Trouble-free charging of electric vehicles

- Evaluating the user experience of the charging procedure

Lisa Ulfwi and Karin Carolin

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MASTER'S THESIS

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Department of Design Sciences
Faculty of Engineering LTH, Lund University
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Supervisor: Héctor Caltenco
Examiner: Johanna Persson

Abstract

The car sector is facing a big challenge with the conversion from gasoline and diesel vehicles towards electric vehicles. This electrification results in new habits and interactions for the users. The major objective for this study is to investigate how to facilitate the charging procedure for the electric vehicle users. The aim of this thesis is to investigate how to, as effectively as possible, evaluate the user experience for the charging procedure in electric vehicles, for both todays and prospective charging concepts. To be able to evaluate the user experience, critical parameters affecting it were identified and evaluated in order to decide how these should be designed to optimize the user experience. Data for this research were obtained from previously done studies and with help of real users. User data was collected by observations, interviews, a questionnaire, a workshop and user tests.

The critical parameters affecting the user experience are the charging cable and the storage of it, the placement and design of the electric vehicle inlet and the charging feedback. The evaluation of these parameters resulted in recommendations for how they should be designed to achieve the best user experience. The recommendations were presented in a context using different user scenarios. Different evaluation methods were examined and the user experience for the charging procedure can be evaluated by empirical methods, involving users, or analytical methods, involving experts in the area. The most effective evaluation method is to only involve experts by using a heuristic evaluation method with guidelines formed from user tests. The guidelines make it possible to include the users' opinions without having to involve them in the evaluation.

Keywords: #userexperience #electricvehicles #vehiclecharging #interactiondesign #evaluationmethod

Preface

The project described in this thesis was carried out by two Master of Science students from Lund University and Linköping University in cooperation with Volvo Car Corporation between January and June, 2017. Lisa Ulfwi studied Biomedical Engineering at The Faculty of Engineering, Lund University and Karin Carolin studied Design and Product Development at the Institute of Technology, Linköping University. The thesis work was carried out at the department of Ergonomics at Volvo Cars in Gothenburg, Sweden. We wish to thank our very helpful colleagues at the Ergonomic department with an extra big thank to our mentors Nadja Lejon and Pernilla Nurbo at Volvo Cars Corporation who have contributed with many helpful discussions. From the Universities we would like to send a thank you to our two mentors, Mats Nåbo at Linköping University and Héctor Caltenco at Lund University for all support you have given us. To Emelie Holmberg, Ebba Knutsson and Hampus Wiklund who opposed at the thesis and to all our participants at Volvo Cars Corporation, we wish to gratefully acknowledge here with our sincere thanks.

Gothenburg, June 2017

Lisa Ulfwi & Karin Carolin

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List of abbreviations

ICE	Internal Combustion Engine
PHEV	Plug-In Hybrid Electric Vehicle
BEV	Battery Electric Vehicle
EV	Electric Vehicle
EVI	Electric Vehicle Inlet
EVSE	Electric Vehicle Supply Equipment
NPS	Net Promoters Score

1 Introduction

The car sector is leaving the traditionally transition from an internal combustion engine (ICE) fuelled with diesel and petrol to plug-in hybrids (PHEVs) and battery electric vehicles (BEVs) [1, p. 40]. The market has increased in the last couple of years, and is expected to increase even more in the nearest future [2]. This electrification results in new habits for the users' due to a whole new level of interaction with the electric vehicle (EV) [2]. Besides the users range anxiousness there are new areas that the user needs to gain knowledge about and the field is filled with different concepts regarding how to charge the EV. This requires more responsibility for the users and this thesis aims to investigate how to facilitate the charging procedure for the EV users. The challenge for all EV manufacturers today is to ease the charging procedure both for today's early adopters as well as the future users [2].

