenges that exist in the current charging infrastructure. The NKL (Nationaal Kennisplatform Laadinfrastructuur) has conducted multiple studies on the cost efficiency of the charging infrastructure and gathered several important insights (NKL, 2016). When it comes to the design of the charging infrastructure, these challenges can be put in several categories: Lack of standardization, inefficient energy use, lack of a regulatory framework and lack of price transparency.

IMPACT ON THE GRID

By 2025, the Dutch government expects to have one million electric vehicles on the road (RVO, 2015). A significant increase compared to the approximately 90.000 EVs present in The Netherlands at the end of 2015 (FIGURE 5.1). The capacity on the energy grid is limited and while EV loads may not affect the grids much in the short-to-medium term, EVs are on the way to obtain such a considerable amount of market share, the impact on peak loads could be significant (RMI, 2016). Intelligent energy distribution systems can help reduce peak loads on the grid by distributing energy over a given amount of time, outside of peak hours.

FIGURE 5.1 > Number of EVs on the road (full-electric and hybrid)



Furthermore, local generation of renewable energy can be used to charge vehicles in peak hours, further reducing the peak load on the grid. In FIGURE 5.2, a graph visualizes the two peaks of power demand and the net power generation of solar energy at houses in the western United States (Fischer, 2014). As can be concluded, solar energy peaks around 10:00 am to 12:00 pm and the power demand peaks around 4:00 to 6:00 pm. Using a local energy storage, the solar power generated in the morning can be distributed among EVs in the afternoon, when the power demand is at its highest level. Using local production of renewable energy, the same principle can be applied to charging stations in The Netherlands.

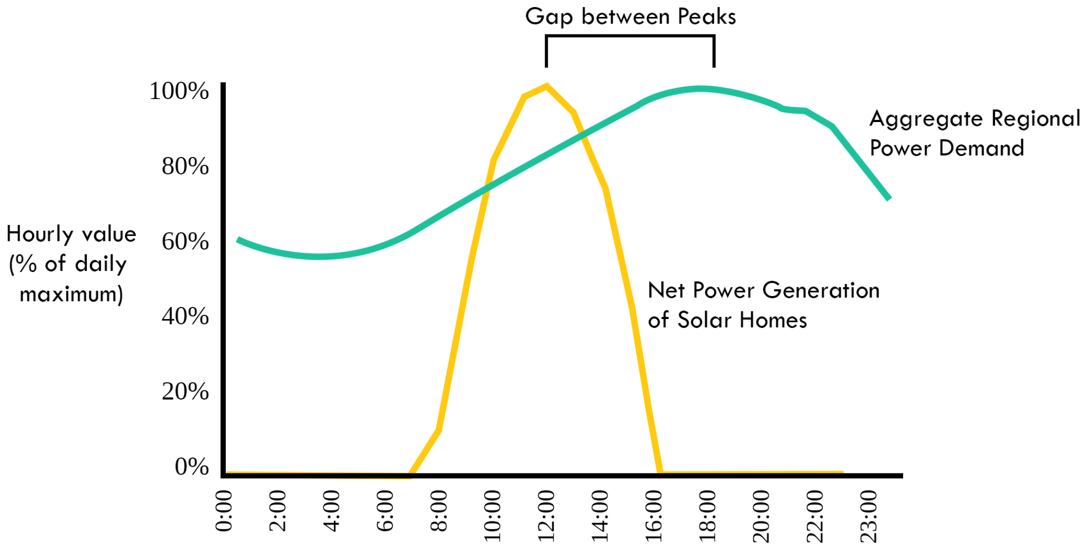


FIGURE 3.1 > Solar homes' power supply vs. total grid power demand (Fischer, 2014)

PRICE

Prices of charging at public charging stations lack transparency. Charging stations do not indicate the price per kWh, due to the high amount of variables that determine the price. According to a study in The Netherlands, these prices vary between 20 cents and 1,10 euro (Radar, 2016). This is due to the vast amount of parties that require a share of the revenue (FIGURE 4), such as the energy provider, service provider of the mobile application, the charge point operator, the concessionaire and a sponsor. While some municipalities control their prices, especially smaller municipalities can demand any price. The ultimate price depends on the company the user is subscribed to and the parties involved at the local charging station. Due the ineffective pricing system, EV users often pay a greater price per kilometer than ICEV users. Increased transparency can enable the user to have more control over their expenditures on charging. This will ultimately result in more awareness towards traveling costs, lower costs per kilometer and the decision to buy an EV will become more attractive.

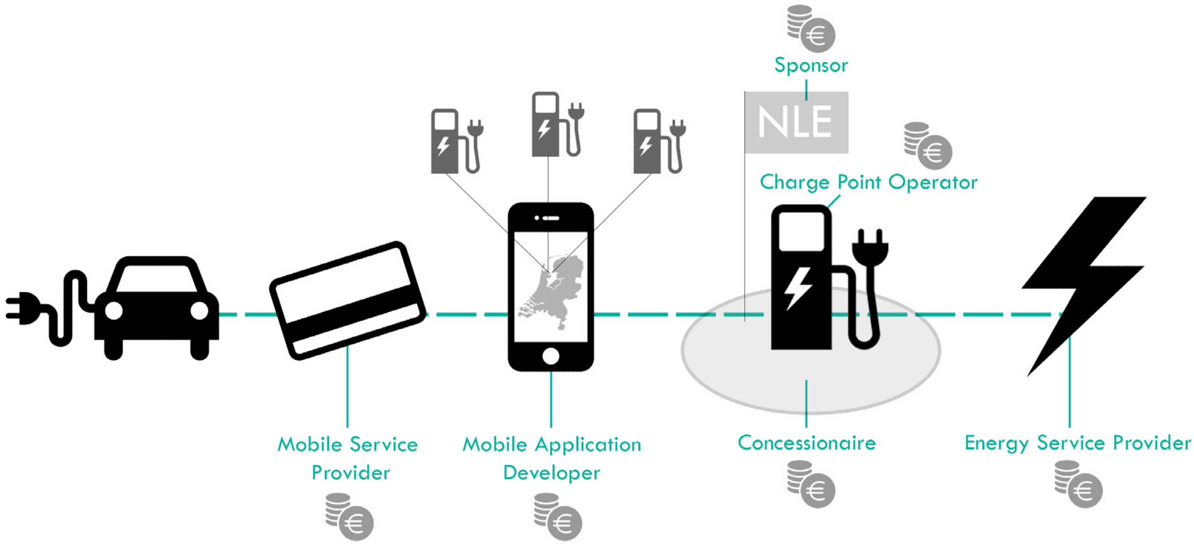


FIGURE 4 > Parties that take up a share of the revenue for EV charging

STANDARDIZATION

Different charging stations are currently still equipped with multiple types of sockets and plugs. In the future, it is predicted that a standardized solution will be created that works with all types of plug-in EVs (PEVs). Furthermore, not all charging stations use the same communication systems. The Open Charge Alliance (OCA) has created several communication protocols that are being used internationally and are becoming a more standardized solution (Open Charge Alliance, 2016). Currently, these are the most widely used protocols between charge points and the central system. These communication systems will be further elaborated in the following chapters.

REGULATORY FRAMEWORKS

Since 2013, installation costs have been decreasing by 30% due to standardization of the placement of charging stations. The estimation for 2020 is that this trend will continue (NKL, 2013). In order to decrease these costs further, solid location implementation plans are necessary that involve all necessary stakeholders. There have been several cases where capital got destroyed because of expiring contracts, while the charging stations still were in a technically good condition. A solid location implementation plan can prevent these situations from occurring. Furthermore, an infrastructure that uses standardized software and modular components can make the system more scalable and more adaptable, preventing capital from being destroyed.

ALLOCATION OF PARKING AND CHARGING BAYS

Parking spaces are currently divided into regular parking bays and EV-only parking bays that facilitate charging. This division will not always correlate precisely with the demand for parking and charging at a given moment. This makes the parking allocation less efficient and requires additional parking and charging bays.

Furthermore, according to a study conducted by the NKL, the duration o fcharging sessions only account for approximately 19% of the total occupancy time (Wolbertus, 2017). FIGURE 5 shows the differences in charging sessions versus the occupation time. Even though charging stations are occupied most of the time, the utilization rate is relatively low. Several solutions have been suggested, such as notifying users to move their car when charging has completed, so-called ‘social charging’, or charging the user an additional fee for occupying a charging bay. However, these solutions restrict the user in their freedom, instead of solving the underlying problem.

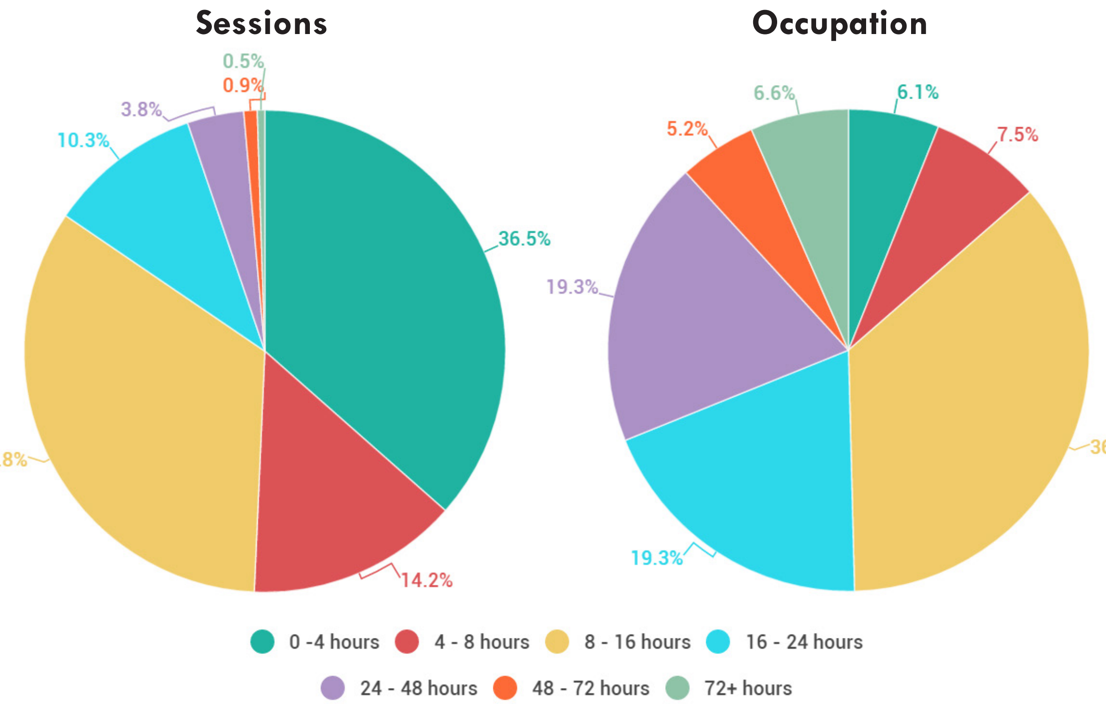


FIGURE 5 > Charging sessions versus occupation of charging bays (Wolbertus, 2017)

FIGURE 6.1 > EV-Box BusinessLine (Cohere, 2016)

Market Analysis I: Market Product Example

For the market analysis, one of the currently most widely used charging solutions will be evaluated: The EV-Box BusinessLine. The BusinessLine model (FIGURE 6.1) is meant for commercial use and can be found on the majority of the charging stations in the inner cities. Since it is one of the most widely used charging stations, the features of this model are listed in TABLE 1.1 and TABLE 1.2 and can be used as a reference later on in the project. The EV-Box charging stations come in different colors and styles to adapt to different corporations that utilize them. In FIGURE 6.2, the user steps are shown in a flow-chart that are necessary to operate the EV-Box.

TECHNICAL FEATURES

Charging capacity per connector	11 kW
Charging mode	Mode 3, Z.E. Ready
Connector type	Mennekes type 2
Number of connectors	2
CE certified	Yes
Output power	3-phase, 230V – 400V, 16A
Temperature range	-25°C to 60°C
Moisture (non-regulating)	Max. 95%
Authorization	Keyfob / RFID card
Information status	LED ring
Communication	GPS / GSM / UMTS / GPRS Modern / controller with RFID reader
Communication protocol	OCPP 1.2, 1.5 and 1.6

TABLE 1.1 > EV-Box technical features

PHYSICAL PROPERTIES

Housing	Polycarbonate
Dimensions (mm)	600 x 255 x 410 (L x W x H / double socket)
Weight	11 kg (max.)
Mounting	Wall or pole
Optional	6 or 8 meter fixed cable

TABLE 1.2 > EV-Box physical properties

Start Charging

1.

Action
Plug the cable into an available charging station and the EV

Feedback
None

2.

Action
Scan the RFID card or keyfob

Feedback
'Beeping' sound
LED blinking

3.

Action
Wait for the LED to turn blue

Feedback
LED turns blue

Stop Charging

1.

Action
Scan the RFID card or keyfob

Feedback
'Beeping' sound
LED blinking

2.

Action
Wait for the LED to turn orange

Feedback
LED turns orange

3.

Action
Remove the charging plug

Feedback
LED will go back to its green 'available' status

FIGURE 6.2 > Stop the charging process of the EV-Box BusinessLine

Market Analysis II: Emerging Technologies and Trends

Innovations in the charging infrastructure succeed each other rapidly. Due to this quickly changing environment, a closer look will be taken on the future technologies and trends that are most relevant for the E-Hub and should be taken into consideration.

SMART CHARGING

As was concluded from the problem analysis, without the implementation of smart grids, problems will occur in the energy grid and demand peaks could lead to great investments in the energy grid. This could ultimately lead to a slower transition to electric mobility.

Smart charging is based on the premise that EVs can function as a flexible load. EVs can increase demand when grid assets are underutilized or renewable generation is abundant and power is cheap, and decrease demand at peak times when power generation is most expensive and grid congestion is more likely (RMI, 2016). Smart charging can make big investments in increasing grid capacity redundant and can provide an additional service to users by making charging responsive to user needs.

Smart charging as an implementation in future charging infrastructures is an inevitable innovation and comes with several design consequences. A case conducted in Norway on charging many vehicles with one intelligent system provides several important insights. First of all, smart charging demands that the power flow should be controlled to optimize power usage (L. Schuddeboom, 2015). In order to optimize control capabilities, the system should be able to redistribute the energy flow over a given amount of time. Renewable energy is one of the possibilities to reduce peak loads, however peak demands on the energy grid and peak production of renewable energy happen at different times during the day. Therefore, a local energy storage in the electric vehicle supply equipment (EVSE) will be necessary if renewables are used as a solution for reducing peak loads.

Besides reducing peak loads, another key factor is to provide an additional service to the EV users. There are two variables that determine the charging profile of an EV according to the needs of the user. These are the time that the user leaves and the range that the vehicle should have to ensure that the user makes it to his/her destination without the need for additional charging. Furthermore, the charging station should be able to link the charging profile with the corresponding connection point.

INDUCTIVE POWER TRANSFER

While inductive charging is not a common charging application yet, this may significantly change in the future. Various fully functioning prototypes already exist that show the potential of this technology. According to the TU Delft, it is possible to achieve an efficiency of over 90 percent with a coil distance of 20 cm (APPM, 2012). In FIGURE 7, a typical inductive charging system is shown.

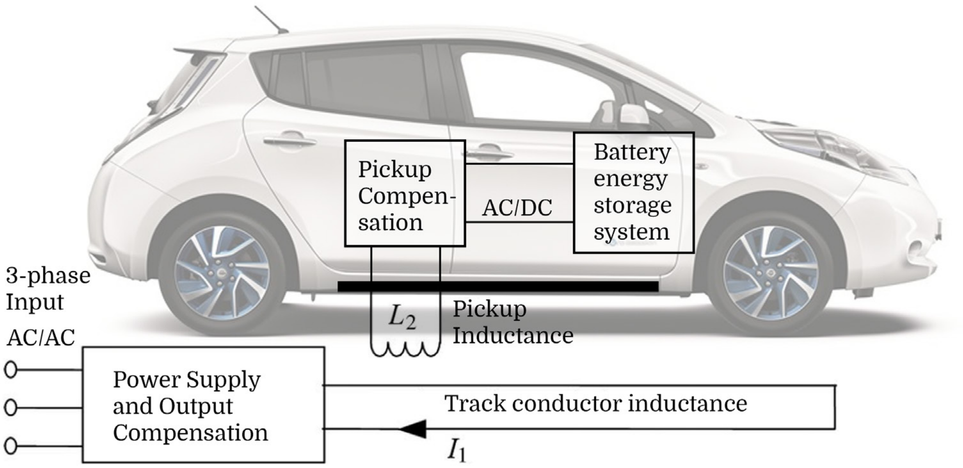


FIGURE 7 > A typical IPT system

Inductive chargers work on the principle of Inductive Power Transfer (IPT). A three-phase input is used that sends power to the transmitter. The power transmitted by the charging conductor will be picked up by the inductive pickup in the EV. Subsequently, a rectifier will convert AC current to a DC current before it reaches the battery energy storage system. Different from conductive charging is that there is no metal-to-metal contact and no cable required to enable energy transmission. The lack of contact prevents corrosion occurring in the connection, which makes the system more durable.

Implementation of an IPT system comes with some design consequences. First of all, an IPT system needs a grid connection to be able to transfer energy. These grid connections are usually directly connected to the charging stations, but this is impossible when the coil is located in or on the ground. Therefore, the grid connection must be external to the charging system and separately installed. Reasoning behind this is that underground grid connections could cause subsidence, moisture, are difficult to access for repairs and give difficulties for physical meter readings (APPM, 2012). Another current design challenge is standardization. Because the system is still in its infancy, multiple systems are currently unable to communicate with one another.

Another important factor is the alignment of the coils. The magnetic coupling decreases rapidly with misaligned IPT coils, decreasing the efficiency of power transfer (Bosshard and Kolar, 2016). Therefore, proper alignment of the coils is crucial for the efficiency of the IPT system.

One of the biggest advantages of inductive charging is the ease of use. Users do not have to exit their vehicle in order to start the charging process, which makes the system more user-friendly and safety can be more easily assured due to the absence of physical interaction with components that provide high levels of current. Furthermore, the impact on the urban environment is limited due to the limited amount of EVSE equipment above the ground and the absence of cables, which could cause people to trip while walking on pavements.

While safety from technical point of view does not seem to be an issue, there are still some concerns regarding health. One of these is the confusion on the radiation and warmth release from an inductive charger. People with a pacemaker could be in danger due to radiation from chargers (APPM, 2012).

LOCAL GENERATION OF RENEWABLE ENERGY AND STORAGE

A major trend in energy usage for future smart grids is large-scale decentralized renewable energy production through photo-voltaic (PV) systems (G.R. Chandra Mouli et al. 2016). A study conducted by the TU Delft has shown that, depending on the size of the charging infrastructure, a local storage as an energy buffer can reduce grid dependency by 25% (G. R. Chandra Mouli et al. 2016). Furthermore, the EVs that are parked for a longer time could be utilized as storage for a vehicle to grid system in the future, where additional power can be stored and redistributed to other EVs.

VEHICLE TO GRID

With vehicle to grid (V2G) technology, EVs can serve as power generators that supply energy to the grid, as well as being grid loads (RMI, 2016). The technology enables EVs to not only transfer energy from the grid to the battery, but also send energy back to the grid. V2G technology allows for more controlled energy distribution, further lowering demand peaks and balancing the energy distribution system. A study conducted in 2011 by MIT found that $100/month could be saved per vehicle by reducing demand charges by allowing vehicles to send energy back into the grid (RMI, 2016).
While V1G systems, where EVs remain a resource on the demand-side of the system, can already provide many services that reduce the impact on the

energy grid and provide cost-efficient energy distribution, V2G can take this one step further. However, it should be noted that there are still many hurdles to overcome if V2G were to be implemented on a large scale. Most EVs currently on the market are not capable of sending energy back into the grid, there are no tariffs that pay EV owners for supplying power back to the grid and there are difficulties on both hardware and software level that have to be overcome. Furthermore, users need to be convinced that their private EVs are being used for grid supply. If the reasons are unclear why personal EVs are being used to send energy back into the grid, users might not tolerate the use of their EVs as a local power source.

User Analysis

Interviews have been conducted to receive input about the current charging infrastructure from users themselves. The results are categorized and listed in TABLE 2. The most frequently received answers are highlighted. The full interviews can be found in the APPENDIX A: INTERVIEWS.

TABLE 2 > Results Interviews

STANDARDIZATION	USE	RELIABILITY	AVAILABILITY	OTHER
Every charging station should follow the same steps	Lack of feedback/ feedback is too slow	Public charging stations provide insecurity	Charging stations can be hard to find, sometimes they seem to be hidden	No issues with using a cable, however it is expected that this becomes obsolete in the future
People are willing to change charging profiles based on pricing	Use of charging card is preferred over mobile application	Prices are unpredictable	Being able to easily locate a charging station is more important than reducing walking distance	Instructions on the charging poles are only read when they are brief
Charging stations should be able to function with debit cards	Lack of info on charging power and price	Sometimes unreliable due to slow feedback	In unknown areas available charging stations can be particularly difficult to find	Using a charging station has a status-enhancing effect (e.g. being an environmentally-friendly user)
	Three-phase charging is superior to single-phase charging	Error sometimes prevents plug from unlocking when charging is finished		Car-sharing makes owning an EV more economical
	Mobile app is useful during the charging process	App can provide support through notifications (in case of errors)		

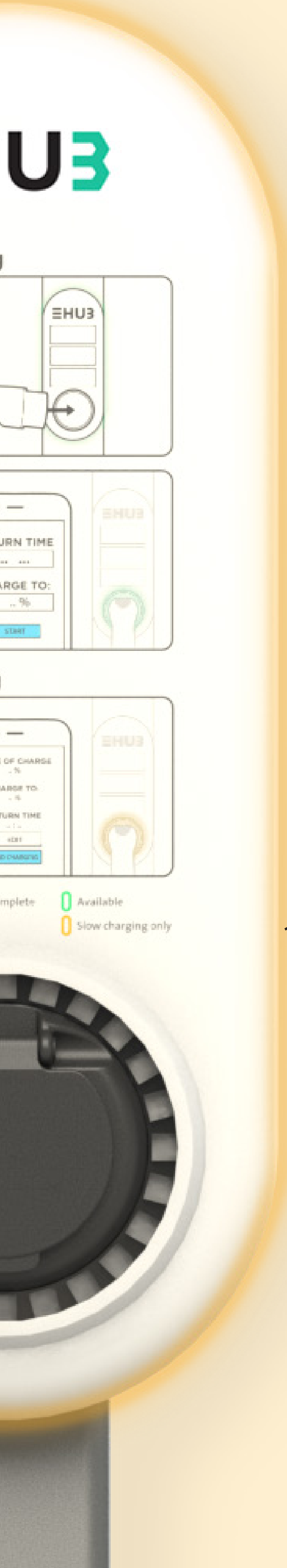
Summary

In the analysis phase, a broad analysis is given regarding the current and future charging infrastructure for EVs. The analysis creates a broad framework on which the project can continue its way into the ideation phase. Certain topics from the analysis phase will later be revised and elaborated into more detail.

From the stakeholder analysis it is clear that energy providers as well as DNOs will play a more significant role in charging solutions in the future. Increased communication with these parties will become inevitable. Furthermore, due to the rapidly expanding platforms for car sharing, driving and charging patterns will change. Cars will be utilized more intensively and charging stations will be occupied with a higher frequency, but for shorter periods. Besides, due to the low variable costs of EVs, consumers will use EVs in an economically smarter way.

To remain future-proof it is important to comply with the latest standards and standardize procedures. This also includes location implementation plans. Charging stations should be able to be implemented at different locations with a rigid plan that prevents capital destruction. Pricing structures should become standardized and more transparent to increase price awareness and make the purchase of an EV more attractive. Furthermore, grid impact should be limited. This can be done by looking at the latest technologies, such as smart charging and the use of locally generated renewable energy.

These technologies do not come without design consequences, such as the need for a local energy storage to make intelligent use of renewable energy. Furthermore, the intelligent control system requires certain inputs to determine charging profiles, such as the time spent at the charging bay, the required battery level and which charging bay is being used. In order to implement an IPT system, above grid connections are necessary, however, several uncertainties still exist regarding standardization and health risks. Lastly, V2G systems can further alleviate grid impact by using EVs as power generators to supply energy to the grid as well as being grid loads. However, there are still a lot of hurdles in the way regarding legislation and pricing structures before large-scale V2G implementation can take place.