In less than ten years, Volvo Cars intends to sell a total of one million plug-in hybrids and battery electric vehicle [3]. The company aims to reach this by drastically expanding its product range. In the next few years, Volvo Cars will offer at least two hybrid versions in each model series and launch and develop several all-electric cars, with the premiere of the first one scheduled for 2019 [4, p. 37]. Volvo's mission is to make life less complicated for their customers and their branding strategy "Designed around you" puts the human in the centre [5]. With the change towards electric vehicles this means that the next step for Volvo Cars is to provide trouble-free charging. To improve customer satisfaction in their future electrical vehicles they need a suitable way to evaluate the user experience around the charging procedure. The thesis will investigate not only the charging concept of today but also the future and the critical parameters affecting the charging procedure will be identified and evaluated.

1.1 Aim

The aim is to provide Volvo Car Corporation the ability to effectively evaluate the user experience for the charging procedure in electric vehicles, for both today's and prospective charging concepts.

1.1.1 **Research questions**

- Which methods can be used for evaluating the user experience for the charging procedure in electric vehicles for a car company?
  - Which of these is the most effective method?

- Which are the critical parameters that are affecting the user experience around the charging procedure in electric vehicles, both today and prospective?
  - How should these critical parameters be designed to optimize the user experience?

1.2 Goals

- Present the best method for evaluating the user experience for the charging procedure in electric vehicles.
- Describe how the critical parameters should be designed to optimize user experience.
- Define how the users will use the electric vehicle both today and in the future with help of User Scenarios.

1.3 Delimitations

The work will cover the physical interaction between a user and an electric vehicle during the charging procedure. This will not cover any interaction with digital displays inside the vehicle. The work will cover interaction between the user and different types of charging stations but will not focus on charging infrastructure.

1.4 Disposition

This section will describe the thesis' different chapters to give the reader an overview of the disposition.

The thesis starts with chapter two, theory about evaluation methods, EV-users and interaction design. The following chapter, Background, includes theory about electric vehicles and charging. Chapter four, Methods, covers theories and methods used in this project. It is followed by two chapters, one for each phase which has its own section for implementation of the methods, results, discussion and conclusion. This division has been made to structure the work and also to facilitate for the reader. The first phase, chapter five, contains the start up with data gathering and analysis methods and ends with the identified parameters affecting the charging procedure. The second phase, chapter six, examines these parameters through user tests, a questionnaire and a workshop. The chapter explains how the users experience the parameters and how they should be formed to ease the interaction. Chapter seven, Final results, will cover the formation of the recommendations, user scenarios and evaluation method. In the end of the report, in chapter eight, a discussion regarding the final results, methods, criticism of sources, further work and ethical aspects is held. The drawn conclusions will be presented in chapter nine. Figure 1 below illustrates the disposition of the report.

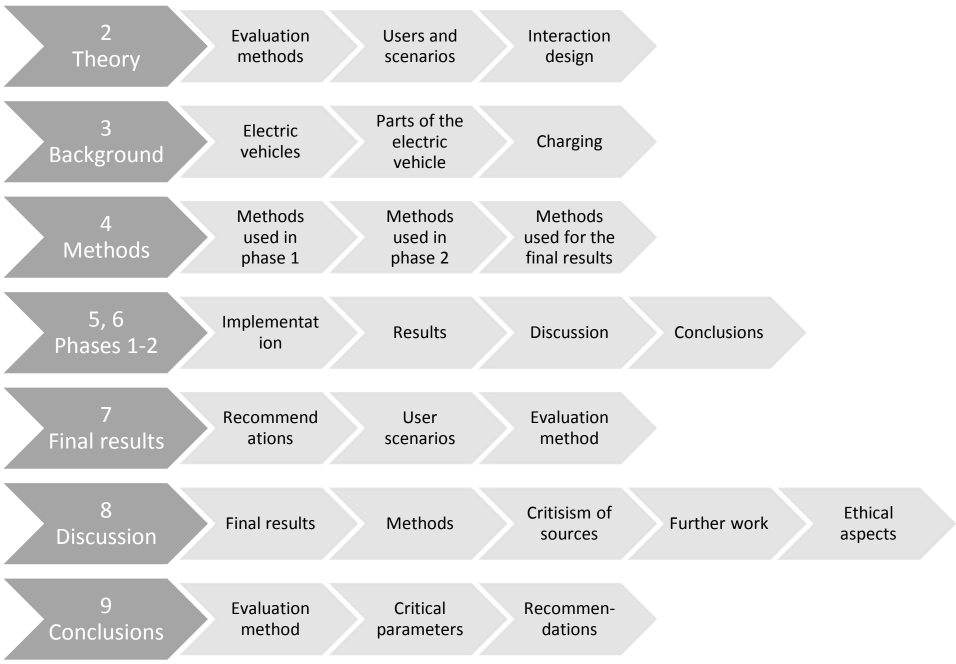

Figure 1: The disposition of the report

2 Theory

This chapter will cover theory about evaluation methods, user experience and EV-users.