Charging point activated,
routine charging only

Ideation

Ideation

In the ideation phase, a basic structure of the E-Hub system will be given that provides insight on the essential components. Furthermore, several human-centered design methods are used to gain insight in solution directions that comply with the system requirements and at the same time satisfy user needs. Furthermore, an overview of possible point solutions is represented.

System Architecture

From the analyses conducted in the previous chapter, several essential components can be derived. These are shown in the functional block diagram in FIGURE 8.1. The diagram only shows the physical components of the system. Back-office systems required for data management and communication are not included. The user will communicate with the E-Hub through a user interface. This interface will provide the E-Hub with the charging time, required battery level when charging finishes and which charging bay is being used. In return, the E-Hub will provide the user with information on the state of charge (SOC), the remaining charging time and the price.

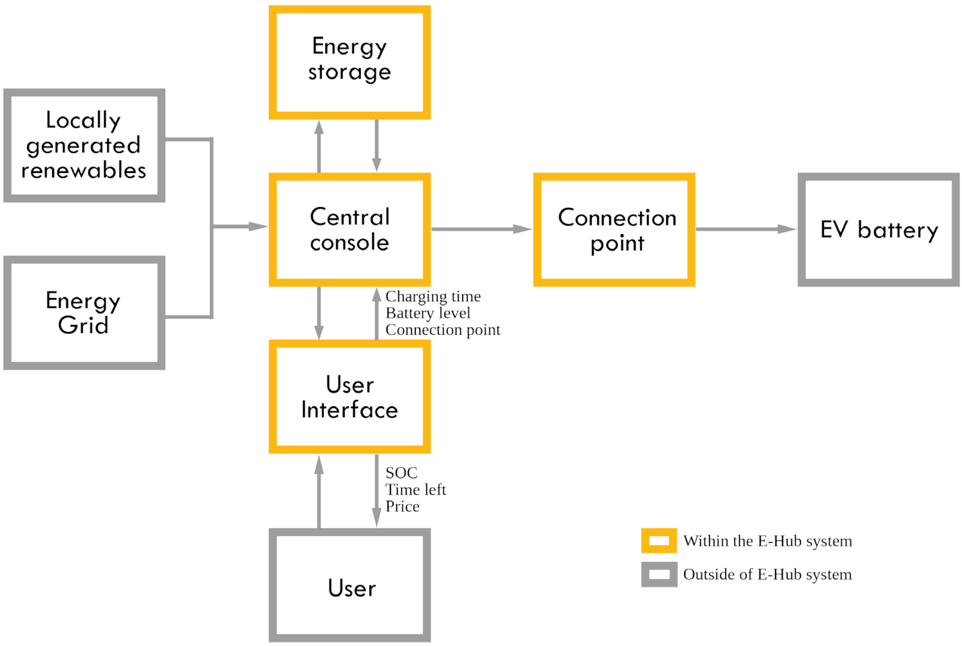


FIGURE 8.1 > Functional block diagram of the main E-Hub components

COMMUNICATION INTERFACES

Communication is an essential element of the E-Hub system since it determines the way the intelligent control system receives and transmits data. It is clear from the analysis phase that several standardized communication interfaces already exist. These are the communication protocols developed by the Open Charge Alliance, consisting of the Open Charge Point Protocol (OCPP) and the Open Smart Charging Protocol (OSCP). The place of these interfaces in the E-Hub system is shown in FIGURE 8.2.

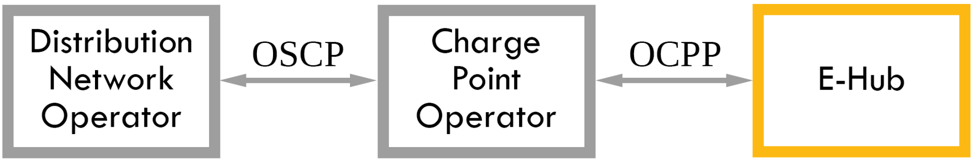


FIGURE 8.2 > Communication interfaces

The OCPP interface is able to create a connection between any charge point and any central system, regardless of the vendor. This increases the reliability of the system, because the operability is not solely dependent on the vendor's service network anymore. OSCP facilitates capacity based smart charging of EVs (Montes Portela et al. 2015) and assists in lowering peak loads on the grid. The OSCP forecasts the load on the grid per cable and calculates the capacity that is left until the maximum acceptable peak load is reached. Furthermore, the forecast calculated by the OSCP can be used to make an estimation on the state of charge of the connected cars over a certain timespan, which could be interesting as feedback for users who want their vehicles to charge up to a certain battery level.

User Interaction

Due to the intelligent charging functionality of the E-Hub system, the user interaction will need to change on several levels compared to conventional charging stations. Early user tests assist in finding the major difficulties in the system and provide insight in the way the system should be used. The results of these early user tests determine how the system should work from a user-perspective and provide insight in the way user steps should be sequenced. Since EV charging is still in an early adopters stage, people are still willing to adapt to changes in the system and adapt their behavior.

APPROACH

A very basic first iteration of the E-Hub is created and represented in a presentation (FIGURE 9). The presentation is based on requirements set by the client, results from the analysis phase and my own insights. Each slide in the presentation corresponds with one or more specific steps of charging an EV at the E-Hub. By going through this presentation with potential users, insights are gathered on which steps are sensible and intuitive and what steps are less intuitive or undesired. Users are given different scenario's in which the state of charge, required battery level and time spent at the charging station vary. The user interface in this iteration is placed in the central console, which is located at the beginning of the parking place. Furthermore, charging bays are divided in quick and regular charging bays. The quick charging bays may only be occupied for a maximum of two hours, which is indicated by traffic signs behind the bays. The results of the user tests are listed in TABLE 3.

TABLE 3 > Results of the user tests

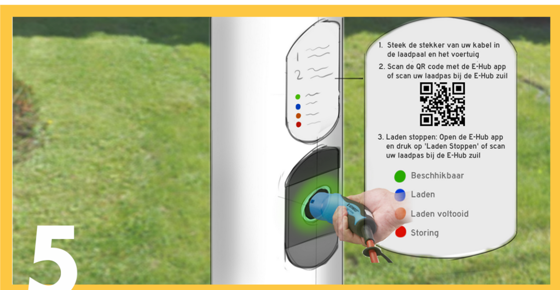
OBSERVATION	CAUSE	RECOMMENDATION
No distinction is being made between slow and quick charging bays	Signs are not clearly visible	• Bigger differentiation required between slow and fast charging bays • Apply the same charging speed to all charging bays
	Users lack awareness of the existence of fast and slow charging stations	• Provide advice at the console or in a mobile application (e.g. when the parameters are filled in, notify the user on which charging bay should be used)
Users find it unintuitive to proceed to a console after plugging in the charging cable	Users do not expect that they should proceed to another console	Implement UI's at the connection points Use a mobile application to fill in the parameters (and allow the user to do this both before or after plugging in the cable)
Users tend to choose the battery level as high as possible	Users are not aware of the range of an electric vehicle	Show battery level in kilometers instead of percentage
	There is no clear price indication	Motivate users to select an accurate time and battery level by price variations on the UI (based on the scarcity of charging bays or energy, the price can either increase or decrease when changing the return time or battery level)
Users do not desire setting an accurate return time	Users do not always want to schedule their return time in advance	Link time frames to activities (such as shopping / short stay / full workday / half workday etc.)
	Users do not always know their return time	Provide time-frames instead of demanding an exact time (this will make it easier to estimate a return time)

1. Find the parking area

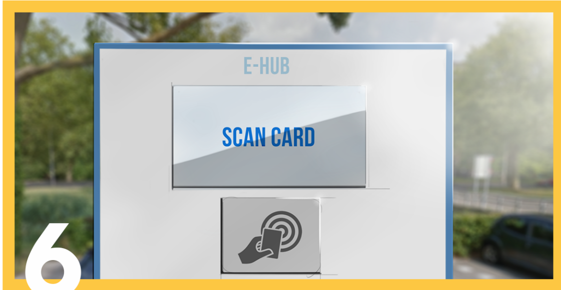
2. Choose a charging bay (quick or regular charging)

3. Proceed to the charging 'column'

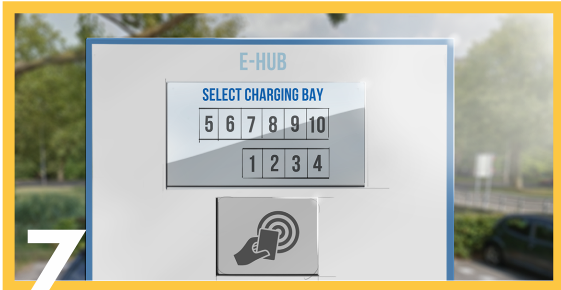
4. Instructions are provided at the connection point



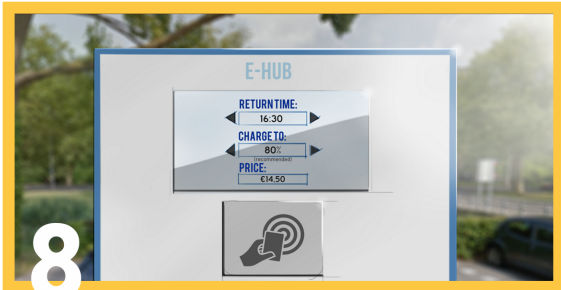
5. Plug in the charging cable



6. Proceed to the console and scan the card

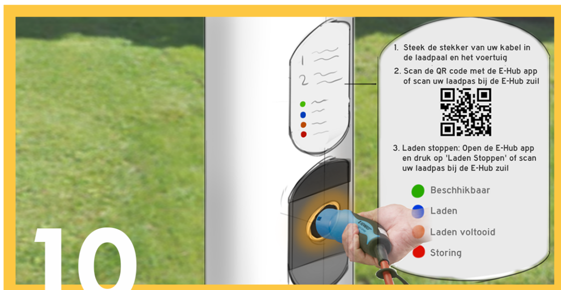


7. Choose which charging bay is being used



8. Fill in the return time and the desired battery level

8. The LED ring will turn blue: Charging has commenced



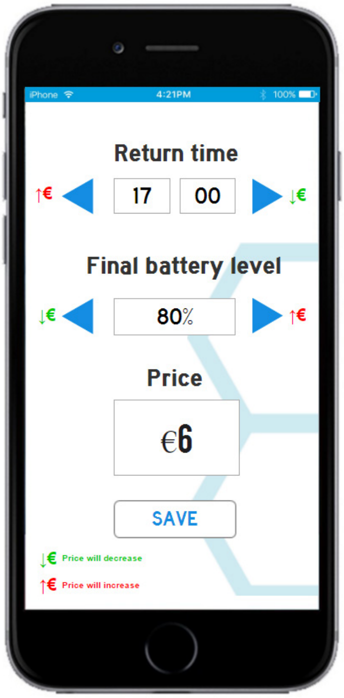
10. When the LED is orange, charging is finished

FIGURE 9 > Taking the user through the charging process

MOBILE APPLICATION

A simple prototype has been created of a mobile application (FIGURE 10). The goal of this prototype is to test how price fluctuations affect the way people choose the parameters that are requested at the user interface. The prototype has been tested with multiple potential users. By letting users play around with the application, a link was quickly noticed between the parameters and the price for charging. Furthermore, when users were informed on the price and how this compared to other charging stations, users were willing to adapt the charging profile to reduce costs. Changing the low variable costs of charging based on the charging profiles determined by the user turned out to be a good motivation for users to change their charging profiles. This will benefit users themselves by increasing control over charging costs and will benefit the system by enabling it to control charging profiles by varying charging costs.

FIGURE 10 > Mobile app used for testing



ERROR HANDLING

While different scenario's were tested, different kinds of errors and difficulties occurred. An overview of these errors can be found in a chart in APPENDIX B: ERROR HANDLING. For each error, one or more solutions are recommended. One of the errors found was the need for emergency charging, which is required when the user needs the parked EV immediately due to an emergency, regardless of the charging time. For this and more errors, different solutions and recommendations are provided.

Point Solutions

Based on the previously conducted analyses, several options are presented that enable the E-Hub to function as a whole and solve the underlying challenges. These solutions are represented in a morphological chart in FIGURE 12. Additional research through literature study has been conducted where necessary. These topics will be further explained. Subsequently, the solutions will be evaluated in the next chapter, based on three different concepts.

SMART PARKING

The first option in FIGURE 12 presents two solutions for allocating EVs and non-EVs in a parking area. Besides the conventional way, separating the charging bays from the regular parking bays, a second option is introduced that is called 'smart parking'.

Smart parking enables charging bays to function as both EV-charging bays as well as regular parking bays. The system divides EV parking spots and regular parking spots in a similar way the system distributes energy: by measuring demand and capacity. When demand for energy is low and demand for charging bays is high (all current charging bays are full), the system is able to activate an additional connection point. When this charging bay is then occupied and the system reaches its maximum capacity, the system can deactivate a charging bay that is occupied by an EV that has finished charging. The LED ring on the connection point will turn orange to indicate charging has been completed and the EV-parking spot will turn into a regular parking spot. This process is visualized with an example in FIGURE 11 and consists out of the following steps:

1. All available charging bays are occupied.

2. Due to the low energy demand of the EVs connected to the system, two additional charging bays are activated.

3. An additional EV starts charging at the E-Hub. The system recalculates the remaining energy capacity based on the charging profile of the EV and decides it is able to charge one more EV. The charging bay of the EV that has finished charging is therefore deactivated.

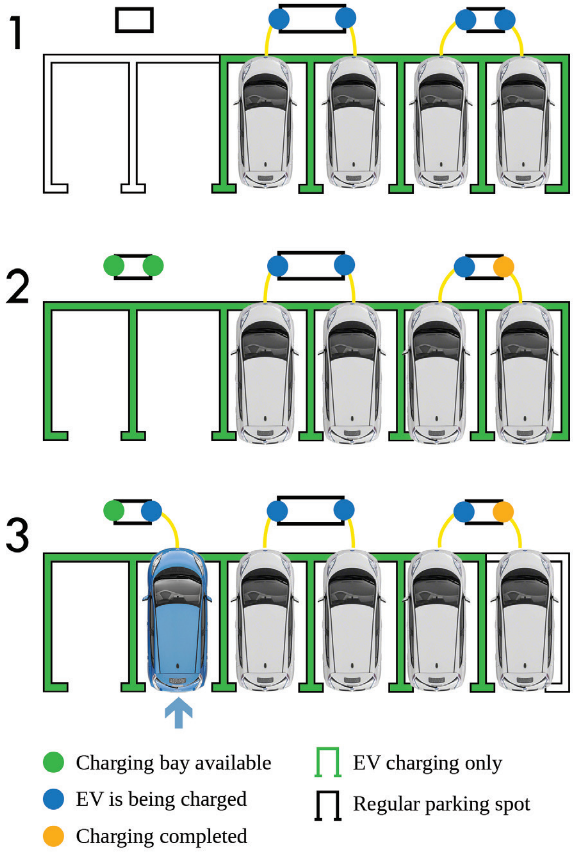


FIGURE 11 > Smart parking situation

ID VERIFICATION

In most current charging stations, ID verification happens through swiping a card with an RFID tag. This card is linked to the energy provider and will charge the user based on the provider it is subscribed to. In order to speed up and simplify user interaction, these cards can become obsolete if the RFID tags are implemented in charging plugs or in cars. The tags would then be read from the reader in either the connection point or the ground.

REQUEST PARAMETERS

The return time and battery level at the end of the charging cycle will be determined by the user. These can either be obtained through a graphical user interface (GUI) that is implemented in the central console, in the form of a mobile application, or from a GUI that is implemented in each connection point. Furthermore, the upper solution makes use of both the mobile application and provides a GUI in the central console as a backup possibility, which enables users to make use of the charging station when the user has no access to a mobile phone.

Parking layout	Charging	Verify ID	Request parameters	Payment
Conventional	Conductive	RFID tag in charging plug	Mobile app and console UI	Automatic transaction or payment at central console
Smart Parking	Inductive	Underground RFID reader	Mobile app	Automatic transaction
		Powerline Communication	UI at charging point	

PAYMENT

Payments can be made through automatic transaction through a mobile application, or users can use a payment terminal at the central console. The first option makes use of both the mobile application and uses a payment terminal at the central console as a back-up possibility. The second option makes use of just the mobile application.

ENERGY BUFFER

In order to use renewable energy during peak demands, a local energy buffer is required. One of the options is the so-called 'second use' of EV batteries. Batteries of EVs have a limited life-span. Most EV batteries last for around 10 to 15 years before defects start to occur. The efficiency of each cycle will go down and the capacity will drop. While these aspects are significant downsides, they could form an opportunity for systems like the E-Hub. Used batteries cost half the price of new batteries (Bloomberg, 2016) and while the capacity may

Energy buffer	Generate renewables	Emergency charging	Wayfinding	Motivate users
Use batteries that can endure many cycles	Solar roofs	Create 'emergency charging' option on mobile app	Road signage	Price variations
Previously used EV batteries	PV panels on surrounding buildings	Charge each EV to a minimum with no power drop	Traffic signs	Automatically charge every EV to 80%
			Signage on console	

FIGURE 12 > Morphological chart

not be good enough for EV use, a combination of used EV batteries may have enough capacity to serve as a local energy storage inside the E-Hub system.

A second option is to make use of new, specialized batteries that are designed to serve as an energy buffer. The advantage is that these batteries will be able to endure more charge cycles and will be more predictable than used EV batteries.

RENEWABLE ENERGY

Using photo-voltaic (PV) panels, renewable energy can be generated locally. The first option makes use of 'solar roofs' above the charging bays. These roofs are covered with PV panels and generate solar power, while providing shelter to the E-Hub users. An example of a solar roof can be viewed in FIGURE 13.

EMERGENCY CHARGING

In order to prevent situations where EVs have a very limited range for a long period of time, two solutions are presented. The first solution involves the mobile application. By implementing a function that enables the user to communicate with the charge point operator, the power supplied to the EV can temporarily be increased. Another option is to set a minimum range the EV needs to be able to cover. Based on this minimum, charging will occur at a higher rate until the SOC of the battery allows the vehicle to cover this distance. Subsequently, the charging power can be varied according to the charging profiles calculated by the control system.

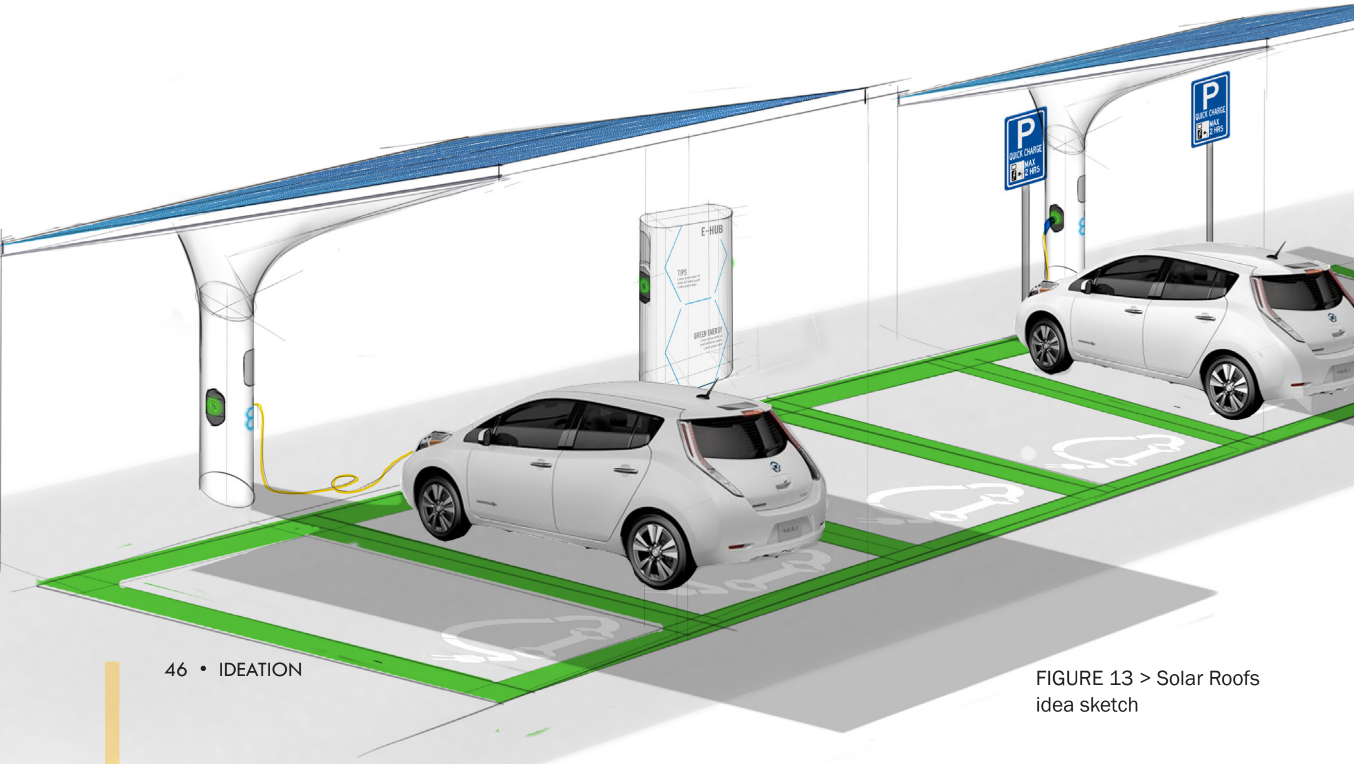


FIGURE 13 > Solar Roofs idea sketch

WAYFINDING

The lack of visibility of charging stations was one of the most frequently stated complaints during the user analysis. Therefore, several options are presented that can increase the visibility of the E-Hub and make finding the charging station easier. Road signs can be used to indicate where the E-Hub is located by guiding the user towards the charging points. This could also be accomplished by traffic signs. A third option is to make use of the central console by making it well-recognizable from a distance. The advantage here is that the impact on the urban environment will be smaller because the design consequences will be kept within the E-Hub system itself.

REQUEST PARAMETERS

In order to make it attractive for users to enter parameters that match with the user needs and optimize the power distribution in the system, two solutions are proposed.

One of the solutions proposes that every EV will be charged to 80%. This percentage is the ‘healthiest’ for Li-ion batteries and will ensure the durability of the batteries. Furthermore, charging after 80% happens at a much slower rate due to the battery management system, which limits the charging power as the battery is being charged to protect the battery (BatteryUniversity, 2017). In this case, charging profiles will be varied based on the selected return time of the user only. The biggest advantage of this solution is it simplifies the user-interaction, making the system more user-friendly.

The other option is to vary the costs based on the requested parameters. There are several characteristics that determine the price. These are the available capacity on the grid, availability of renewable energy and the charging profiles of the EVs. First of all, the time the user starts charging will determine how price varies over time. If the user decides

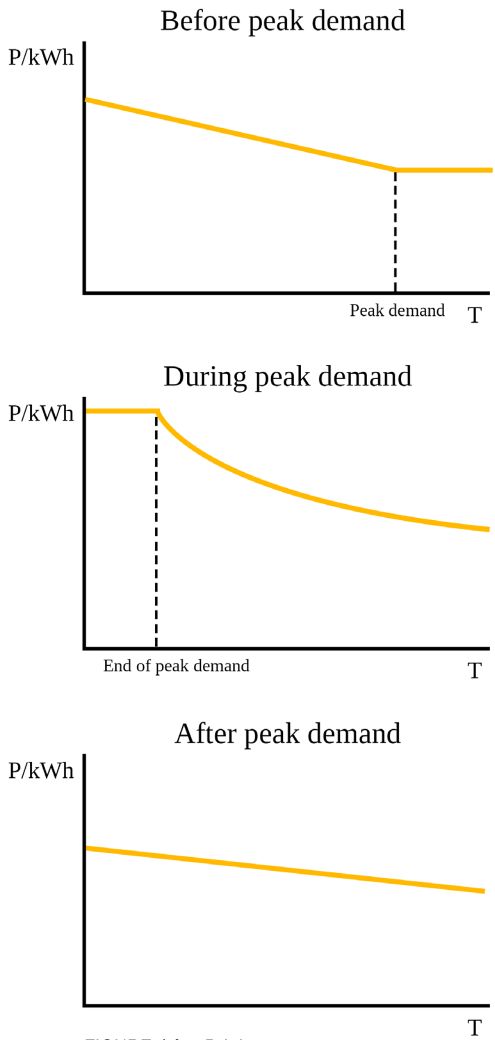


FIGURE 14 > Pricing structure

to charge the EV during peak demand, the price will significantly drop when a longer time span is selected because this will reduce the demand for energy during peak hours, as shown in FIGURE 14. If the user starts the charging process after peak hours, selecting a longer timespan will have a limited impact on price because the energy demand is significantly lower during this time. It should be noted that the pricing structure displayed in FIGURE 14 is based on the fact that the smart parking system is being used, which makes energy the only scarce product. When smart parking is not used, the amount of available charging bays will be an additional constraint and should be taken into account. In this case, the pricing structure would vary based on which aspect forms the bottleneck of the system: availability of energy capacity or the availability of charging bays.