2.1 Evaluation methods

There are a lot of different methods to use when studying and analysing the human when working and interacting with a product. Evaluating the interaction between a human and a product can either be done with help of real users, called an empirical study, or with an analytic study performed by experts in the area with knowledge in areas such as ergonomics. Empirical studies are participative which means that there are real users that evaluate the interaction [6, p. 483]. This can be done with user tests that can be performed in a real situation or in a lab environment [6, p. 525]. The participants should for best result correspond to the real target group and they should evaluate different predefined tasks [6, p. 525]. The time for the whole test should not be over an hour and the time for the different tasks should not be more than half an hour [6, p. 525]. However, user tests are very time consuming and the recommendation is to not have less than five participants in order to ensure that all possible problems will be identified [6, p. 526]. In an analytic study there are no users participating but it is an advantage if the experts have user experience within the product. Some examples of analytic methods are heuristic evaluation and procedure passes. An analytic method that does have a low grade of participation of real users is called an expert method and the advantages are that fewer resources are needed and it is more time efficient. [6, p. 481]

Another analytic method is NASA Task Load Index which is a subjective method to assess workload [6, p. 481]. It is a multidimensional instrument that has six dimensions; Mental Demand, Physical Demand, Temporal Demand, Frustration, Effort and Performance [7]. The one performing the method will perform tasks and grade all six dimensions after how they affect the total workload [7]. Another way to evaluate a product regarding different criteria is to use the methods heuristic evaluation or standard inspection [6, p. 523]. In these two methods it is a group of experts analysing without any input from real users [6, p. 523]. A heuristic evaluation is done by a group of two to three persons [6, p. 523] who looks at an interface to decide what is good and bad about it [8] regarding already developed criteria [6, p. 523]. Standard inspections evaluates against standards or guidelines which often is easier than using heuristics, which are more general [6, p. 523]. The first step in both heuristic evaluation and standard inspection is to develop a list with important design principles based on the interface, user group and context [6, p. 523]. There exist many different lists describing different heuristics for good user experience, one common heuristic list is Nielsen's for evaluating a technical system [8].The discrepancies are noted and graded due to how important the criteria is. The methods do not lead to any specific solutions but can form the basis for an idea generation [6, p. 524]

2.2 Users and scenarios

According to Vassileva and Campillo the typical EV driver is a well-educated male with medium-high income [9]. The user, on average charges the EV three times a week, drives 38 km every day, which is similar to what a user with an ICE vehicle drives and they do have energy remaining upon recharging according to Franke and Krems [10, p. 75]. According to Bunce et al. 49 % of the 207 users in their study charge their EV on a regular interval regardless of the amount of power in the battery, and often the charging was done overnight at home or during the workhours [11, p. 283]. Franke and Krems analysed the average charge level when starting charging the EV. The most common battery status in percentages when plugging in the vehicle was 30% [10, p. 82]. Figenbaun and Kolbenstvedt have also studied the charging habits of 3111 BEV drivers and 2065 PHEV drivers in Norway [12, p. 34]. According to these authors almost all EV users charge daily at home. When charging at home 66% of the BEV drivers and 90% of the PHEV driver used the supplied cable. The supplied cable is also the most common way to charge the EV at work for these users, 78% of the BEV drivers and 84% of the PHEV drivers use the cable instead of a wallbox. A wallbox is a small dedicated charging station installed either on a wall or a pillar close to a parking space [13]. Figenbaun and Kolbenstvedt have also investigated different charging problems, 20% of the EV drivers have experienced a problem when charging. The most common problem are "no power available" and damaged cable/charge socket. [12, pp. 34-40]

The most attractive motive for the users to buy an EV is the low environmental impact and on second place comes cost-efficiency which cover charging and other maintenance costs according to Vassileva and Campillo [9]. The third motive for buying an EV is due to its new, exciting technology [9]. Figenbaun and Kolbenstvedt have made a similar study in Norway and for pure BEVs the main reason for buying their vehicle is low energy cost followed by best for my need and value for money [12, p. 16]. PHEV owners have short trips on electricity as the number one motive for buying the vehicle followed by best for my need and reliability [12, p. 16].

In the study by Franke and Krems 87% of their 79 users thought that charging was easy, but 57% said that the charging cable was hard to handle and therefore cumbersome [10, p. 81]. Franke and Krems study also shows that 78% of the users did not bother about the longer time required charging when comparing to refuel a vehicle with an ICE.

Hardman et al. have studied low- and high-end early adopters to investigate if there is any difference between them [1]. Most users who were classified as low-end adopters drove a Nissan Leaf and the high-end adopters drove a Tesla Model S. The authors show that there is a difference between how the two user groups perceive the charging time of their BEV in comparison to refuelling an ordinary ICE vehicle. According to Hardman et al. [1] the low-end adopters thought that the time charging their BEV took longer than refuelling an ICE and can therefore be a potential barrier for the low-end adopters to buy a new BEV. Hardman et al. think that it is surprising that the high-end adopters believe that the time to charge their BEV is similar to refuel even though recharging a Tesla model S takes far longer than to refuel an ICE. But the amount of interaction with the BEV is not more time consuming than inserting a pump with petrol or diesel into an ICE vehicle which might be the explanation of this result. [1]

2.2.1 **Acceptance model**

According to Everett M. Rogers the first 2.5 percent to accept a new innovation are the innovators followed by 13.5 percentages of early adopters [14, p. 287]. The next one to adopt the idea is the early majority which is 34 percent of the adopters followed by the late majority, also 34 percent. The last ones to adopt the innovation is the laggards which is 16 percent of the adopters. See Figure 2 for Rogers's acceptance model.

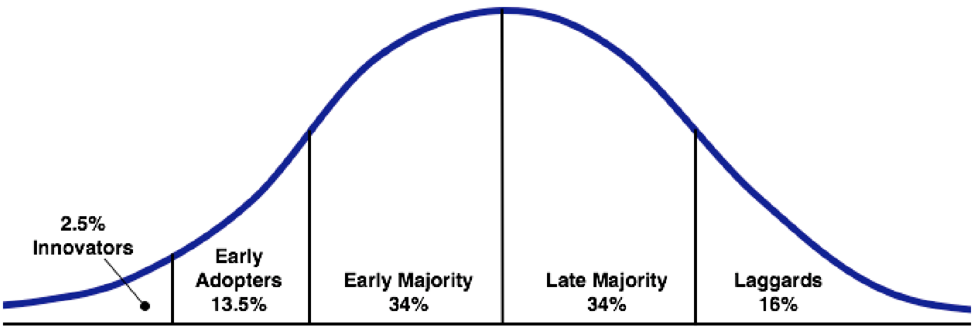

Figure 2: Roger's acceptance model

2.3 Interaction design

The aim with design overall is to develop products that help the user achieve its goals [15, p. 319]. Moving on to interaction design, Preece et al. defines interaction design as “designing interactive products to support the way people communicate and interact in their everyday and working lives” [15, p. 8]. Arvola defines interaction design as “a way to design interactive products that support the way people communicates and cooperates in the everyday life” [16, p. 20]. Interaction design is being used as an overall term covering areas including user interface design, software design, user-centered design, product design, web design, experience design and interactive system design [15, p. 8]. The typical interactive design process generally involves four steps, establishing requirements, designing alternatives, prototyping and evaluating [15, p. 15]. The aim of interaction design is hence to develop interactive products that are both usable and enjoyable, that is products that reduces the negative and enhances the positive parts of the user experience [15, p. 2].