Functions and Key Drivers

Based on the analyses and the suggested solutions, the key drivers of the E-Hub are identified. The key drivers represent the main features or aspects that have the biggest impact on the success of the E-Hub. In TABLE 4, an overview is given in which key drivers and functions are identified, as well as how they are related to eachother.. The cells marked with an 'X' show which functions influence the corresponding key driver.

Functions/Key drivers	Scalability	Reliability	Adapt-ability	Usability	Avail-ability	Power distribu-tion	Costs
Charge EVs	X	X	X		X	X	X
Draw power	X	X	X			X	X
Control power flow	X	X	X	X		X	X
Control payment		X		X			
Receive user prefer-ences		X		X			
Inform user		X		X	X		
Inform operator		X		X			
Secure system	X	X					X

TABLE 4 > Functions and Key Drivers

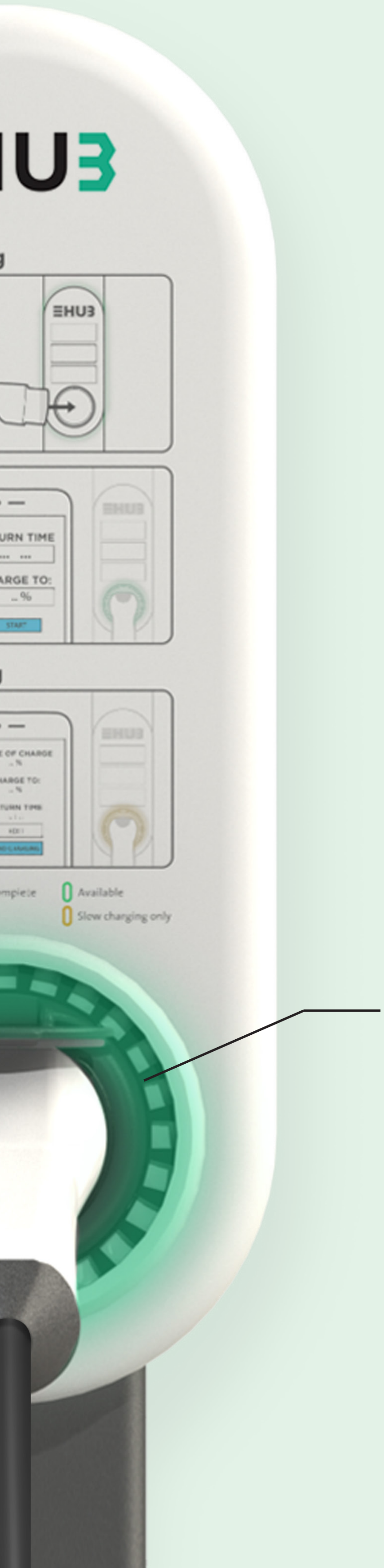
Summary

In the ideation phase, a basic system architecture is presented that explains the main subsystems of the E-Hub, consisting of the connection points, the central console, the local energy storage and the user interface. Furthermore, OSCP and OCPP communication interfaces can be used to enable communication between the E-Hub, the charge point operator and the distribution network operator.

A human-centered approach has been used to investigate different user interactions with the system. This has resulted in several insights. These include the observation that requesting a specific return time is undesired, distinguishing between fast and regular charging bays can be difficult and moving user interaction to a secondary column or console makes the system less intuitive and should therefore be prevented.

An overview of possible solutions is given that solves different challenges that resulted from the previous analyses. An intelligent parking system controlled by the E-Hub can provide a solution to the parking problem. User interaction can be simplified by using RFID tags that are integrated in charging plugs or EVs. A third option is to use power-line communication. Furthermore, an energy buffer can be created by making use of existing batteries that have previously functioned as EV batteries. However, new batteries have a longer lifespan and can be designed specifically to comply with all the requirements from the E-Hub. Furthermore, in order to improve the interaction between the user and the E-Hub, a price structure is proposed that motivates users to select a return time and an appropriate battery level that benefits both the system and the user. The system will be enabled to vary charging profiles more based on the demand profile on the energy grid and the user can reduce charging costs by varying the parameters.

At last, a diagram is presented that identifies the key drivers of the E-Hub and links these to functions that have the biggest influence on these key drivers. The extent to which these functionalities are executed effectively will determine how well the E-Hub performs on the selected key drivers and therefore determines the quality of the system as a whole.


Available
Slow charging only
Charging plug detected,
ready to start charging

4 Concept Generation

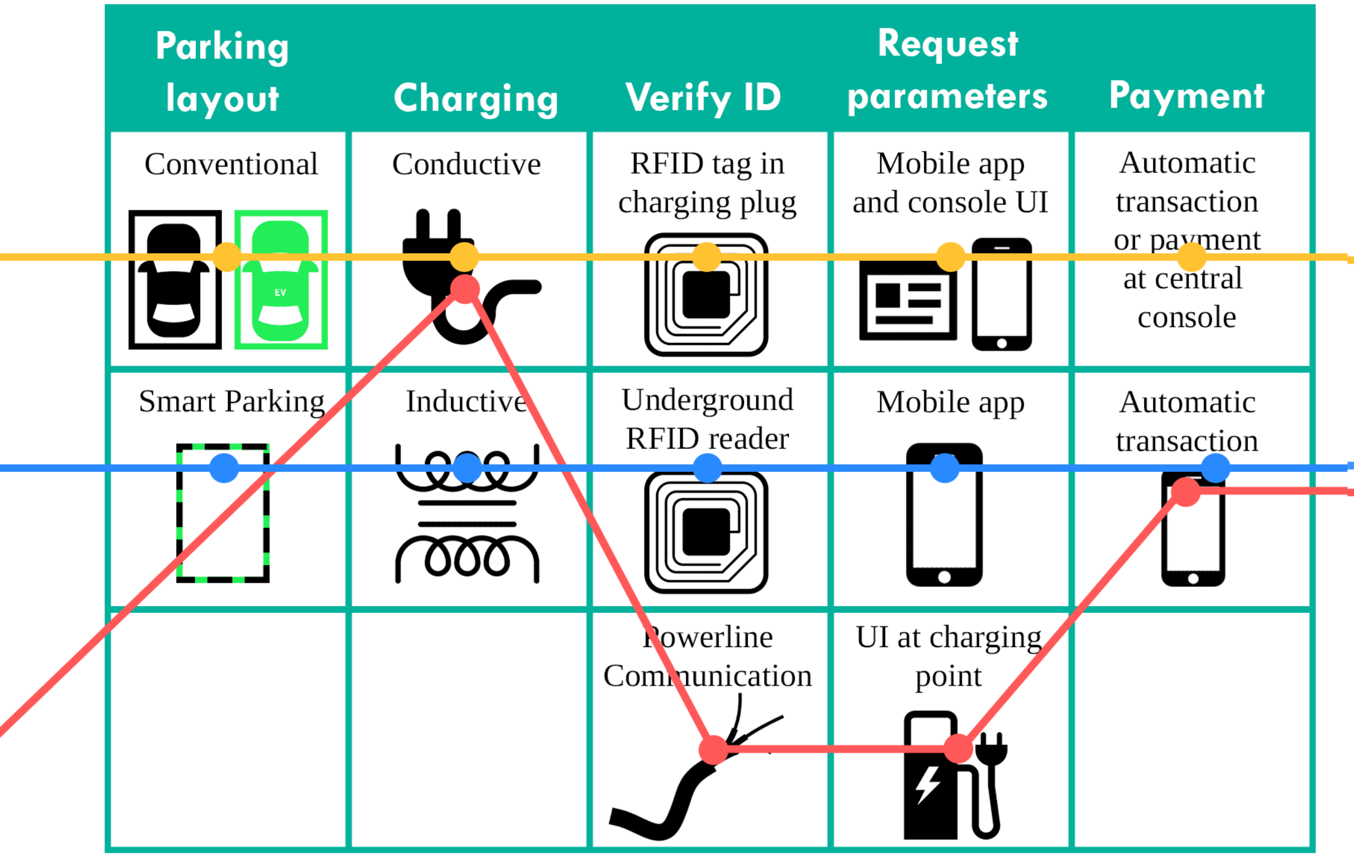
Concept Generation

In the concept generation phase, the previously found solutions will be combined to form three different concepts. The lines combining the three different concepts are visualized in FIGURE 10.1. Beside the solutions presented in the chart, the concepts are based on several design starting points that will be further explained.

MENNEKES PLUG

The E-Hub will make use of the IEC 62196 Type 2 (Mennekes) cable (FIGURE 15) that facilitates charging according to the IEC 62193-1 standard for Mode 3 charging (IEC, 2014). This is an active connection between an EV and a fixed EVSE. The Mennekes cable is capable of providing both single-phase as well as three-phase charging.

FIGURE 15 > Mennekes plug (Mennekes, 2013)



CHARGING BAYS

One of the starting points of the E-Hub is dividing the charging bays into four fast-charging and six slow-charging bays. However, later it was decided that the charging stations must be modular and easily scalable. Therefore, in the next section, the sketches depict six charging bays, among which are four regular and two fast-charging bays. However, the number of charging bays can be expanded or reduced based on the local charging demands, as shown in FIGURE 16. Later on in this report, this decision will be further discussed. In the following section, the concepts are presented and evaluated.

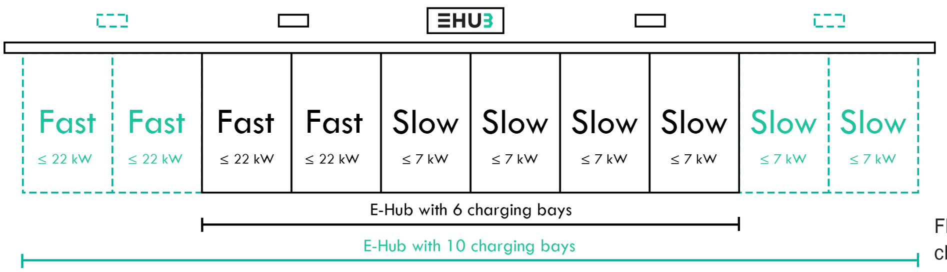


FIGURE 16 > Layout charging bays

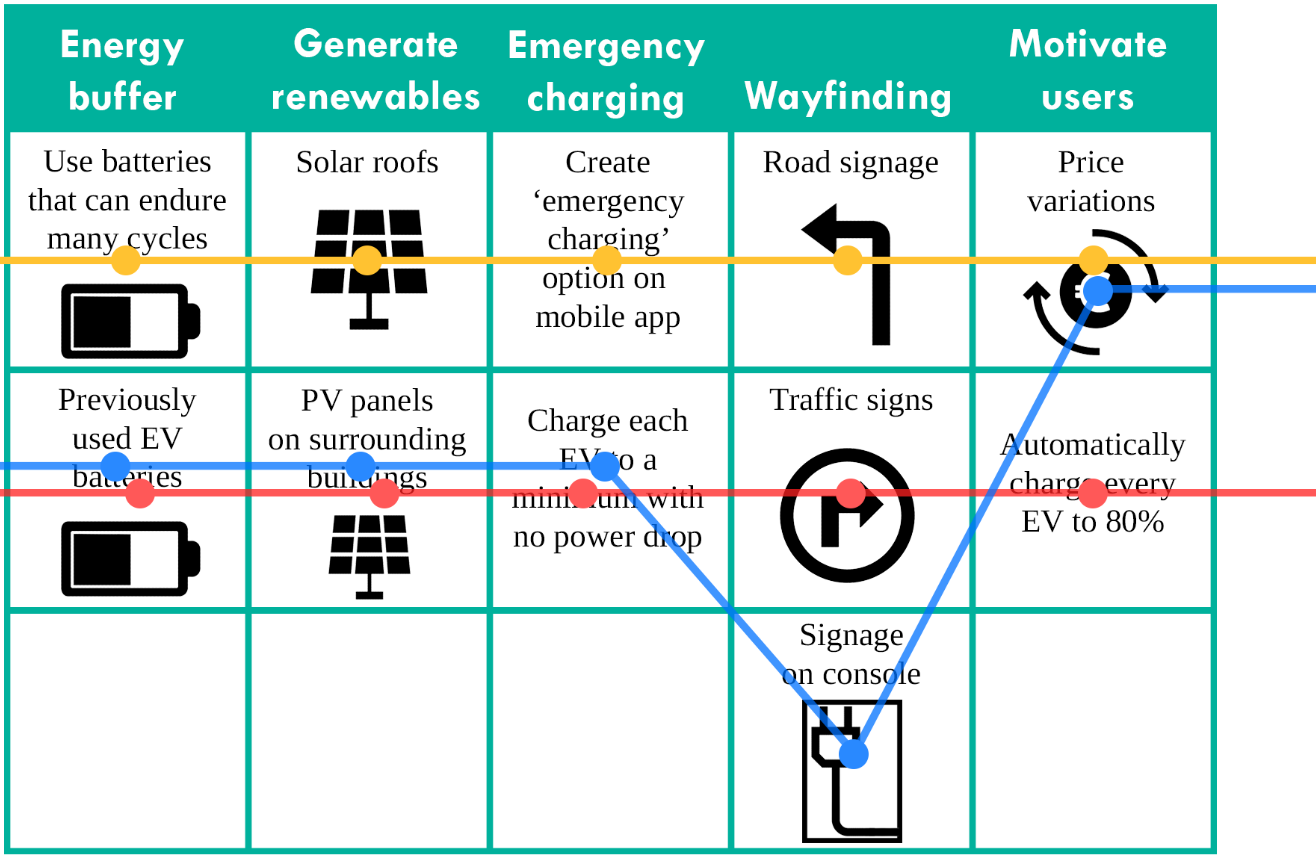
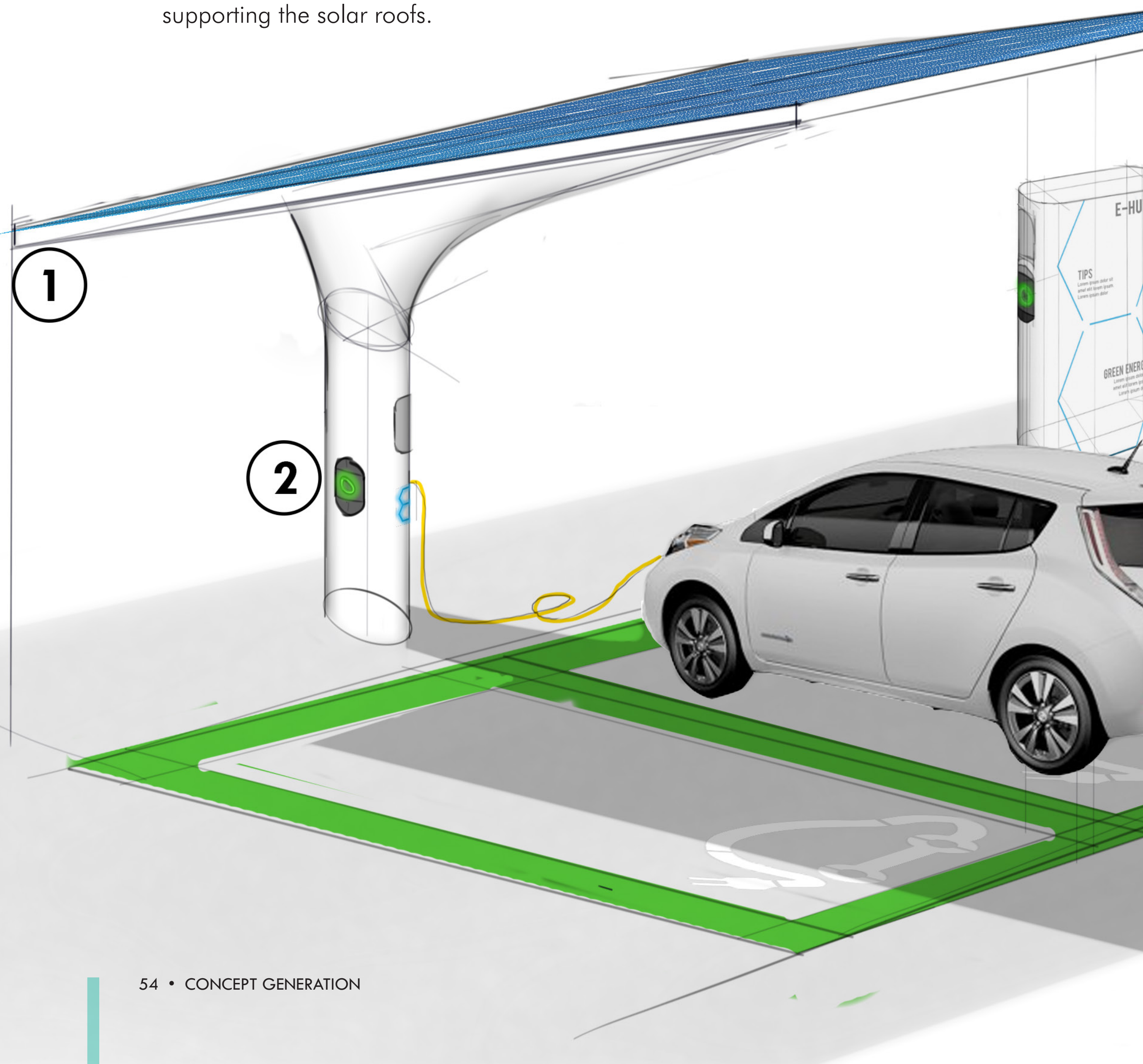


FIGURE 17 > Combined Solutions

Concept 1

1. The solar roof provides shelter for the EVs and generates renewable energy that will be sent to the local energy storage to charge the EVs.

2. The connection points contain RFID readers that are able to scan the RFID tag that is implemented in the charging plug. If the charging plug does not have an RFID tag, a charging card can be scanned at the connection point.
Instructions will be provided on the front side of each of the columns supporting the solar roofs.



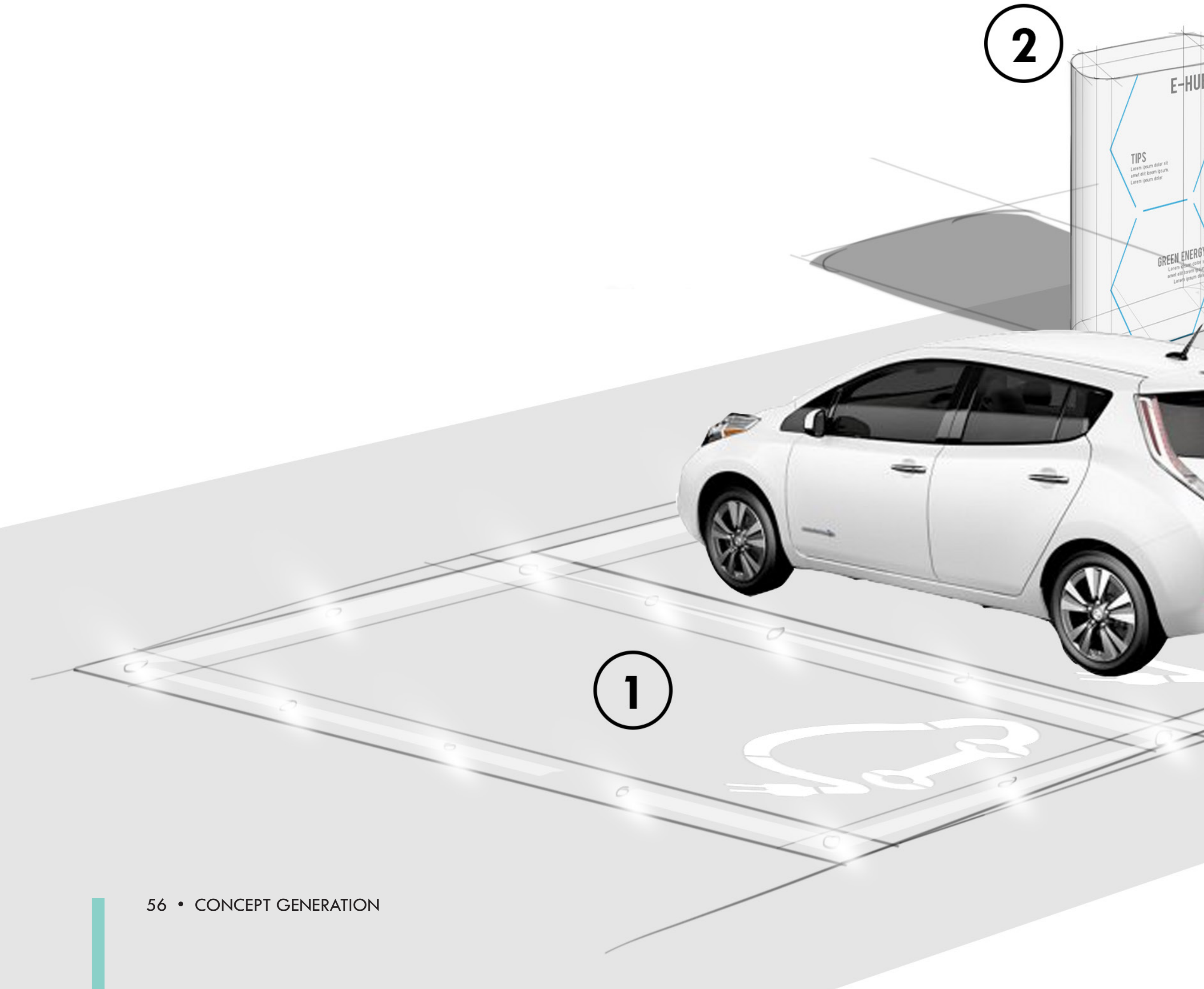
3. The green line around the charging bays indicate that these parking spots can be used for EVs only. Furthermore, road signs will be used to make wayfinding easier.

4. The mobile application allows users to select the charging bay, fill in their time of return and request the desired battery level.