2.3.1 **User experience**

The user experience according to ISO standards is defined as “a person’s perceptions and responses that result from the use or anticipated use of a product, system or service“ [17]. But the author Christian Kraft define User Experience “as the feelings that the user gets when using a product” [18, p. 1]. The user experience involves the quality of the interaction with the product and which emotions it generates in the user according to Preece et al. [15, p. 12]. In order to develop a product with an enjoyable user experience, it is important for the designer to understand the user, the technology and the interaction between them [15, p. 10]. One cannot design a user experience, but one can design for the user experience [15, p. 12]. Three important questions that needs to be answered before developing an interactive product is who the user is, how the product is used and where it is used [15, p. 6] [19, p. 221]. The first step in developing an interacting product is getting to know the user. This involves understanding human cognition, emotions, abilities and limitations [15, p. 66]. A user can interact with a product in different ways, for instance haptic, speech, touch, air-based gestures [15, pp. 189-202]. To answer the question about where the product is used the designer needs to identify activities when the user is using the product [15, p. 6]. A user-centred approach is a design process that involves the user. This can be done with help of observations, interviews, workshops and questionnaires [6, pp. 484-490] [15, p. 16].

2.3.2 **Design principles**

Cognition can be explained as a way to understand and make use of the human abilities and limitations when designing products [15, p. 66]. Stone et. al thinks that three elements of Don Normans seven are the key elements when designing for a great interaction [20, p. 97]. They are discoverability (visibility according to Stone), affordances and feedback. Discoverability is by Norman the ability for a user to discover what a product does [21, p. 72] and Stone et. al mean that it should be obvious what a control is used for [20, p. 97]. When understanding what a control is used for the next step for the user is to understand how the control is used [20, p. 97], which is called affordance. The last key element, feedback, should help the user to understand that a control has been used [20, p. 97] and that it should be easy to determine the new state [21, p. 72]. A feedback must be immediate because if the delay is to long the user can give up and move on to other activities [21, p. 23]. There are some guidelines regarding choices of colours, which also is perceived different in different cultures [21, p. 129]. The colour red is in the design of display lights perceived as an emergency, green as ready and working and yellow to show delay or the need to check [22] [6, p. 404]. Other elements affecting the interaction is mental models [21, p. 26], consistency [19, p. 137] and mapping [21, p. 72]. A mental model is the model a user have in it is own mind about how a product or system works [21, p. 26]. Consistency describes how well a system's controls is similar and do have consistency between each other, and a highly consistent system lets the user to quickly learn how to operate it [19, p. 138]. Mapping is about how different controls is placed and their relationship, it´s important that the actions follows the principles of good mapping and should therefore be placed close to the control [21, p. 72].

3 Background

This chapter will describe theory about electric vehicles, their parts and how the charging procedure works.

3.1 Electric Vehicles

An electric vehicle (EV) is a vehicle that is driven by one or more electrical motors [23, p. 227, 24, p. 10]. This could be anything from an electric bicycle to an electric car. There are several sub-categories of EVs and the ones related to this project are presented below and summed up in Figure 3.

A plug-in-electric vehicle (PEV) is a type of electric vehicle that is charged using external sources of energy, such as AC power sockets or wallboxes. A sub-category to a PEV is the battery electric vehicle (BEV), which is a pure EV that stores energy in an electric battery [25, p. 19].

A hybrid-electric-vehicle (HEV) has two or more power sources, for instance one electrical propulsion and one conventional powertrain, usually powered by fossil fuel. A powertrain is the main components in a motor vehicle that generates and delivers power for propulsion. [26, p. 412]

A plug-in-hybrid-electric-vehicle (PHEV) is a combination of PEV and HEV. It combines two or more propulsion systems, and is charged using external energy sources. [26, p. 465]

A PHEV with a range extender operates primarily with the battery but switches to operate on the built in Internal combustion engine (ICE) running on gasoline or diesel when the battery is low [27, p. 117].