Concept 2

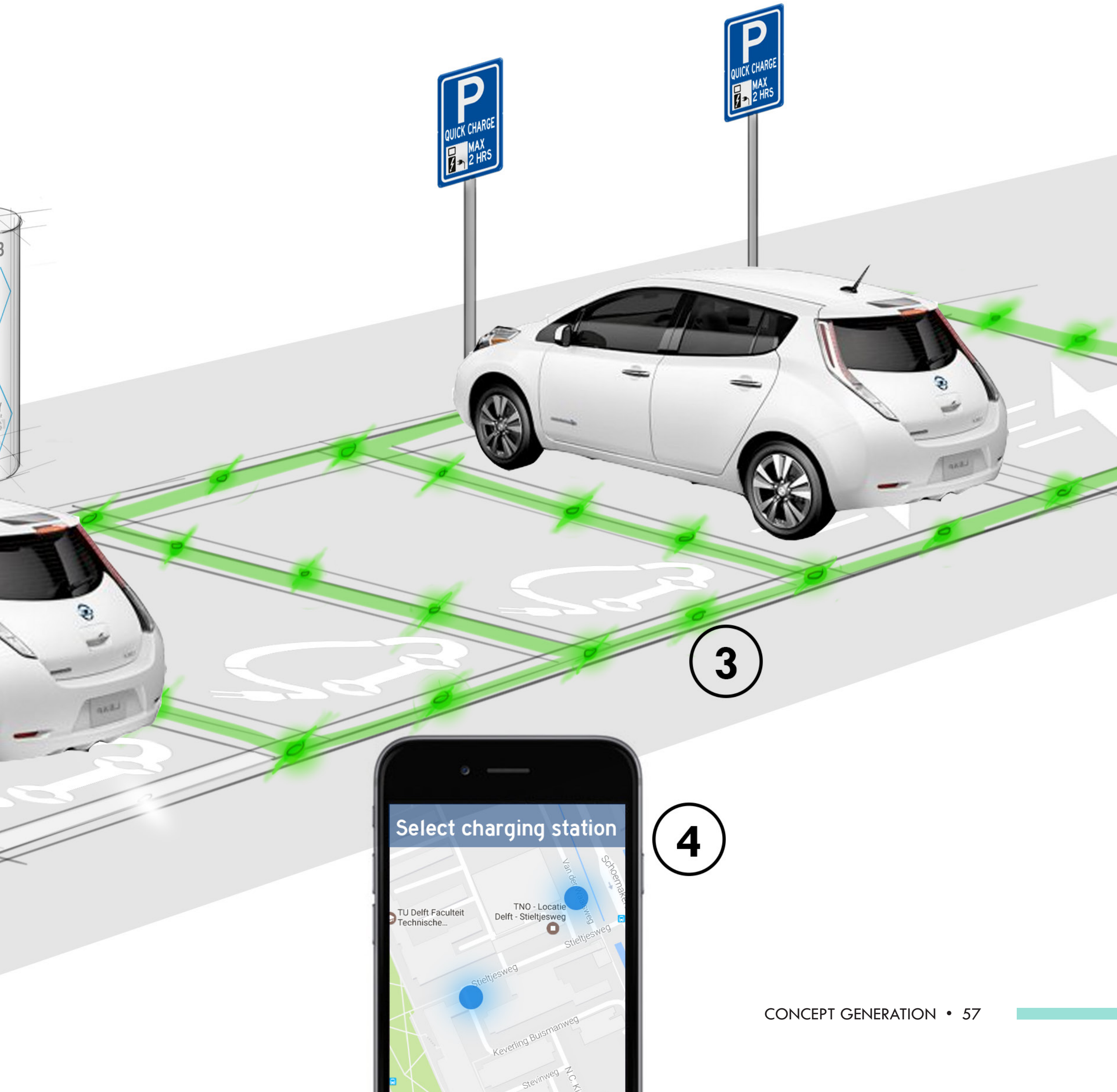
1. Beneath the charging bays, inductive charging coils are installed. Within this underground module, high-frequency RFID readers are placed that can read RFID tags that are placed in the car.

2. The central console will be designed in a well-recognizable way that makes it easy for users to find the E-Hub from a distance.



3. The E-Hub can depict activation or deactivation of charging bays by switching the LED colors around the charging bays to respectively green or white.

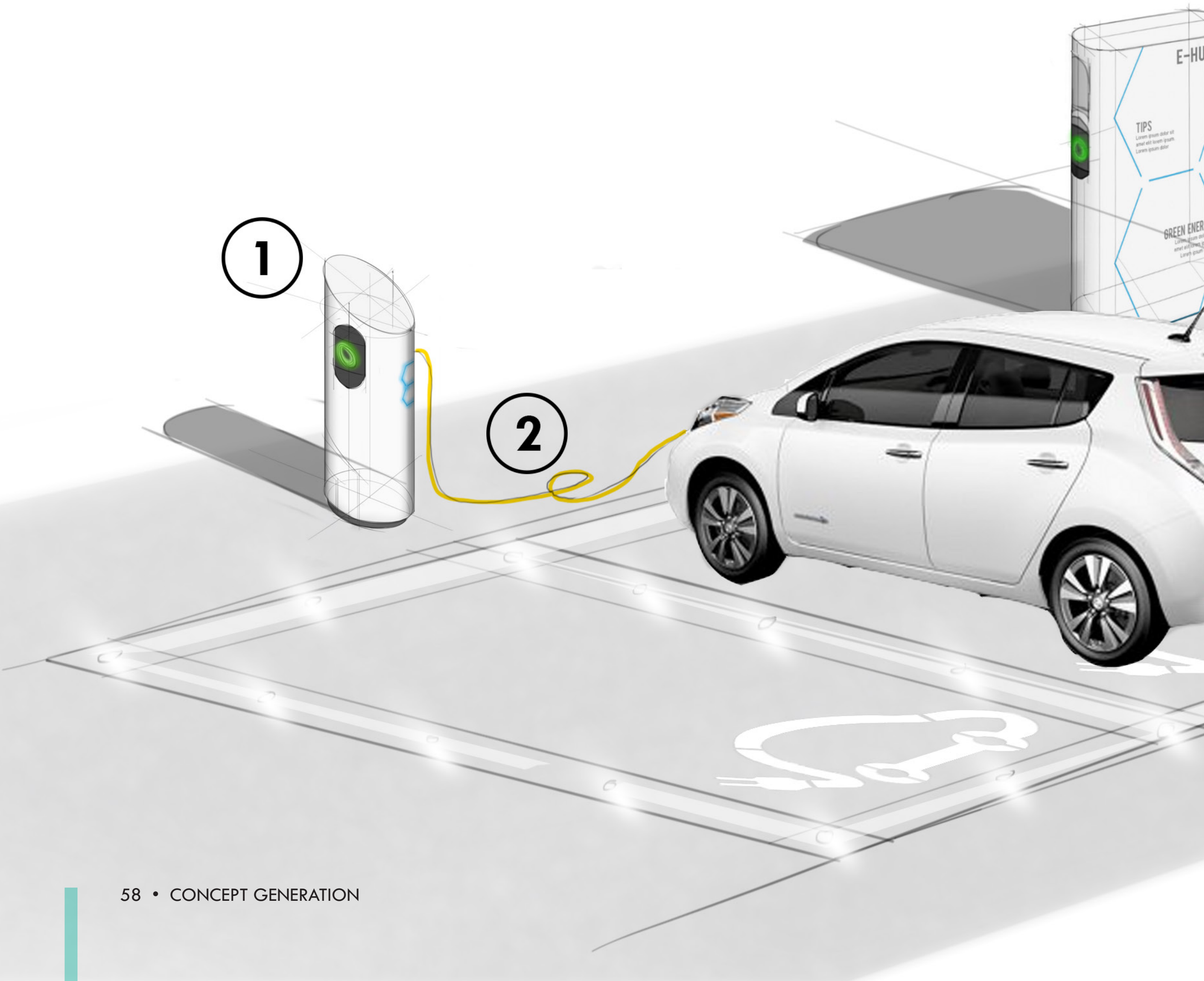
4. The mobile application allows users to select the charging bay, fill in their time of return and request the desired battery level.



Concept 3

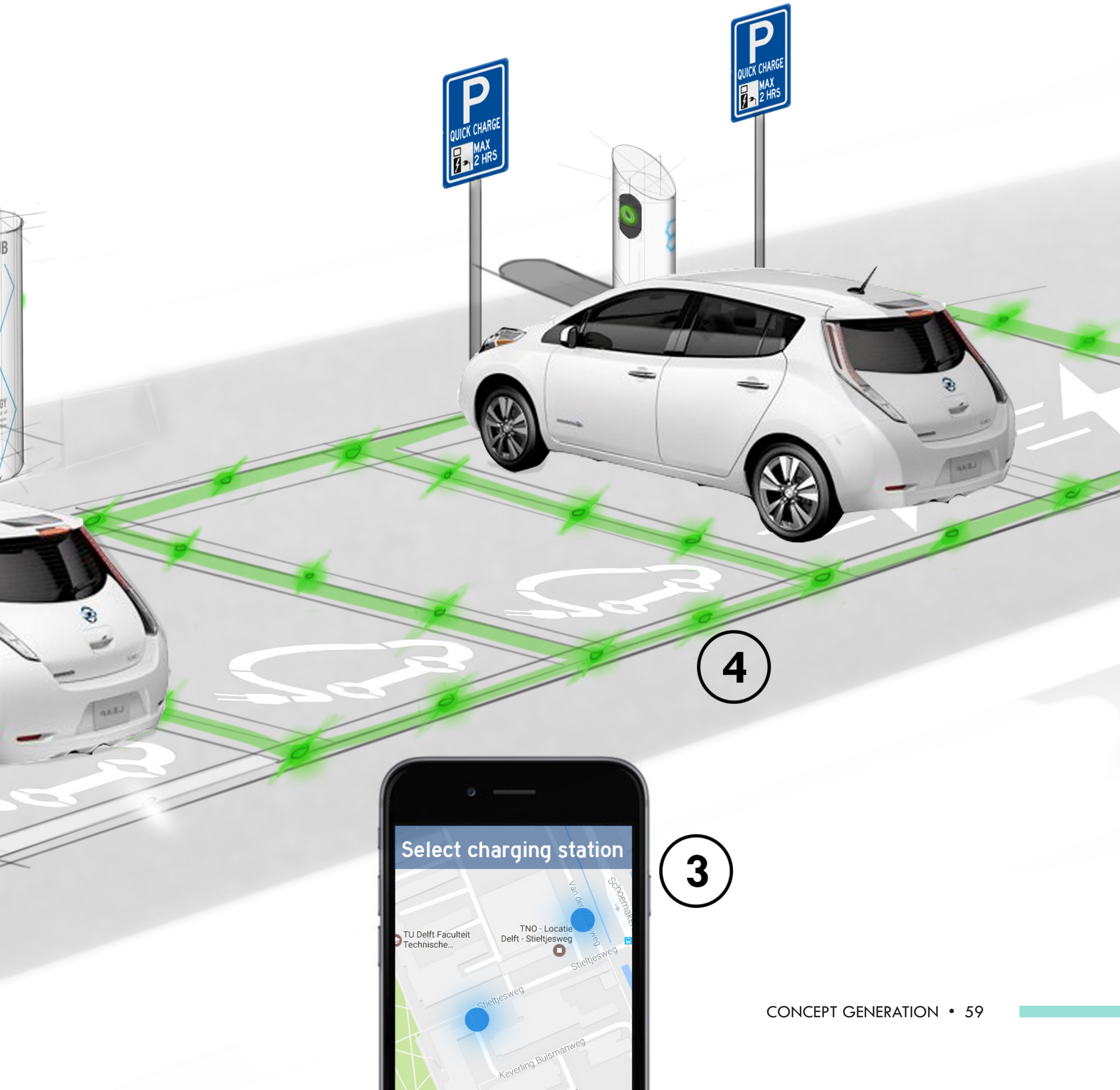
1. Each charging pole provides two connection points. On the sloped side of the charging pole that faces the charging bays, instructions will be provided.

2. Vehicle-data is communicated to the E-Hub through the cable by using power-line communication.



3. The mobile application allows users to select the charging bay, fill in their time of return and request the desired battery level.

4. The E-Hub can depict activation or deactivation of charging bays by switching the LED colors around the charging bays to respectively green or white.



Concept Evaluation

In [TABLE 5], the concepts are rated according to previously determined concept decision criteria. The criteria are based on the key drivers of the E-Hub. Each criteria is assigned a weight and each is rated on a scale of one to five. As can be observed from the figure, the overall scores of the concepts are relatively close, however the scores for the seperate key drivers are somewhat different. Therefore, it is chosen to look at the point solutions seperately and create a final concept that consists of a combination of the highest scoring point solutions. This concept will form the basis for the rest of the project.

		Weight	Concept 1	Concept 2	Concept 3
Scalability		3	4	3	4
Reliability		3	5	3	3
Adaptability		3	3	3	2
Availability		2	3	5	5
Usability	*Affordances*	1	3	5	4
	Discoverablity	1	3	5	4
	Feedback	1	3	3	4
	Visibility	1	5	3	3
Costs		3	2	2	3
Overall		**18**	**62**	**57**	**61**

TABLE 5 > Concept Decision Criteria

Point Solutions

Resulting from the evaluated results, a new set of solutions has been chosen to form the final concept, which is shown in [(FIGURE 18)]. These solutions have been chosen based on the ratings assigned to each concept as shown in [TABLE 5]. The decisions made for each solution will be further explained.

Parking layout	Charging	Verify ID	Request parameters	Payment
Smart Parking	Conductive	RFID tag in charging plug	Mobile app and console UI	Automatic transaction or payment at central console

SMART PARKING

The smart parking system solves the parking allocation problem on parking areas and removes the amount of connection points as an availability constraint. Regarding [TABLE 5], smart parking increases scalability, adaptability and availability. Furthermore, this solution distinguishes the E-Hub from existing charging systems.

CHARGING

IPT as an EV charging solution currently lacks standardization and there are still insecurities related to health and safety. Therefore, it is chosen to use conductive charging instead. However, IPT is not ruled out completely. Since a future transition to inductive charging is likely, the E-Hub will be prepared for a transition to reduce future installation costs. This will be further elaborated in the next chapter.

ID VERIFICATION

A low-frequency passive RFID tag generally has a reading distance of around 10 cm (SkyRFID, 2015). The RFID reader and tag should be placed carefully in order to ensure that the tag is read by the right reader. It should be within range of the reader in the connection point that is being utilized and out of reach for the reader on the opposite side of the pole that is implemented in the other connection point.
This solution combines two steps into one, resulting in fewer actions the user is required to perform. Besides, users do not have to think about the sequence in which these two actions should be performed, making the system less ambiguous.

Energy buffer	Generate renewables	Emergency charging	Wayfinding	Motivate users
Use batteries that can endure many cycles	PV panels on surrounding buildings	Charge each EV to a minimum with no power drop	Signage on console	Price variations

FIGURE 18 > Solutions Final Concept

REQUEST PARAMETERS

The concepts that have backup options score higher on reliability. For this reason, a GUI will be placed in the central console on which the parameters can be filled out. However, the mobile application will serve as the user interface for the routine use case. When the user has no access to a mobile phone, the GUI in the console provides a backup option. Another advantage of the mobile application is that users can fill in the parameters even before or after they park their EV at the E-Hub. As soon as the parameters are confirmed after the charging cable is plugged in, charging will commence.

A local Wi-Fi spot will be provided that enables E-Hub users to connect to the wireless network. Every user with an E-Hub account will be able to make use of the network to enter the parameters for charging.

PAYMENT

Similarly to the previous solution, payment will be possible through the mobile application, which will support automatic transactions. As a backup option, a payment terminal in the central console can be used which will be located next to the user interface.

ENERGY BUFFER

The use of new, specialized batteries designed for charging stations are chosen as the solution to store energy locally. While used EV batteries might be the cheaper option, adoption of these batteries has several downsides. The technology of used EV batteries are relatively old and capacity will have dropped, as well as the efficiency of each cycle. Furthermore, this degradation is not a linear process, making the battery less predictable (Pressman, 2016). This makes it difficult to deploy these batteries in a grid setting, where predictability and reliability are of great significance. Therefore, it is proposed that new batteries are used that are specifically designed for dynamic charging and can endure more charge cycles, resulting in a more efficient, reliable and predictable system.

In APPENDIX 4, a general cost analysis is given that shows the main costs of the E-Hub. From this analysis, it is clear that the energy buffer takes up a relatively great amount of the total costs. Therefore, the energy buffer will be a location dependent solution, since not all locations may be suitable for implementing PV panels and storing renenewable energy in a cost-efficient way.

GENERATE RENEWABLE ENERGY

The way renewable energy is generated is highly dependent on the location. Parking areas, curbside parking spots and parking garages all require a different solution as to how renewable energy is generated. Therefore, it is chosen to look at each location specifically to determine how renewable energy can be generated. A standardized solution for the implementation of PV panels will therefore not be provided, since this would reduce the adaptability of the E-Hub in different settings and locations significantly.

EMERGENCY CHARGING

In order to ensure that people are able to meet their minimum driving demands quickly, connected EVs will be charged to a minimum with a set amount of power. In the next chapter, this will be discussed more specifically.

WAYFINDING

In order to ensure people are able to find the E-Hub, a well-recognizable console will be designed that can be found easily when entering the parking area.

MOTIVATE USERS

Using price variations will motivate users to select appropriate parameters. This will increase the amount of flexibility the E-Hub has over the charging profiles, because users are more likely to choose a specific battery level and a return time that is close to their actual return time. From the user point of view, this will make charging more cost efficient.

User Interaction

The flow chart in FIGURE 19 explains the steps necessary to interact with the final concept of the E-Hub. The user can either scan a charging card to verify the user ID, or this can be done automatically through an RFID tag implemented in the charging plug. The yellow rectangles show information that is received on the mobile application and provided for the user. Furthermore, the user can change the parameters after confirmation has taken place. The E-Hub wil subsequently calculate the new charging profile and price profile.

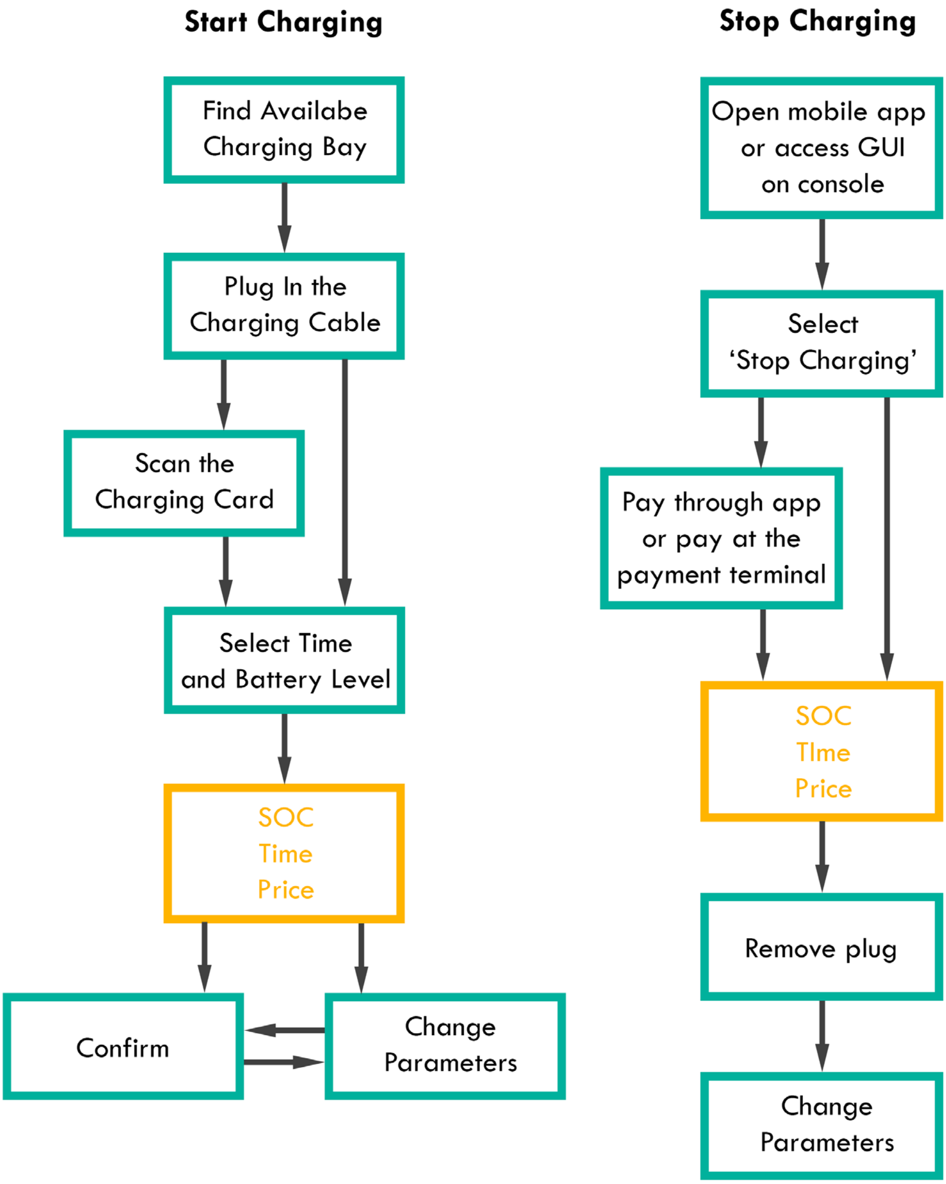


FIGURE 19 > Flow chart of the user interaction

Summary

The three different concepts have been rated by using the key drivers of the system. Based on these criteria, a combination of solutions has been defined that combines the highest scoring aspects of the three concepts. One of the important decisions made is the decision for smart parking. This solution aims to improve the allocation of EVs and regular cars in parking areas and aims to increase the utilization rates of charging points. Furthermore, IPT systems will not be implemented, but the E-Hub will take a future implementation of IPT into account. The usability of the system will be increased by implementing RFID tags in charging plugs, while remaining compatible with car sharing services. To increase the reliability of the system, several backup options are implemented, such as a GUI and a payment terminal in the central console.

The implementation of an energy buffer, as well as implementation of PV panels, will be a location dependant solution. Furthermore, the cost-effectiveness of energy buffers should be further analyzed to determine if energy buffers should be considered a requirement for the E-Hub, since the current costs of an energy buffer increase the total costs by a relatively great amount.

The flexibility of the system will be increased through the price variations that occur based on the charging demands requested by the user. By calculating the price profile, the user is given more control over charging costs and the E-Hub is able to distribute power more efficiently.

As a result from the user analysis and the selected solutions, a flow chart is created that represents the user interaction with the system for both starting and ending a charging process.


Available
Slow charging only
Car is being charged

Concept Development

Concept Development

In the previous chapter, a foundation for the final concept has been created. This concept gives an overview of the different solutions the E-Hub should contain. From this concept, the most crucial solutions that are most influential for the success of the E-Hub will be further elaborated. These include the smart parking system and the the future transition to IPT. These two aspects influence multiple key drivers of the E-Hub, such as the availability, adaptability and scalability. Furthermore, a design of the final concept will be created and presented in the form of a virtual model. The design considerations will be discussed according to the key drivers of the E-Hub.

Three-phase charging

Initially, it was assumed that charging bays would be divided into fast (up to 22 kW) and regular (up to 7 kW) charging. The regular charging bays will contain single-phase chargers that charge up to 7 kW. The fast charging points will be able to provide a maximum of 22 kW through a three-phase charger. However, additional desk research pointed out that using three-phase chargers for all connection points provided several advantages over the use of single-phase chargers.

First of all, three-phase chargers provide a higher efficiency than single-phase chargers, resulting in less energy loss. Furthermore, three-phase charging allows for smaller, less expensive wiring and lower voltages, making it safer and less expensive to run (Allen, 2014). Installation costs of three-phase chargers are significantly higher than the costs for installing single-phase chargers. However, the costs for a future transition from single-phase to three-phase will be even higher. With the rapidly increasing market of EVs, it is likely that single-phase chargers will be replaced with three-phase chargers in the future. The decision for three-phase chargers only therefore makes the E-Hub more future-proof.

Communication Interfaces

Before proceeding to the smart parking system, it is important to define how the E-Hub communicates with other parties that exchange data with the E-Hub. In FIGURE 20, the interfaces between these parties are shown in a functional block diagram. In the following sections, it will become more clear which specific interfaces should be addressed and possibly adjusted in order to use the functionalities of the E-Hub to its full extent. A full overview of data communication van be found in APPENDIX C: N2 DIAGRAM.

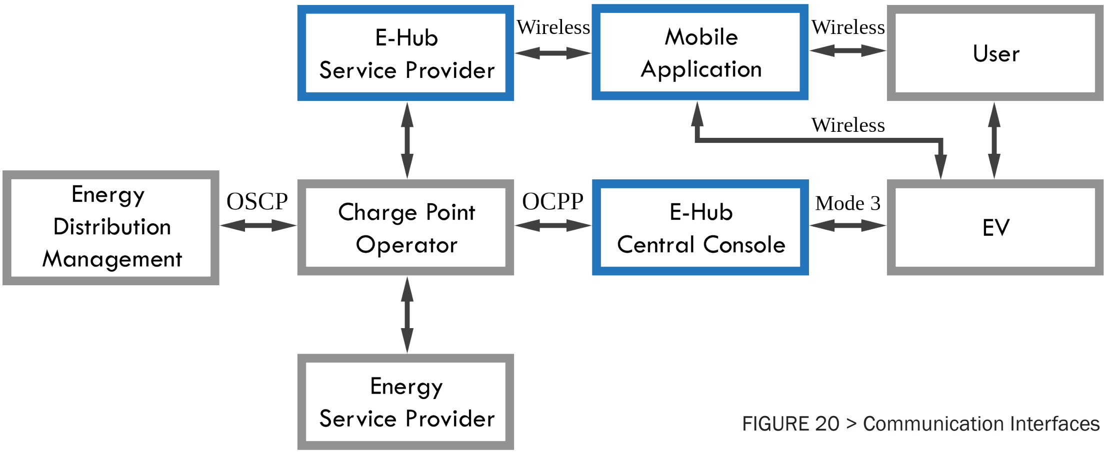


FIGURE 20 > Communication Interfaces

Smart Parking

The goal of smart parking is to solve the allocation problem of cars in a parking area. Furthermore, it aims to remove a constraint regarding availability of charging bays by making the system control the amount of charging bays that are activated.

Smart parking enables the E-Hub to autonomously activate or deactivate charging points. In order to create a system for this, several requirements have to be determined that should be met before a connection point can be activated. Multiple factors play a significant role in determining these. These include the non-linear power flow during the charging process. Furthermore, the changing demands of future E-Hub users should be taken into account. The E-Hub should ensure that the demands of users can be met for each active charging point.

CHARGING PROFILES OF LI-ION BATTERIES

To get a good understanding of the energy requirements for activated charging bays, the charging profile of EV batteries should be analyzed. The most common EV batteries in today's EVs are Lithium-ion (Li-ion) batteries. A Li-ion battery contains a Battery Management System (BMS). The BMS controls the maximum amount of current that can be delivered to the battery. When a certain capacity is reached, the BMS will decrease this amount to protect the battery.

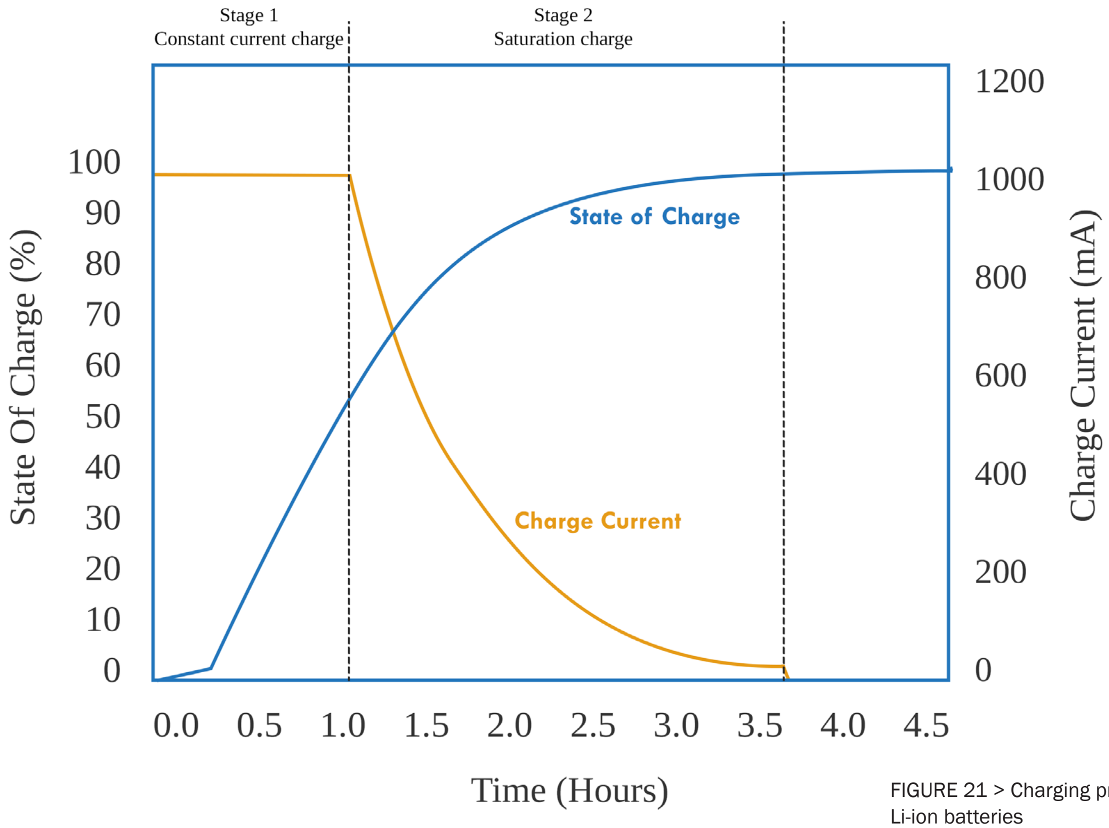


FIGURE 21 > Charging profile of Li-ion batteries

In FIGURE 21, the charge states of a Li-ion cell are shown. The charging process mainly consists of two stages: Constant current charge and saturation charge (BUG, 2016). As can be derived from the graph, the current drops after stage one has passed, which corresponds to a SOC of approximately 50%. After this stage, the charging process moves to Stage 2: Saturation stage. In this stage, the current decreases as the capacity of the battery increases. When the user sets the desired battery level to a relatively high charging state (60% - 100%), the power supply of the E-Hub will be significantly greater during the first charging stage and gradually lower as it moves through the second stage. Therefore, the E-Hub must be able to provide sufficient power for the first hours an EV starts using the charging bay and should therefore 'reserve' enough energy capacity for the first hours an EV starts charging at an active connection point.

CHARGING DEMANDS OF USERS

The E-Hub focuses on semi-public charging infrastructure. These mainly include residential street parking and parking when at work. Furthermore, secondary users are more short-term related, such as people visiting shopping malls or the use of shared EVs owned by fleet-operators. Data collected through the Centraal Bureau voor Statistiek and Kennisinstituut voor Mobiliteitsbeleid are shown in TABLE 6. Furthermore, the average charging time at the TU Delft has been calculated by using statistics provided by the Facilitair Management en Vastgoed (FMVG).

TABLE 6 > Average data on travel distances and charging

Avg. commuting distance (km) (KiM, 2010)	23
Avg. daily mileage (km) (CBS, 2012)	37
Avg. charging time (hrs) (FMVG, 2015)	5,0
Avg. charging amount (kWh)	8,0

The statistics give a basic understanding of what an average charging cycle currently looks like. It should be taken into account that in the future, batteries will have larger capacities and the charging demands will be more diffuse than in the current situation. Besides that, as range becomes less of an issue, EVs will travel longer distances. Furthermore, shared car systems will require shorter charging times. Therefore it is important to apply relatively large margins to determine the requirements for active charging bays in the future.

MINIMUM CHARGING DEMANDS

In case an EV is parked with a very low battery level, the system will put a limit on the minimum charging power. The E-Hub will not charge at a lower rate than 7 kW until the range of the EV has reached approximately 1,5 times the average commuting distance. This corresponds to approximately 34,5 km. For the average EV, this range can be reached comfortably with 7 kWh storage capacity in the battery. For a Nissan Leaf with a 30 kWh battery, this would be reached at approximately 23%. This will ensure that the EV reaches an acceptable range in time, in case the user needs the EV earlier than initially expected.

STATE ADOPTION

Based on the data found on current charging profiles and the analysis on charging profiles of Li-ion batteries, an estimation is made on the requirements for active connection points. The requirements can be found in TABLE 7. The smart parking system divides charging bays into three stages: 'Full operability', 'routine charging only' and 'no operability'. The term 'routine charging' defines charging for the routine use case, which consists of charging times from several hours up to a full day. Each state has its own requirements that should be met before the state can be adopted by the smart parking system. The basis of the smart parking system lies on the fact that energy capacity is 'reserved' for each active connection point.

If an amount of 21 kWh is available and can be distributed to an EV within 3 hours with an average power of at least 11 kW (the amount commonly used to describe 'semi-fast' charging) during the first hour, the connection point will indicate the 'full operability' state (state 1). The outer LED ring on the connection point will emit a green color. If these requirements cannot be met for a connection point, but there is still sufficient energy available for charging at a slower rate, the connection point will adopt the state for 'routine charging only' (state 2). While semi-fast charging speeds cannot be met with this state, it still meets the demands for overnight charging or for longer charging times, such as when the user parks the car during a workday. When these charging requirements cannot be met either, the LED rings will be turned off completely and the parking space can be used as a regular parking space (state 3).

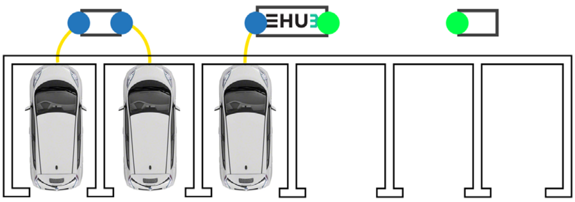
State	1: Full operability	2: Routine charging only	3: No operability
State adopted when	No other charging bays are available, energy requirements are met	No available charging bays are available, energy requirements for full operability are not met but energy requirements for routine charging only are met	Other full operable charging bays are available, energy requirements are not met
LED color	Green	Orange	LED turned off
Reserved capacity	21 kWh	12 kWh	0 kWh
Charging speed during the first hour	Minimum average power of 11 kW	n/a	n/a
Available energy during the first three hours	21 kWh	12 kWh	n/a
Average charging power during the first three hours	7 kW	4 kW	n/a

TABLE 7 > Requirements per adopted state

SWITCHING BETWEEN STATES

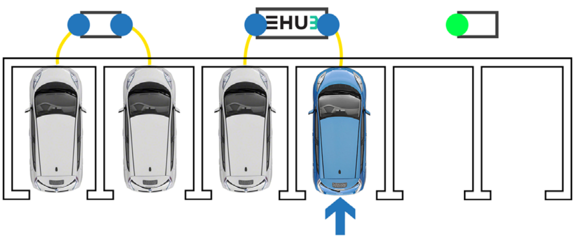
The method for the flexible charging bay system works on the basis that every active charging bay initially has a reserved capacity that ensures the amount of energy can be transmitted over a given timespan. Depending on the size of this capacity, the E-Hub will decide which state will be adopted. The ways the E-Hub switches between states are explained in FIGURE 22. When an EV enters the E-Hub, the E-Hub will recalculate the availability of charging bays based on the charging profile of the EV. Based on the charging demands of the new customer, the E-Hub will decide whether it should activate an additional charging point, add an additional charging bay in state 2, neither activate nor deactivate additional charging bays, switch a charging bay from state 1 to state 2 or switch a charging bay from state 1 to state 3.

FIGURE 22 > Switching between states



Situation 1

- Connection points 1-5 meet the requirements for state 1
- Connection points 1-3 are charging EVs according to the calculated charging profile
- Available energy capacity is insufficient to power connection point 6
- Assumption: The energy distribution is in perfect balance. The EVs charge exactly according to their reserved capacity.



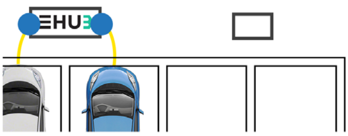
Situation 2

An additional EV starts charging at the E-Hub. Based on the charging profile of the additional EV, the E-Hub can choose one of the following options:

Option 1

- Energy demands exceed requirements for the reserved available capacity

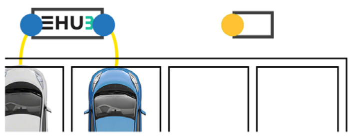
➔ **Connection Point 5 switches to state 3:**



Option 2

- Energy demands exceed requirements for the reserved available capacity

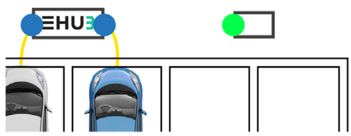
➔ **Connection Point 5 switches to state 2:**



Option 3

- Energy demands exactly meet the requirements for the reserved capacity

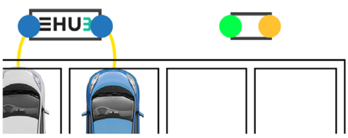
➔ **Connection Point 5 *remains* in state 1:**



Option 4

- Energy demands are below the requirements for the reserved capacity

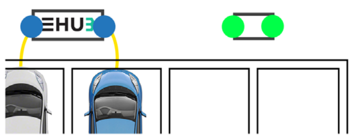
➔ **Connection Point 6 switches to state 2:**



Option 5

- Energy demands are below the requirements for the reserved capacity

➔ **Connection Point 6 switches to state 1:**



It should be noted that charging bays can only adopt the second state when all other charging bays adopting the first state are occupied. As long as charging bays in state 1 are available, the second state will not be used. This state will only be used when no other charging bays are available. Furthermore, since ICEVs are allowed to park on non-active charging bays, there will be a set minimum amount of charging bays activated to ensure there are enough charging bays available.

VEHICLE IDENTIFICATION

Before a connection point can be activated, the E-Hub must know if the corresponding parking spot is available and not in use as a regular parking spot. Furthermore, if an ICEV parks at an active charging bay, the E-Hub can deactivate the charging bay and activate an available parking spot when it notices that the connection point is not being used.

Vehicle detection can be used to enable the E-Hub to indicate whether a car is parked at one of the bays connected to the E-Hub. The SENSIT IR by NEDAP can be used to accomplish this. The SENSIT IR is a wireless vehicle detection device that can be mounted into the ground. It uses a dual detection mechanism that involves infrared and earth magnetic field (Nedap, 2016). Since it communicates wirelessly, installation can be done relatively fast and cost effectively.

Another benefit of using wireless vehicle detection sensors is that it can provide information on availability to the user. However, since the sensor only detects whether a vehicle is present or not, it is not able to detect the available spot is EV-only or for regular parking use. Therefore, the E-Hub should combine the data collected by the vehicle detection system with the data on available charging spots. In FIGURE 23.1, the communication between the different subsystems are shown. The signal of the sensors is sent to a relay node that

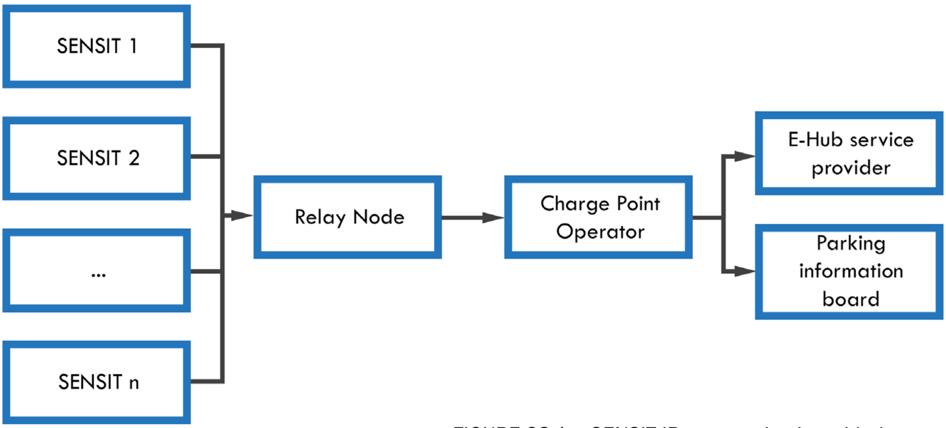


FIGURE 23.1 > SENSIT IR communication with the system

collects the signals from all the sensors and sends the data to the charge point operator. The information on available parking and charging spots can then be sent to an information board at the corresponding location (FIGURE 23.2) and to the back-office system of the E-Hub to implement the availability of the charging bays into the mobile application.

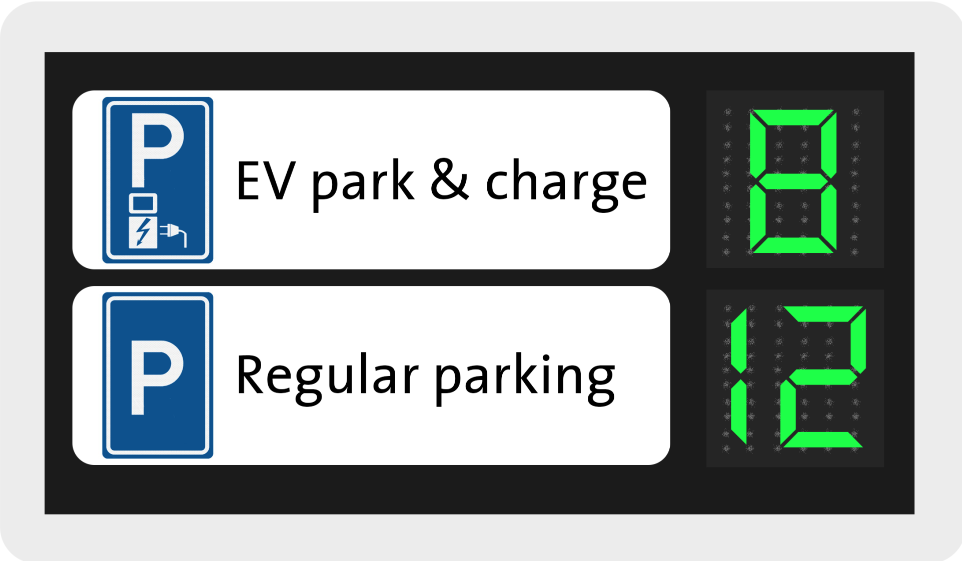


FIGURE 23.2 > Parking and charging information board

Future Implementation of IPT

For the implementation of an IPT system in the E-Hub, there are several design trade-offs that should be considered. IPT for EVs is still an emerging technology and placement of coils in EVs and EVSEs have not been fully standardized yet. Therefore, it is not yet possible to design a fully IPT-ready system in the E-Hub. Instead, several requirements and trade-offs will be given to provide a basis for a future implementation. In TABLE 8, an overview is given on additional requirements necessary for IPT implementation.

COIL SIZE

First of all, the placement of the transmitting and receiving coil have to be determined. While the location of these coils on the EV-side have not been standardized yet, proper alignment of the coils is crucial for the efficiency of the IPT system. Magnetic coupling decreases rapidly with misaligned IPT coils, decreasing the efficiency of power transfer (Bosshard and Kolar, 2016).

Therefore, a sufficient misalignment tolerance is needed to limit variations of the magnetic coupling. Over-dimensioning of the transmitter coil and the power electronics or the use of multiple transmitters can provide sufficient tolerance. However, there also exists a trade-off between the coil size and the complexity of the transmitter (Bosshard and Kolar, 2016). A larger coil requires a more complex transmitter and increases installation costs and will also require higher material costs on the vehicle-side components.

COOLING

Depending on the materials used for housing and the power, active cooling might be required to prevent a potential loss of efficiency and the possibility of overheating. It is important to note that for relatively compact IPT coils that make use of high power levels, it can be especially difficult to implement sufficient cooling technology (Bosshard and Kolar, 2016).

SHIELDING

There should be minimal interference with the charging process. This can be the case for specific parking bays that are made out of concrete with reinforcing bars (Plugless, 2016). For these cases, a shield that blocks potential interferences should be used. The shield can be made out of a rigid aluminum and ferrite composite construction. This is also used for the 'Plugless Power' inductive charging systems.

SAFETY STANDARDS

The IPT system should comply with all relevant safety standards for the magnetic field. There still exist some insecurities in how IPT systems influence the health of humans. For example, there could be a possibility that the IPT system influences pacemakers, endangering people with a heart condition. Therefore all relevant safety standards should be met for places accessible for humans, consisting of the passenger cabin and the space around the vehicle.

VARIABLE POWER LOADS

Considering the smart charging system of the E-Hub, the inductive charging system must be able to distribute variable power loads. A controller already exists that is able to divide wireless charging into 10 user-defined levels (Moghaddami and Sarwat, 2016). The levels include the standard wireless charging levels for light-duty EVs as defined by SAE TIR J2954 (Schneider, 2016), reaching up to 22 kW.

VEHICLE IDENTIFICATION

As an alternative to the user identification through the charging cable, an in-ground High-Frequency RFID reader can be used. The RFID reader will read an RFID tag that is placed in or under the vehicle. As a back-up solution, the RFID reader in the conventional connection point can still be used to scan a separate charging card. Furthermore, it should be made sure that no interference with the IPT system occurs. However, due to the large differences in frequencies, this is an unlikely event (a typical HF RFID system operates at frequencies ranging between 3 – 30 MHz (IMPINJ, 2012), whereas the IPT system operates at a maximum of 100 kHz (Boys & Covic, 2013).

No.	Requirement	Specification
1	There should be sufficient misalignment tolerance	No noticeable energy loss
2	Coils should be sufficiently cooled	No noticeable efficiency reduction, no overheating
3	IPT system should provide shielding for when the charging station is placed on concrete with reinforcing bars	
4	IPT system should comply with the relevant safety standards for the magnetic field in all regions that are accessible to humans (Bosshard and Kolar, 2016)	In the passenger cabin and at all sides of the vehicle
5	There must be a communication protocol that is compatible with all vehicle-side IPT equipment (Boys and Covic, 2013)	
6	E-Hub should be able to vary the power supplied to the EVs	
7	The IPT system should be able to provide power ranging up to 7 kW when conductive charging is optional	
8	The IPT system should be able to provide power ranging up to 22 kW when conductive charging is fully replaced	
9	The E-Hub should provide user identification through an in-ground HF RFID reader	

TABLE 8 > IPT implementation requirements

RECOMMENDATION

Based on these requirements and trade-offs, a recommendation is made for the future implementation of the IPT system. In order to create a cost-efficient IPT system, the coil size should be kept to a limited size. However, this will increase the difficulty of enabling high power transfer. According to the study conducted by Bosshard and Kolar, a cost-efficient IPT system that limits the construction volume on the vehicle-side and limits installation and material costs would enable charging ranging between 3 and 7 kW. This is sufficient for the majority of the charging demands for the E-Hub. Since the E-Hub has an integrated unit that controls both the conductive and inductive charging, inductive charging could be used to improve the convenience and safety for the routine use case for charging between 3 and 7 kW, whereas faster battery charging is still possible with the conductive charger (up to 22 kW).

ELECTRIC WIRING

One of the things that should be taken into account in the current E-Hub design is the electrical connections for the IPT system. Implementing wiring for the IPT system at the first installation of the E-Hub will prevent high secondary installation costs later on. The connection points of the IPT system with the grid should be implemented in the central console. Furthermore, the separate connection points with the charging coils should be provided for each charging bay. FIGURE 24 gives a simplified representation of the electric wiring for the conductive and inductive charging connection points.

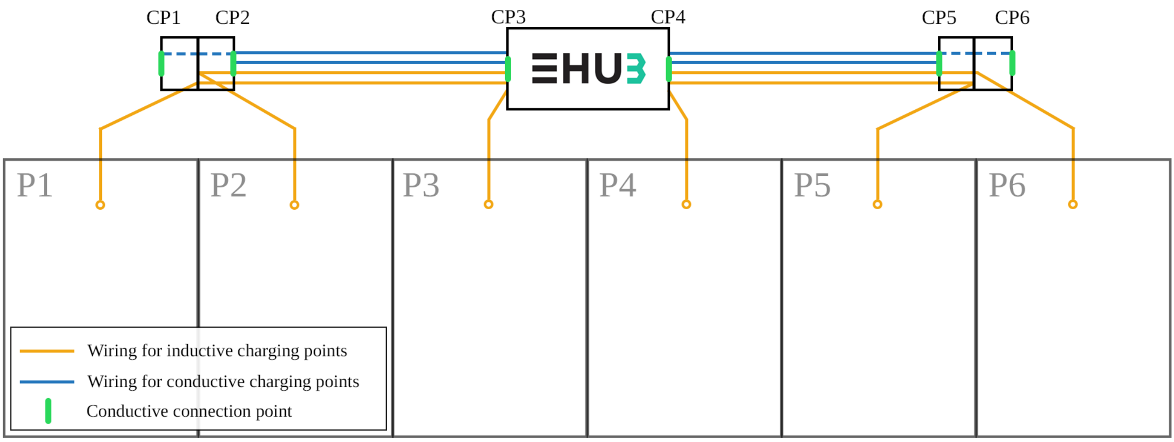


FIGURE 24 > Wiring for conductive and inductive charging

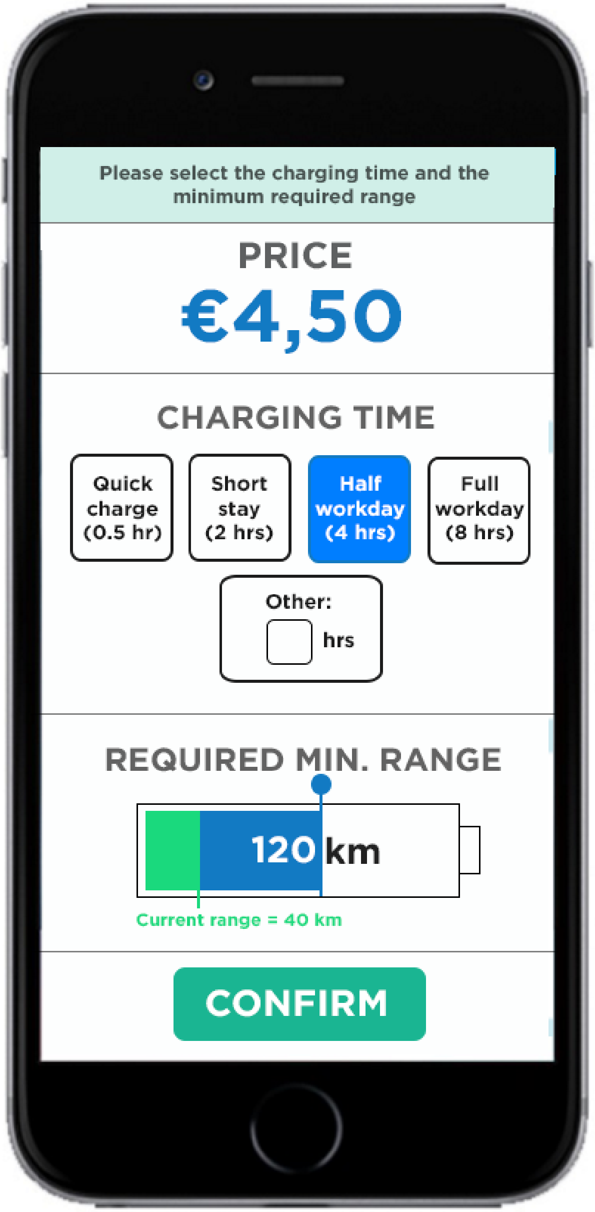
Mobile Application

Creating a fully functional mobile application is not within the scope of this project, however some recommendations and proposals will be given based on the conducted analyses in this project.

In FIGURE 25, a proposal for the design of the GUI for the mobile application is given. By letting users adjust the parameters (charging time and required minimum range), the price will vary. The user can tune the parameters until the user is satisfied with the price, charging time and the required minimum range.

From the user analysis it was clear that users did not desire to fill in an exact return time, because this would put too much pressure on the user in terms of planning their stay. To make this more flexible, four standard options are given that are related to activities, such as using the E-Hub for short quick-charge, or parking the EV during a full workday. This way, the user no longer has to plan an exact return time and the system shows more flexibility.

FIGURE 25 > Design proposal for mobile application



Furthermore, the SOC is given in kilometers instead of a battery percentage, which makes the UI more intuitive, since this will give the user a better understanding of the charging requirements.

On the E-Hub, accounts can be created that will be linked to the IDs of the RFID tags in the charging cards or in the cables. This way, the E-Hub knows which charging profile should be linked to which connection point. Furthermore, the E-Hub should request the SOC from the car. Current applications for EVs communicate the SOC through the servers of the car manufacturer. Therefore, the E-Hub application should be linked to the EV application that requests the SOC from the server. Another option is to make the E-Hub application communicate with the servers directly through a wireless network.

Instructions

While the mobile application is the main medium for communication between the E-Hub and the user, there is also information present for the user on the location. These are provided through instructions on the connection points, as presented in FIGURE 26. The instructions explain the steps that should be taken before charging can commence. From the user analysis it became clear that users did not read instructions if they were presented too comprehensively. Therefore, the instructions are given in a brief and clear way. The instructions are designed in such a way that the images by themselves provide sufficient information for using the E-Hub, since this is the first thing the user notices. A better look at the instructions will subsequently provide the user with a full understanding of the steps that should be taken.

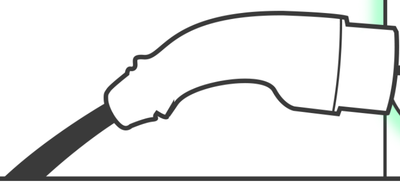
Design

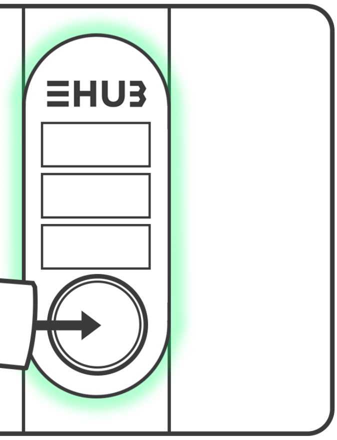
In the following section, the design of the different components will be presented. The design choices will be explained for each of the components. Furthermore, the E-Hub will be shown in multiple contexts to give a representation of the ways the E-Hub could be implemented. Several sketches that ultimately led to this design can be found in APPENDIX D: SKETCHES.

Start Charging

1.

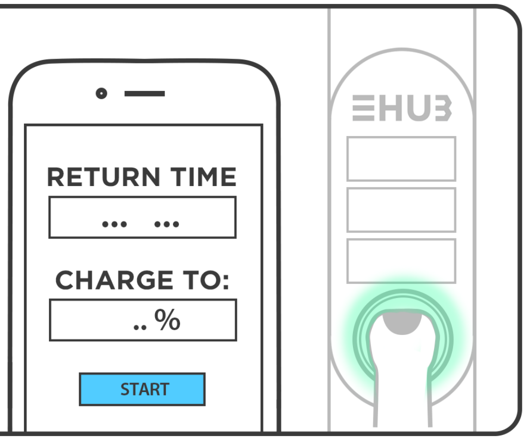
Plug the charging cable into the E-HUB connection point and the socket in your car. The LED ring will turn green.





2.

Open the E-HUB app, fill in the parameters and press START



Stop Charging

Open the E-HUB app, press END CHARGING and remove the plug when the LED turns orange

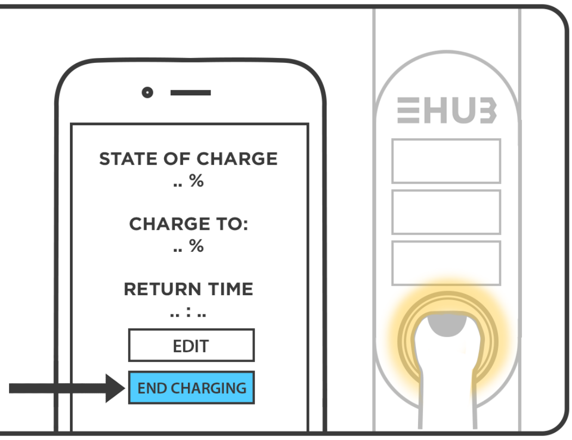


FIGURE 26 > The instructions that will be placed on the conncetion points

Connected
Charging complete
Available
Charging
Error
Slow charging only

Central Console

The housing of the central console contains the E-Hub logo and a graphic that gives a connotation of a charging station. The logo is located on the same height as most common traffic signs: approximately 2.2 meters from the ground. Furthermore, the graphic emits a green light to ensure the console is visible during the night.

Two connection points are connected to the central console. Currently, the connection points emit a green light to indicate that they are available for charging.

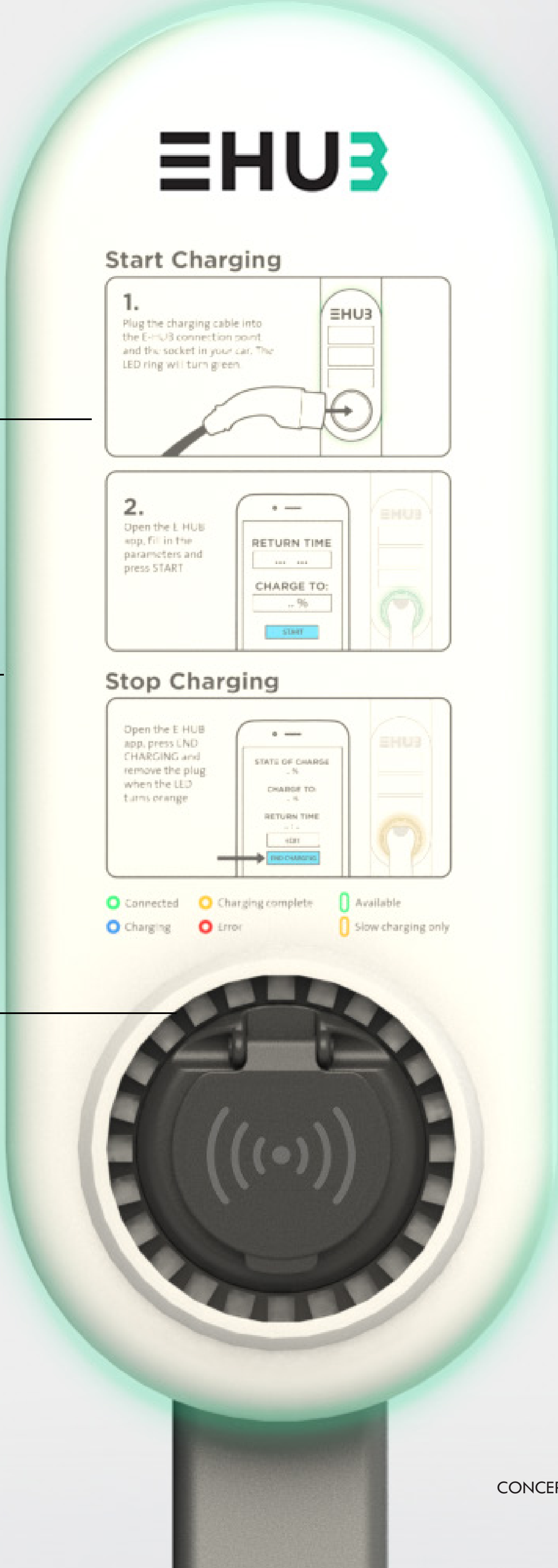

EHUB

Connection Point

Infographic that provides instructions to lead the user through the charging process

Outer LED ring that shows whether a connection point is available or not available, or if it is available for routine charging only

The LED ring around the connection point indicates the charging status.
A green color indicates the plug is connected properly, blue indicates charging has commenced and orange indicates that charging is complete

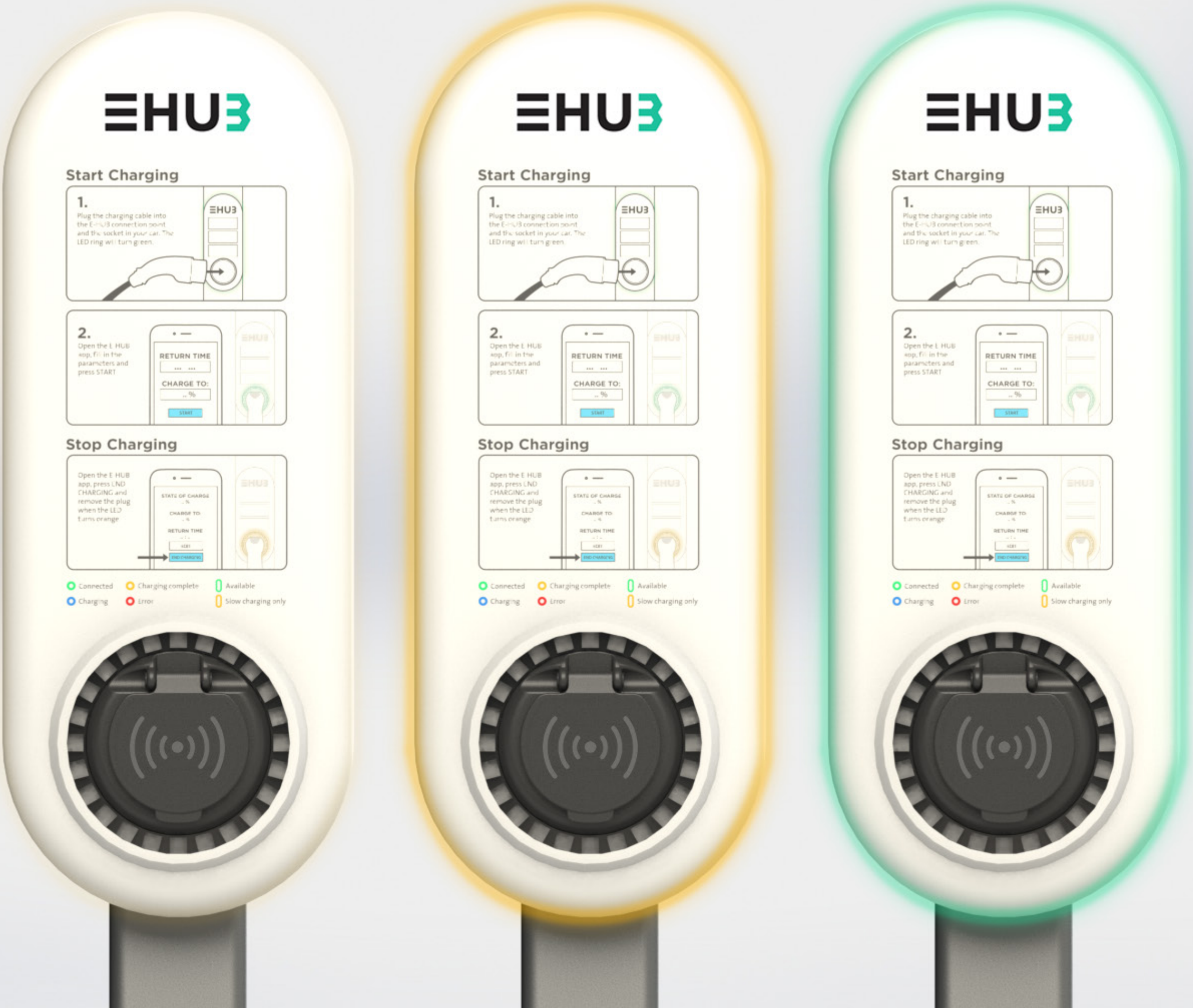

Start Charging
1.
Plug the charging cable into the E-HUB connection point and the socket in your car. The LED ring will turn green.
2.
Open the E HUB app, fill in the parameters and press START
RETURN TIME
CHARGE TO:
START
Stop Charging
Open the E HUB app, press END CHARGING and remove the plug when the LED turns orange
STATE OF CHARGE
CHARGE TO:
RETURN TIME
Connected
Charging
Charging complete
Error
Available
Slow charging only

Connection Points

1. Connection point not activated

2. Connection point activated. Routine charging only.

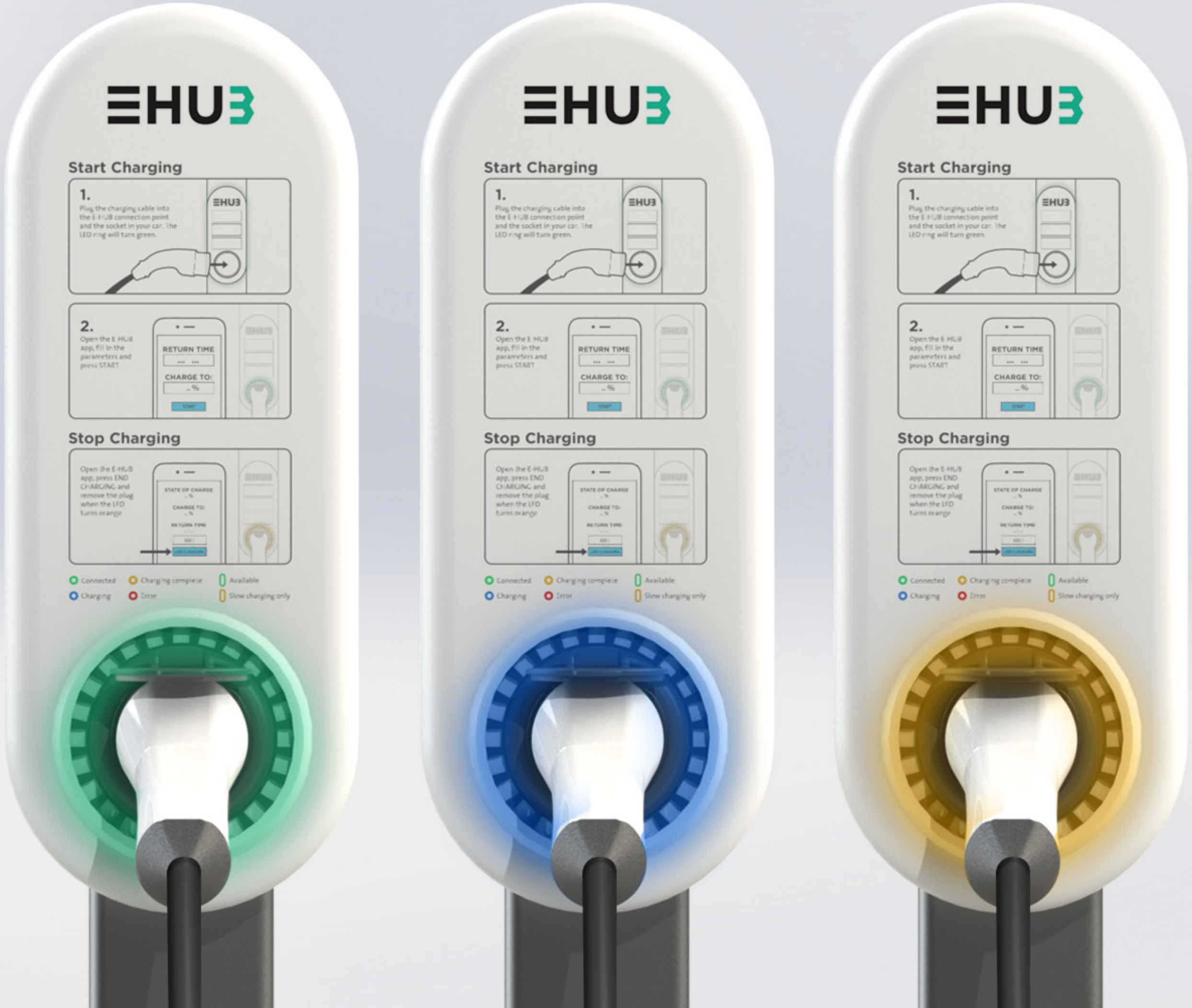
3. Connection point activated



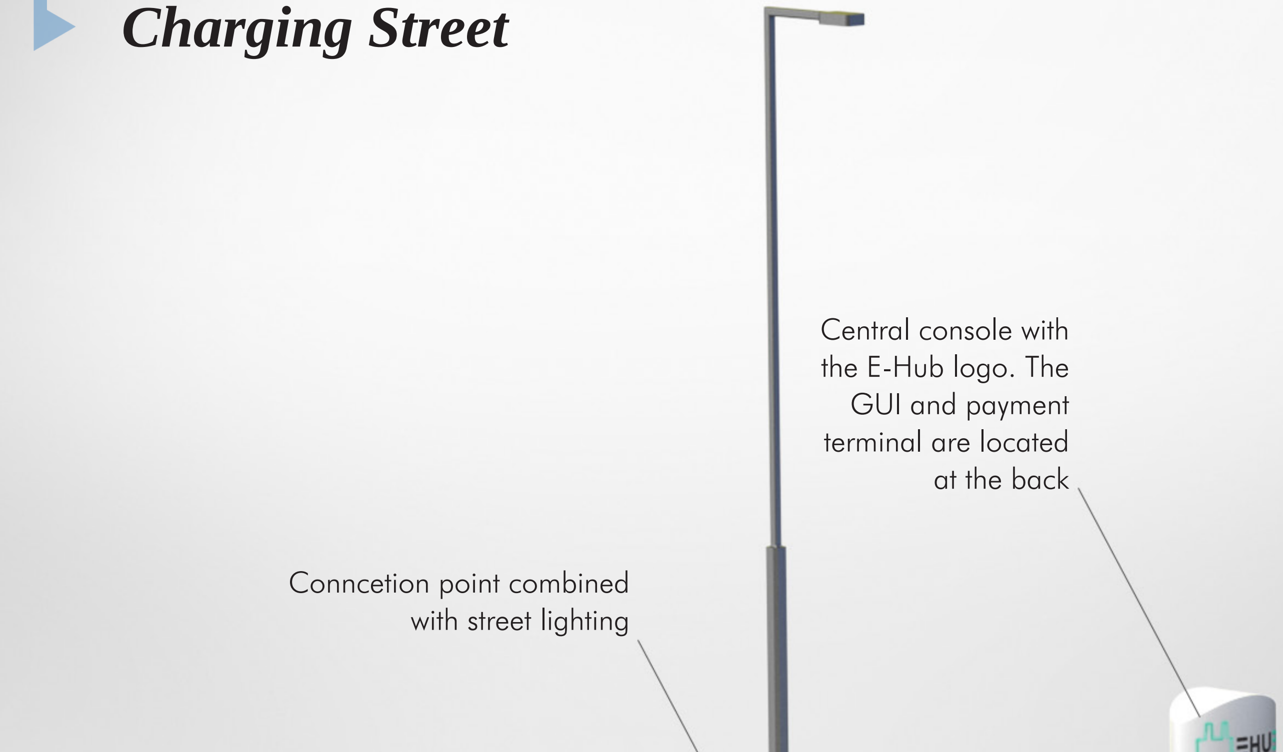
4. The cable is successfully plugged in.

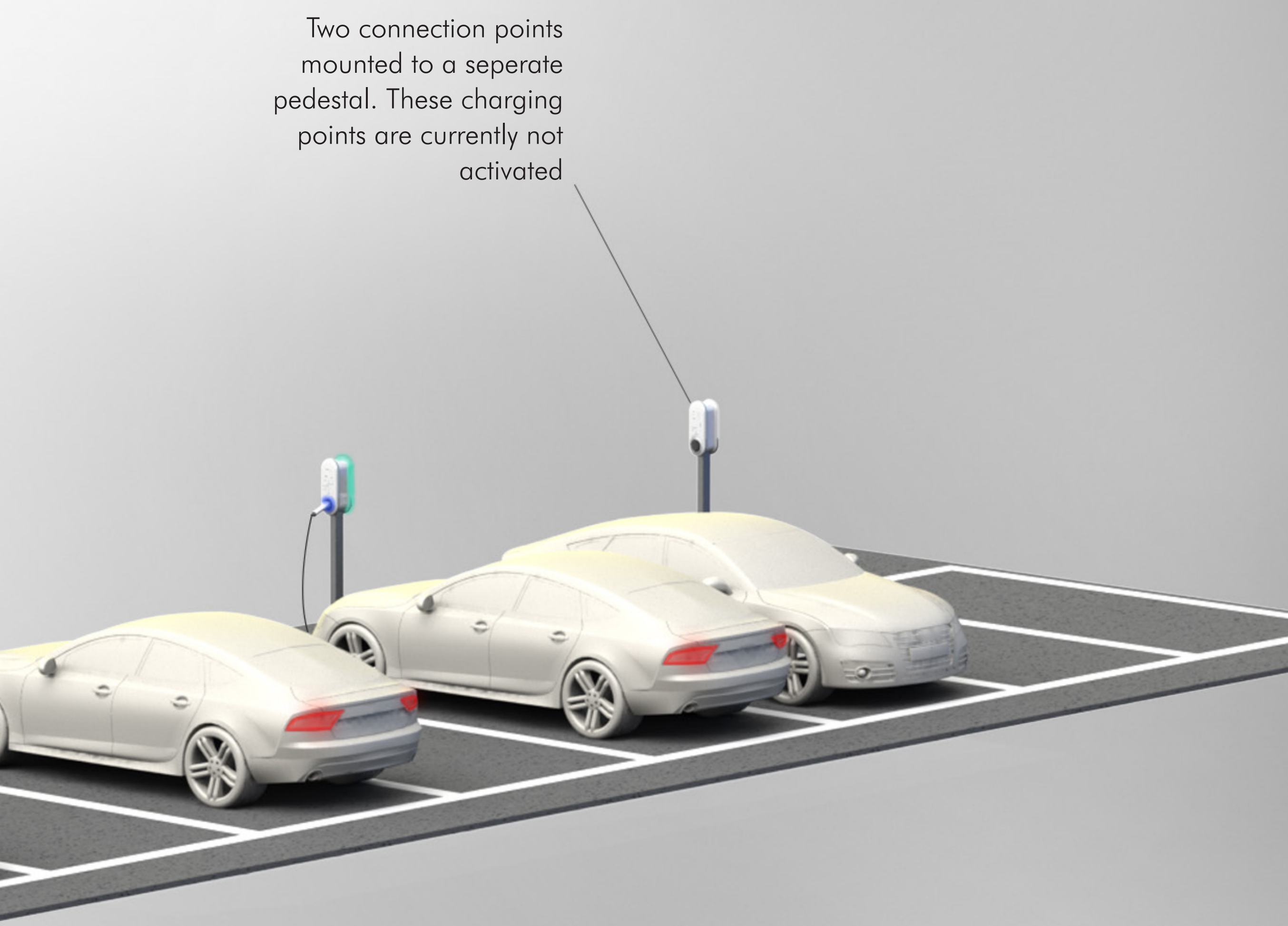
5. EV is being charged

6. Charging process complete. The plug can now safely be removed.

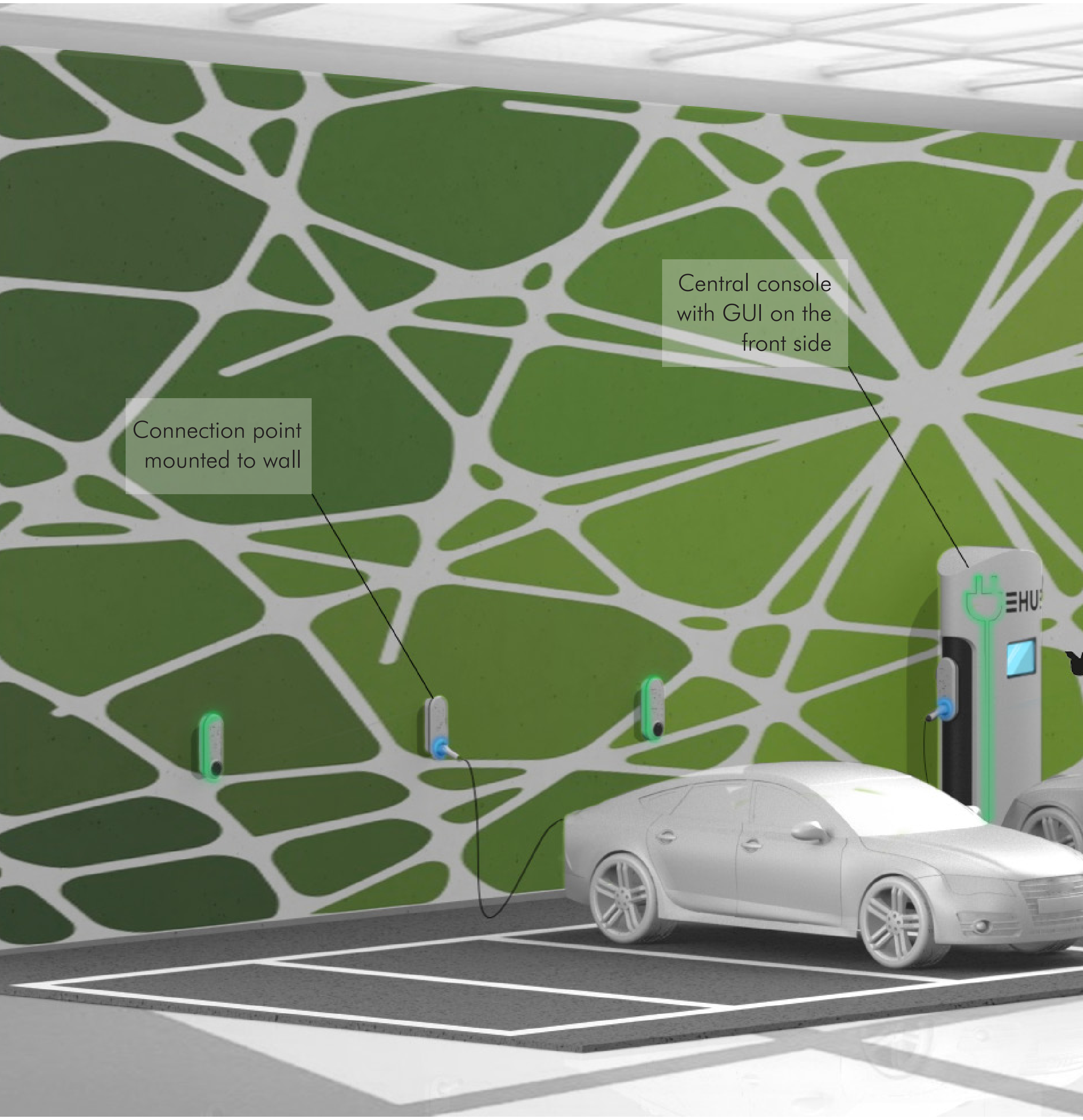


Charging Street

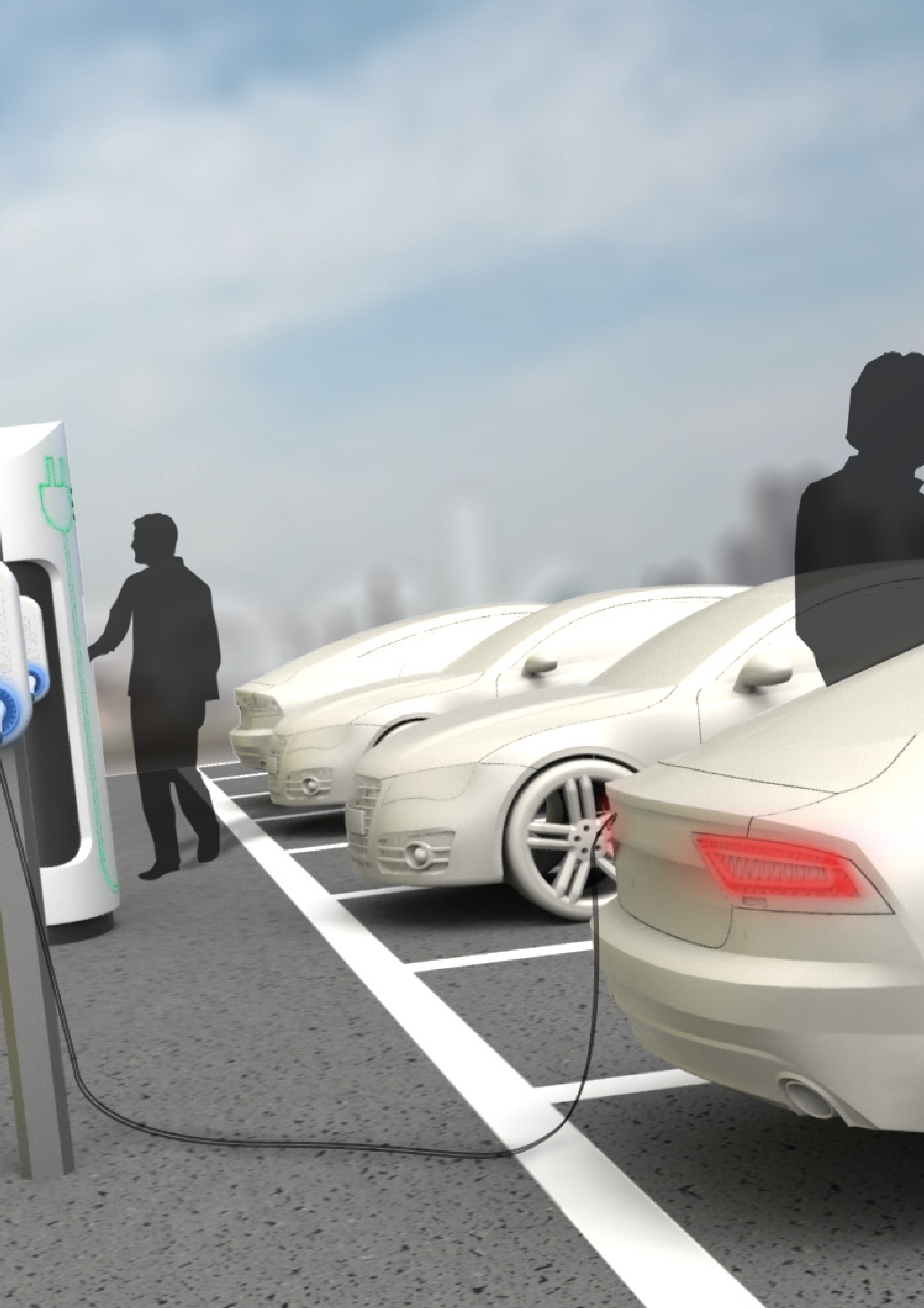


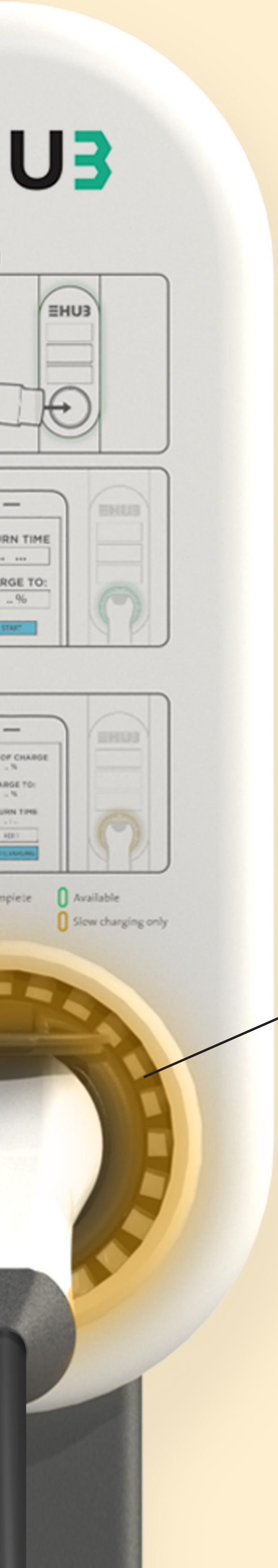

Two connection points mounted to a seperate pedestal. These charging points are currently not activated

Parking Garage




EHUB
Start Charging
1.
Plug the charging cable into the E-HUB connection point and the socket in your car. The LED ring will turn green.
2.
Open the E-HUB app, fill in the parameters and press START
RETURN TIME
CHARGE TO:
START
Stop Charging
Open the E-HUB app, press END CHARGING and remove the plug when the LED turns orange
STATE OF CHARGE
CHARGE TO:
RETURN TIME
EDIT
END CHARGING
Connected
Charging
Charging complete
Error
Available
Slow charging only





Charging process complete,
the plug can now safely be removed

6

Conclusion

Conclusion

With the final design of the E-Hub, a concept for a charging street is presented that is able to adjust to its environment, can be easily scaled and is ready for future innovations. The E-Hub distinguishes itself with a smart parking system that increases the utilization rate of charging points, increases the availability of connection points and optimizes the parking allocation of electric and non-electric vehicles. Regarding user interaction, the E-Hub provides a new type of interaction that creates more awareness and increases control over charging costs, while reducing grid loads and meeting customer demands. Furthermore, several aspects are taken into account to ensure the reliability of the system, including a minimum charging speed for every vehicle until an acceptable range is reached and several backup possibilities to enable users to be able to charge at all times.

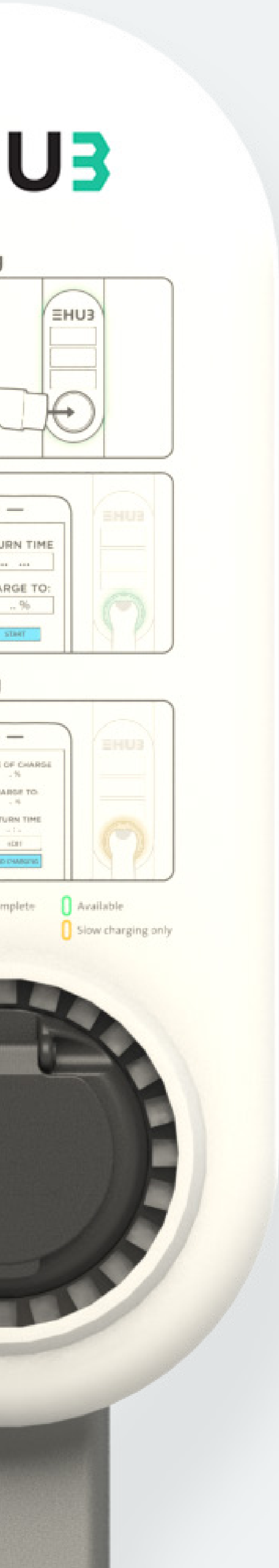
Due to the wide scope of the project, several decisions were made on which solutions had to be elaborated more specifically and which solutions were defined as a solution direction or design proposal. These decisions have been carefully made with the purpose to highlight the most important aspects of the E-Hub. However, there remain several options that require additional, more specific research or require quantification. Therefore, some recommendations will be given on the topics that require additional research for a follow-up project.

Future Research

One of the starting points of the E-Hub project was to divide charging bays into fast and regular charging bays. During the project, it was found that using three-phase charging for all connection points would be a better fitting solution. However, the exact number of connection points that can be implemented in a single E-Hub system remains unclear and was not within the scope of this project. However, both scalability and adaptability are key drivers of the system. The extent to which the E-Hub will be scalable and adaptable greatly depends on the amount of connection points that can be realized within one system and should therefore be a focuspoint in a follow-up project.

A basic framework for a smart parking system has been created. The exact requirements for each adopted state should however be further analyzed. This depends on the limits within the system such as the energy and power constraints, but also the precise demands of the user. Since charging demands will change in the future, smart parking could even be taken one step further by using existing charging data to determine the requirements for each adopted state per connection point. The charging data per location can be used to create a self-learning flexible system that adapts its charging profiles to the changing user demands.

The intelligent control system in the E-Hub processes vast amounts of data. The way this data is received and transmitted should be clearly defined. Several uncertainties still exist, such as the link between the state of charge and the available range of the EV. This data can be acquired either by creating a link between the E-Hub application and the mobile application of the EV manufacturer, by requesting the data from the server of the EV manufacturer or by making the user specify the type of EV they are driving. Furthermore, communication on the availability of parking spots should be communicated either through the Open Charge Point Protocol, or through a seperate communication interface.


START
Available
Slow charging only

Appendix

A. Interviews

Correspondent 1

1. What type of electric vehicle(s) do you own?

A Renault Zoë

2. In a general sense, what are things you enjoy about driving an EV and what are things you dislike?

The driving experience is very pleasant, better than conventional cars. The biggest downside is the extra planning that is required for longer trips. Furthermore, public charging stations create insecurity due to a lack of information or availability. General commuting traffic is not a problem, there is always a charging bay available.

3. How do you plan your trip? For example, do you someties have to postpone your trip because the battery has not yet finished charging?

I do not postpone a trip, but instead I plan an extra stop at a fast-charging station. The extra time needed for the additional charging station has to be calculated beforehand to make sure I am abla to arrive at my destination on time.

4. What is your experience with using charging stations? Are there any difficulties?

The proceedings are rather simple, however it would be better if there was a standardized procedure for every charging station. Besides the charging stations, the sequence of steps differ based on which EV one is driving.

5. What are the differences between charging stations according to your experience and are specific aspects better at some charging stations?

A beeping sound while scanning the card works well. Some charging stations only indicate this with a color changing LED, however this can sometimes be hard to notice in daylight. Furthermore, I would like to know the charging speed before starting the charging process. This is not always indicated. Besides that, the mobile application provides important feedback during the charging process, such as the SOC and the remaining time until the battery is fully charged.

6. What is your experience with the use of a charging cable?

This is not a problem for me, this is something I got used to very quickly and I have not experienced this as a hassle.

7. What is your experience with the charging card?

This works very smoothly, I prefer the use of a charging card over the use of a mobile application. The physical component of a charging card provides a robust and reliable interaction with the charging station.

8. What is your experience with the availability of charging stations?

The availability is quite poor. Sometimes the charging stations are really hard to find and seem to be hidden. A trained eye is required to be able to locate them. I have a sequence of steps I follow for finding a charging station. First I look for traffic signs, then for empty spots or road signs. If there is still no charging station I look for poles at the bank of the parking area. It would be better if charging stations were always located at the beginning of a parking area. A possible increase in walking distance is something I would take for granted.

Correspondent 2

1. What type of electric vehicle(s) do you own?

A Mitsubishi Outlander

2. What is your experience with the use of EVs and electric charging infrastructure?

Driving an EV is very enjoyable. However the use of charging stations is not always as pleasant. Every charging station seems to work differently. A standardized procedure would solve this.

3. What proceedings do you undertake to ensure your EV starts charging at a charging stations?

To make sure my card is scanned properly, I tend to scan it multiple times. Sometimes the feedback is received rather late, this also differs among charging stations. The easiest interaction is offered by the charging stations that allow me to scan the card on top of the pole. I get easily confused when there are multiple connection points at a single pole and the instructions are provided very comprehensively, which demotivates me to read them.

4. How do you plan your trip? For example, do you someties have to postpone your trip because the battery has not yet finished charging?

For this reason, I own a hybrid car. The internal combustion engine ensures that I can always meet my destination, regardless of the battery level.

5. What is your experience with using charging stations? Are there any difficulties?

The interaction is usually fine, however the sequence of proceedings should be standardized. The order does not really matter in my opinion, except for the fact that this order changes per charging station.

6. What is your experience with the mobile application?

A downside of the mobile application is the fact that the feedback through the app does not always work properly. Furthermore, the availability of a charging station is not always indicated accurately.

7. What is your experience with the use of a charging cable?

This is not really a problem. A small downside is the fact that the cable becomes dirty when the weather is poor and I need to store it in my car.

8. What is your experience with the charging card? Would you prefer using a mobile application instead?

The card works perfectly fine. I see no reason to replace this with a mobile application.

8. What is your experience with the availability of charging stations?

In cities, the availability is quite good. However in smaller villages, the availability is very poor. In general the application indicates the charging stations quite well, but the number of charging stations in rural areas is insufficient.

9. What do you think will happen to the charging infrastructure in the future?

I expect there will be a system that allows me to wirelessly charge my car without the need of a cable. Furthermore, I expect the charging speed to increase drastically. Waiting for two hours to charge my car is something I expect will not be necessary in the future.

Correspondent 3

1. What type of electric vehicle(s) do you own?

Tesla Model S and a VW E-Golf

2. In a general sense, what are things you enjoy about driving an EV and what are things you dislike?

What I dislike about current charging stations is the fact that the spot where the charging card should be scanned differs per charging station. The use of a card does not form a problem, but the proceedings that should be undertaken to use a charging station could be more standardized. Furthermore, it would be easier if the charging stations would also enable debit cards to be scanned.

3. What is your experience with the use of a charging cable?

This is not a problem, except when the cable becomes dirty. However, curled cables currently deal with this problem quite well. A problem on more on the charging station side is that sometimes the charging plug is not unlocked properly. In order to unlock the cable, we had to call the charge point operator, who solved the problem for us. Furthermore, sometimes it takes the charging station too much time to provide the feedback. This once led to a fine for not checking in properly, because the feedback was not received adequately.

4. Do you receive enough feedback from the charging station and mobile application?

I would like to have a better insight in the pricing structure. Furthermore, I receive feedback from the application that is linked to my car. My husband plans some of his trips by using the mobile application.

5. What is your experience with the charging cable? Do you always have a charging cable in your car?

Yes, this belongs to one of the standard objects I have in my car, just like the warning triangle, et cetera.

6. What is your experience with driving an EV in terms of planning your trip?

The EV allows me to be more flexible, since I do not have to plan a stop at the gas station. This accounts for all commuting trips. For longer trips, additional planning is required to fill up the battery at a fast charging station.

7. Do you variate charging times based on the cost of charging at the charging station?

At more expensive charging stations, I sometimes choose to charge the battery for a shorter amount of time when this is possible.

8. Do you consider it easy to find an available charging station? What do you look for?

SInce most of the travels are commuting trips, this is quite easy. I look at traffic signs. If I can not find an available charging bay, I prefer parking in a regular spot and driving past a fast charging station on my return trip.

Correspondent 4

1. What type of electric vehicle(s) do you own?

A BMW i3, Mercedes B52 E and a BMW X5 40 E PHEV

2. In a general sense, what are things you enjoy about driving an EV and what are things you dislike?

Driving in an EV with a relatively large range is superior to conventional cars.

3. What is your experience with the use of charging stations?

Sometimes they function differently. This should become more standardized in the future. Some charging stations require you to scan a card twice, which works very poorly. Furthermore, the pricing structure is highly diffuse, which makes it very unreliable.

The three-phase chargers work very well and allow for short charging times. Single-phase charging takes way too long to charge the battery in my opinion.

4. What is your experience with the use of a charging cable?

This is not a problem, however I do expect that this will become obsolete in the future. In terms of psychology, the cable has a status-enhancing effect. For some cars, the design of the car is very similar to ICEV cars. The cable functions as a differentiating factor (such as showing that the user is concerned with the environment etc.).

5. What is your experience with charging stations in terms of availability?

Availability in my own neighborhood is very good.

6. Do you receive enough feedback from the charging station and mobile application?

Yes, through the mobile application. The app is very useful during the charging process. It increases the reliability because the charging system from a technical point of view is still quite unreliable.

Before the charging process starts, I do not wish to use the mobile application. I will just use the charging card instead.

7. Do prices of energy influence your charging times?

Not really, because of the low variable costs. Only for fully charging the battery (e.g. at a fast charging station) would I consider the price of the energy as a possible factor for reducing charging times.

B. Error Handling

Operation		**Characteristics of error**		**Action**		**Notes**
No.	**Step**	**Error**	**Effect**	**Recommendations**		
1	Choose appropriate charging bay	User parks at wrong charging bay	Car is charged too slowly	Advise the user to move to a different charging bay when entering parameters		
2	Plug is not connected properly	Charging will not commence	EV will not be charged	LED ring will turn red to indicate an error has occured	The user will be notified that the plug is not connected properly when filling in the parameters	
3	Read RFID chip	RFID tag in charging plug is not recognized	Charging will not commence	Try again using a charging card	Go to the central console to log in manually	
4	Select return time	User does not yet know the return time	Car might be charged too fast or too slowly	Allow the user to change parameters during the charging process		The charging costs may turn out higher due to a less efficient energy distribution
5	Change return parameters during charging process	User demands exceed system capabilities	User demands will not be met	Inform the user on the options that are closest to the user's demands	Call CPO to temporarily increase power of concerned connection point	
6	Follow the steps on the mobile application	User does not have access to a smartphone	User is not able to start the charging process	Make use of the GUI on the central console to start the charging process		

C. N² Diagram

Distribution Management System					Remaining grid capacity			
	Energy Service Provider	Energy subscription		Price profiles				
	Payments	User	Return time Desired SOC		Payments			
		Price SOC Finish time	Mobile Application	Return T Desired SOC				
	Final price		- Parameter boundaries - Price - SOC	E-Hub Service Provider	- # active charging points - Power(T) per CP			
				- Remaining grid capacity - Availability renewables - Charging bay occupancy	Charge Point Operator	- States of charging bays - Energy distribution per CP - Distribution of power drawn from grid and renewables		
					- Charging bay occupancy - Availability renewables	E-Hub Central Console		
							EV	SOC
				SOC				EV Service Provider

D. Cost Analysis

Product	Part	Quantity	Price (€)	Total price (€)	Price per product (€)	Product amount	Total price (€)
Console	Local energy storage	1	7000	7000	10.080	1	10.080
	Payment system	1	1000	1000			
	Graphical User Interface	1	700	700			
	Housing	1	100	100			
	Wi-Fi transmitter	1	80	80			
	Internal electronics	n/a	1200	1200			
Connection point	Type 2 socket	10	120	1200	380 (excl. wiring)	10	4.500
	Housing	10	5	50			
	LED rings	30	10	300			
	Wiring	n/a	800	800			
	RFID reader	10	95	950			
	Mounting components (pedastal, wall-mounting, lamppost mounting, console mounting)	6 to 10	150	1200 (Avg.)			
Charging bay	Vehicle detection system (10 parking spots)	1	3.600	3.600	3.600	1	3.600
Additional (optional)	PV panels	n (location dependent)	600	600n	600	n	600n

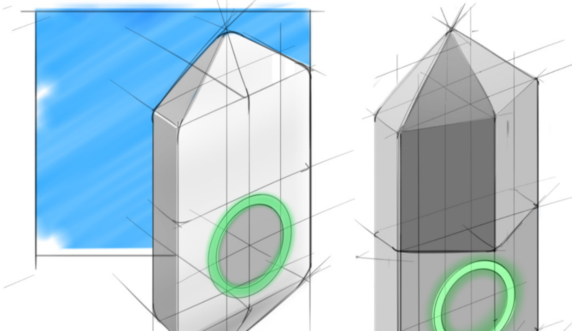
Total costs (10 charging bays)

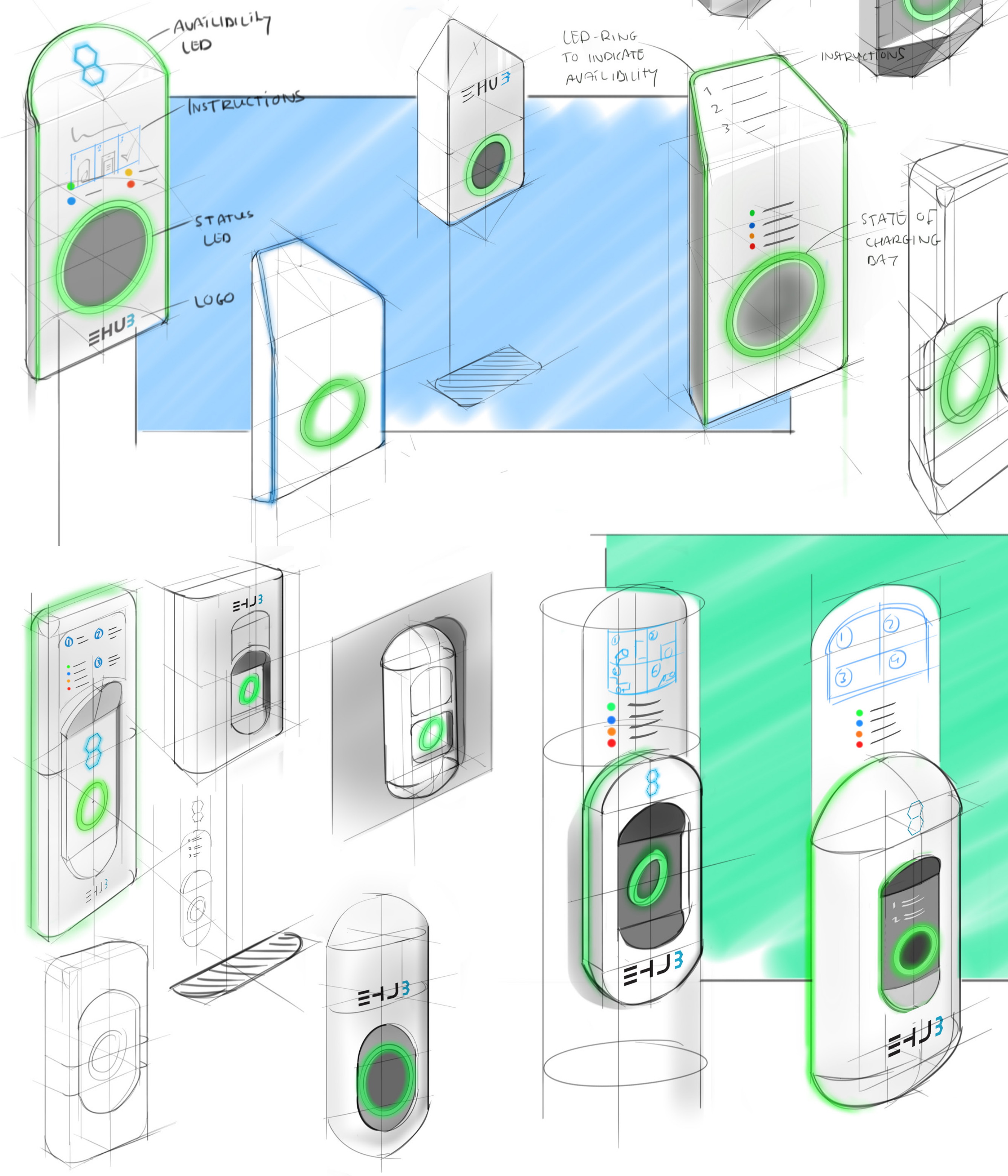
10.080 + 4.500 + 3.600 (+ 600n) ≈ € 18 • 10^3 + 600n

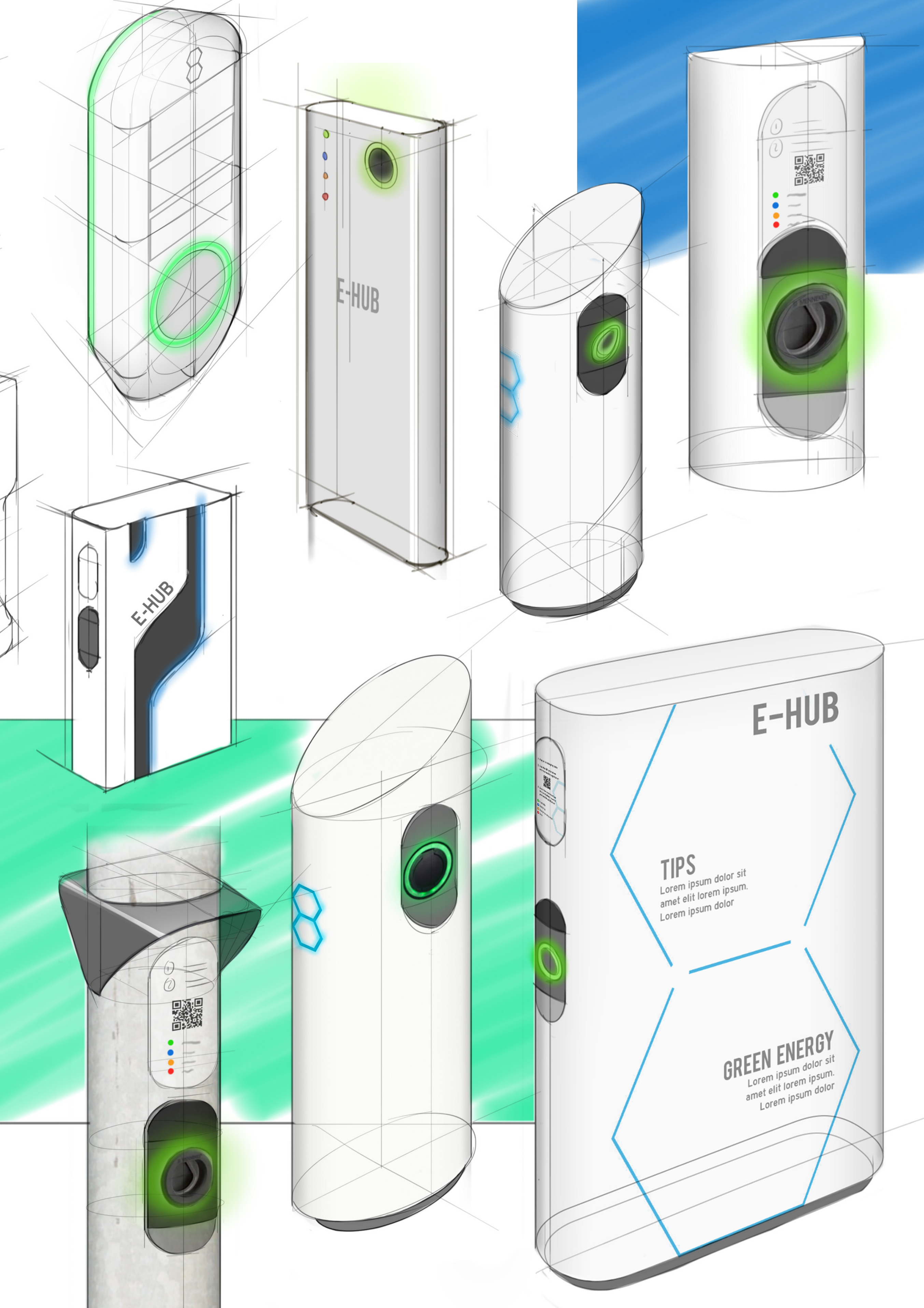
Sources

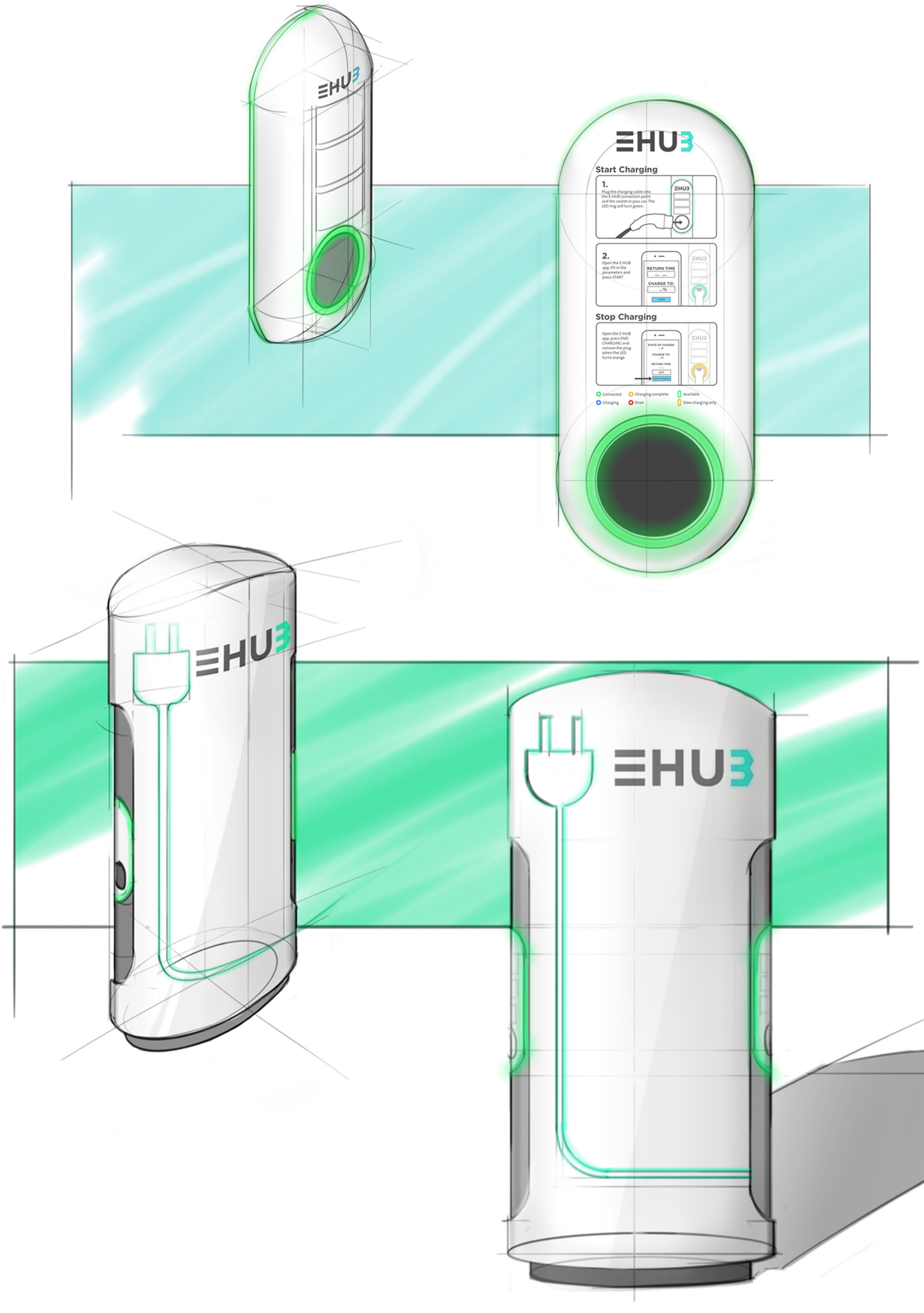
- https://www.tesla.com/nl_NL/powerwall?redirect=no#design
- https://www.pinwinkel.nl/pinautomaten/mobiele-pinautomaten/verifone-vx680-mobiele-pinautomaat.html?gclid=CJ-8lPPh_dECFcsV0wodlqcNDg
- https://www.centralpoint.nl/niet-gecategoriseerd/elo-touch-solution/10i1-10-pcap-black-art-e021014-num-4516479/
- https://www.centralpoint.nl/wlan-access-points/ubiquiti-networks/enterprise-ap-lr-unifi-art-uap-lr-num-3152267/?utm_source=google&utm_medium=cpc&utm_campaign=productlistingads&ref=115&gclid=CKOHoK_j_dECFaIW0wodE9YLUQ&gclsrc=aw.ds&dclid=CMHbp6_j_dECFUyZdwodHeoNfg
- https://www.centralpoint.nl/wlan-access-points/ubiquiti-networks/enterprise-ap-lr-unifi-art-uap-lr-num-3152267/?utm_source=google&utm_medium=cpc&utm_campaign=productlistingads&ref=115&gclid=CKOHoK_j_dECFaIW0wodE9YLUQ&gclsrc=aw.ds&dclid=CMHbp6_j_dECFUyZdwodHeoNfg
- https://www.enexis.nl/consument/diensten-en-tarieven/tarieven/kosten-werkzaamheden-aansluiting-of-meter?stap=Kosten-werkzaamheden-aansluiting-of-meter_1_2
- https://evconnectors.com/Type-2-Electric-Vehicle-Charging-Cables-and-Sockets/Type-2-Connectors-32-amp/Type-2-32-amp-Charging-Sockets-Inlets
- http://www.tme.eu/nl/details/pololu-2538/lichtbronnen-led-modules/pololu/adafruit-24-ws2812-led-neopixel-ring/?brutto=nl&gclid=CIjU2t3m_dECFQ4R0wodtG8B8w
- https://www.enexis.nl/consument/diensten-en-tarieven/tarieven/kosten-werkzaamheden-aansluiting-of-meter?stap=Kosten-werkzaamheden-aansluiting-of-meter_1_2
- https://www.bypos.nl/giga-tms-gp20-proximity-reader-bypos-1346?keyword=&utm_source=google&gclid=CJiq54Po_dECFQEG0wodHkwALg
- https://www.pluglesspower.com/shop/plugless-pedestal/
- http://www.tinynode.com/?q=car_detection_starter_kit
- https://www.zonnepanelen-info.nl/zonnepanelen/kosten/

D. Sketches


INSTRUCTIONS


AVAILIBILITY LED
INSTRUCTIONS
STATUS LED
LOGO
HUB
HUB
LED-RING TO INDICATE AVAILIBILITY
STATE OF CHARGING BAY

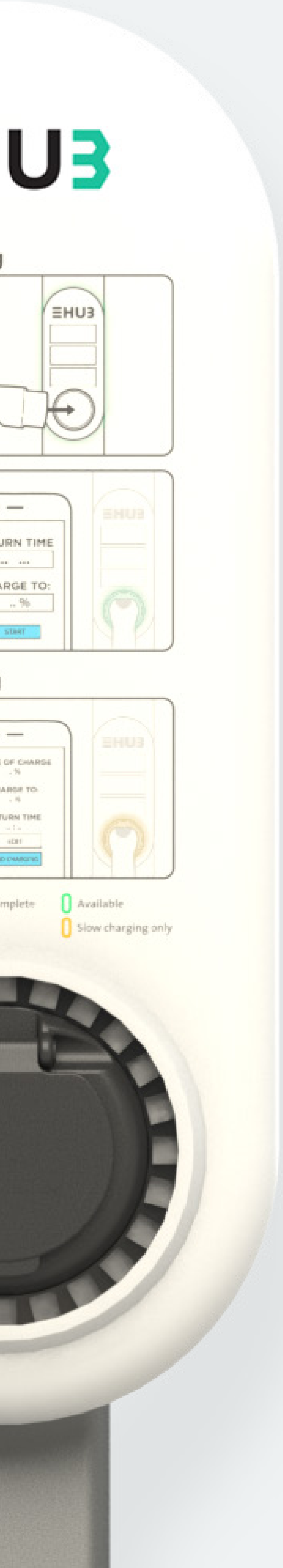

E-HUB
E-HUB
E-HUB
TIPS
Lorem ipsum dolor sit
amet elit lorem ipsum.
Lorem ipsum dolor
GREEN ENERGY
Lorem ipsum dolor sit
amet elit lorem ipsum.
Lorem ipsum dolor



Start Charging
1.
Plug the charging cable into the E-HUB connection point and the socket in your car. The LED ring will turn green.
2.
Open the E-HUB app, fill in the parameters and press START
RETURN TIME
CHARGE TO:
Stop Charging
Open the E-HUB app, press END CHARGING and remove the plug when the LED turns orange
STATE OF CHARGE
CHARGE TO:
RETURN TIME
EDIT
Connected
Charging complete
Available
Charging
Error
Slow charging only

E. Glossary

Client	Dutch-INCERT
E-Hub	Electrical charging station of the future
Electric vehicle	A vehicle that uses one or more electric motors for propulsion. In this report, the electric vehicle (EV) will be used to describe plug-in electric cars that can be charged at charging stations. These include full-electric as well as hybrid cars.
Interface	A point where two systems meet and interact
Point solution	Individual solution to a subproblem that is part of a set of solutions
Routine charging	Charging of an electric vehicle in the routine use case
Subsystem	A self-contained system within a larger system
System architecture	A conceptual model that defines the structure, behavior, and more views of a system
User interface	The means by which the user and a computer system interact, in particular the use of input devices and software


START
Available
Slow charging only

References

References

- Allen, M. (November 2014). Single Phase vs. Thre Phase Power: What You Need to Know? Retrieved from https://www.linkedin.com/pulse/20141106222822-3267680-single-phase-vs-three-phase-power-what-you-need-to-know
- Battery University Group (2017). BU-409: Charging Lithium-ion. Retrieved from http://batteryuniversity.com/learn/article/charging_lithium_ion_batteries
- Bosshard, R. Kolar, J.W. (September 2016. Inductive Power Transfer for Electric Vehicle Charging – Technical Challenges and Tradeoffs. IEEE Power Electronics Mafazine, pp. 22-30. Retrieved from https://www.pes.ee.ethz.ch/uploads/tx_ethpublications/7_Inductive_Power_Transfer_for_Electric_Vehicle_Charging_Bosshard.pdf
- Boys, J.T. Covic, G.A. (2013) IPT Fact Sheet Series: No 1 – Basic Concepts. The University of Auckland. Retrieved from https://pdfs.semanticscholar.org/5c4e/4f9dfdae6d9ad6fa30bc425395844cd634ee.pdf
- CBS (2012). Personenauto's rijden gemiddeld 37 km per dag. Retrieved from https://www.cbs.nl/nl-nl/nieuws/2012/10/personenauto-s-rijden-gemiddeld-37-kilometer-per-dag
- Clement-Nyns, K. Haesen, E. Driesen, J. (2010, February). The Impact of Charging Plug-In Hybrid Electric Vehicles on a Residential Distribution Grid. IEEE Transactions on Power Systems, 25:1. Retrieved from http://ieeexplore.ieee.org/document/5356176/?part=1
- COB (May 2009). Ondergronds parkeren. De Onderbouwing, 17. Retrieved from http://www.cob.nl/uploads/media/De_Onderbouwing__4__2009_.pdf
- Codani, P., Le Portz, P.L., Claverie, P., Perez, Y., Petit, M. (2015). Coupling local renewable energy production with electric vehicle charging: a survey of the French case. EVS28 International Electric Vehicle Symposium and Exhibition. Retrieved from: http://www.evs28.org/event_file/event_file/1/pfile/EVS28_Codani_coupling_RES_EV.pdf
- Cohere (2016). EV Box flat png. Retrieved from http://www.cohere.eu/laadpaal-ev-box/

- CROW-KpVV (2016, September). 55% meer deelauto's in Nederland. Retrieved from http://kpvvdashboard-4.blogspot.nl/
- Fitzgerald, G. Nelder, C. Newcomb, J. (2016). Electric Vehicles as Distributed Energy Resources. Rocky Mountain Institute. Retrieved from http://www.rmi.org/pdf_evs_as_DERs/
- Hammerschmidt, C. (2016, May). Nissan Integrates e-Mobility with Smart Grid. Retrieved from http://www.eetimes.com/document.asp?doc_id=1329706
- Hjorthol, R. (2013, April). Attitudes, ownership and use of Electric Vehicles – a review of literature. Institute of Transport Economics (TØI), 1261/2013. Retrieved from http://www.compett.org/documents/wp_2_report_attetitudes_ownership_and_use_of_electric_vehicles_a_review_of_literature.pdf
- IEC (June 2014). Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 1: General requirements, 3.0. International Eletrotechnical Commission Retrieved from https://webstore.iec.ch/publication/6582
- IMPINJ (2012). The Different Types of RFID Systems. Retrieved from http://www.impinj.com/resources/about-rfid/the-different-types-of-rfid-systems/
- Kane, M. (2016). Fastned Opens 50th Fast Charging Station in The Netherlands. Retrieved from http://insideevs.com/fastned-opens-50th-fast-charging-station-along-the-highway/
- Katzev, R. (2003). Car Sharing: A New Approach to Urban Transportation Problems. Analyses of Social Issues and Public Policy, December 2003. Retrieved from https://www.researchgate.net/publication/227718696_Car_Sharing_A_New_Approach_to_Urban_Transportation_Problems
- Kennisplatform voor Verkeer en Vervoer (2016, September). 55% meer deelauto's in Nederland. Retrieved from http://kpvvdashboard-4.blogspot.nl/2016/09/55-meer-deelautos-in-nederland.html
- Loop, van der H. (2010). Verklaring reistijdadvies en betrouwbaarheid hoofdwegen 2000-2010. Kennisinstituut voor Mobiliteitsbeleid. Retrieved from https://www.kimnet.nl/publicaties/rapporten/2012/05/07/verklaring-reistijdverlies-en-betrouwbaarheid-op-hoofdwegen-2000-2010.-empirisch-onderzoek-naar-aspecten-van-bereikbaarheid
- Mennekes (2013). Mennekes Type 2 Connector [Digital Image]. Retrieved from http://www.mennekes.de/index.php?id=latest0&L=4&tx_ttnews%5Btt_news%5D=929&cHash=5776533c6270bfd03a554a09e9d21954

- Moghaddami, M. Sarwat, A. (December 2016). Self-Tuning Variable Frequency Controller for Inductive Electric Vehicle Charging with Multiple Power Levels. IEEE Transactions on Transportation Electrification. Retrieved from http://ieeexplore.ieee.org/document/7781643/
- NKL (2016, August). Verslag van de workshop Benchmark Kosten Publieke Laadinfrastructuur 2016. Nationaal Kennisplatform Laadinfrastructuur (August 2016). Retrieved from http://nklnederland.nl/uploads/files/Verslag_workshop_Benchmark_Kosten_Publieke_Laadinfrastructuur_2016.pdf
- OCA (2016). Factsheet OCPP 1.6. Open Charge Alliance. Retrieved from http://www.openchargealliance.org/uploads/files/Factsheet_OCPP_1.6_2016.pdf
- Plugless, (2016). Plugless Requirements. Retrieved from http://www.pluglesspower.com/wp-content/uploads/2015/08/PluglessQuickGuide_AltParking.pdf
- Pressman, M. (2016). Tesla co-founder JB Straubel hints at forthcoming autonomous driving and battery breakthroughs. Retrieved from https://evannex.com/blogs/news/117920965-tesla-co-founder-jb-straubel-hints-at-forthcoming-autonomous-driving-and-battery-breakthroughs-video
- RVO (2015). Elektrische rijden in de versnelling. Plan van aanpak 2011-2015. Rijksdienst voor Ondernemend Nederland. Retrieved from http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/energie-en-milieu-innovaties/elektrisch-rijden/stand-van-zaken/cijfers
- Schneider, J. (May 2016). SAE Publishes TIR J2954, Wireless Power Transfer EV/PHEV. IEEE Standards University. Retrieved from http://www.standardsuniversity.org/e-magazine/june-2016/sae-publishes-tir-j2954-wireless-power-transfer-evphev/
- SDOT (2014, March). 2013 Seattle Free-Floating Car Share Pilot Program Report. Seattle Department of Transportation. Retrieved from https://worldstreets.files.wordpress.com/2014/04/2013_free_floating_car_share_report.pdf
- SkyRFID Inc. (n.d.) Retrieved from http://skyrfid.com/RFID_Tag_Read_Ranges.php
- Steinbuch, M. (2015, March). 2018: the take-off for Electric Driving? Automotive & Mobility. Retrieved from https://steinbuch.wordpress.com/2015/03/04/2018-the-take-off-for-electric-driving/