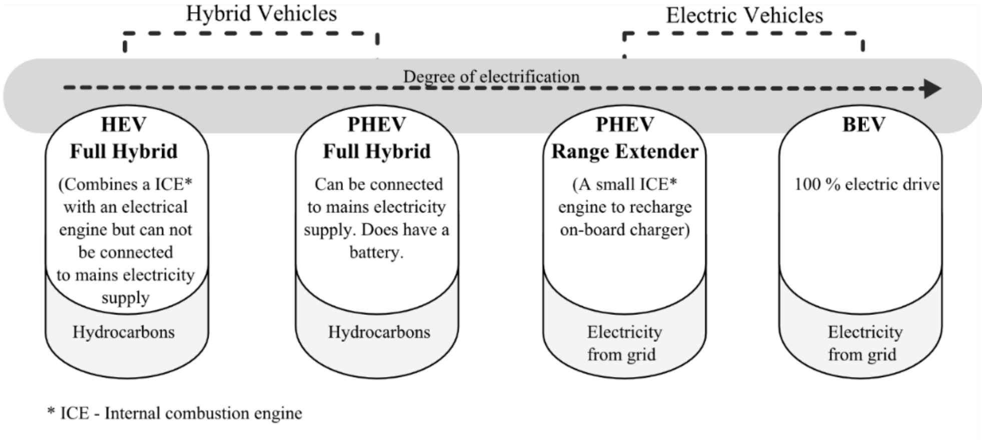

Figure 3: Different types of EVs

3.2 Parts of the electric vehicle

The electric vehicle (EV) contains different parts and needs different gadgets to be charged, illustrated in Figure 4. The EV has a battery and an electric vehicle inlet (EVI). One way to charge the EV is with a charging cable that can be plugged into the EVI with a connector [25, p. 19]. The charging cable can have a control unit with a residual current device and must be plugged into a household or industrial socket to gain power [28, p. 297]. Another way to charge the EV is with a fast charger that has a fixed cable with a built in residual current device, the only thing needed to charge the EV is to plug in the connector into the EVI [26, p. 441]. With the fast charger the user can charge with DC unlike the ordinary charging cable that only provides AC from the main electric supply [26, p. 441].

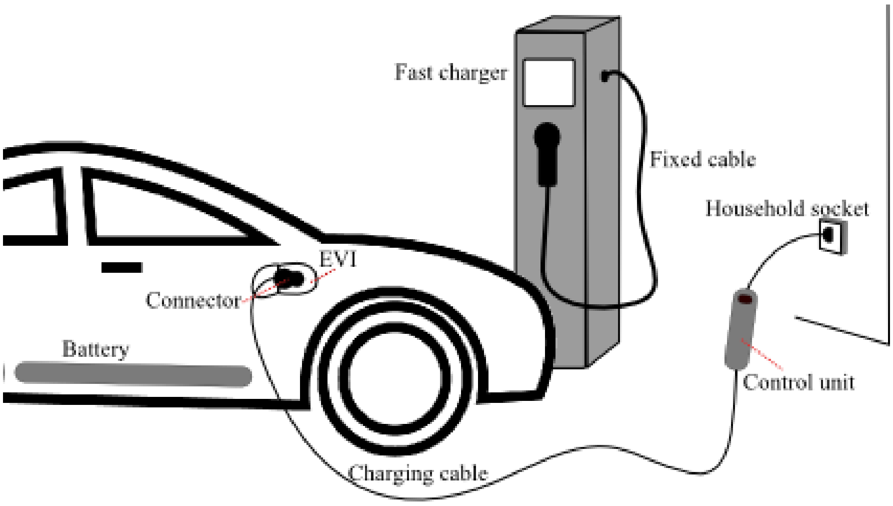

Figure 4: Parts of the electric vehicle

3.3 Charging

The following section contains information about the charging procedure and the components needed for charging the EV. There are many different components that the user must have knowledge about when charging the EV. In Table 1 below the different components are described.

Table 1: Different charging equipment

Cable assembly	Piece of equipment that is used to establish the connection between the electric vehicle and the electric vehicle supply equipment [24, p. 11].
EVI door	The door that covers the EVI [24, p. 13]
EV connector	Part of a vehicle coupler integral with, or intended to be attached to, one flexible cable [24, p. 13]
EV Inlet	Part of a vehicle coupler incorporated in, or fixed to, the electric vehicle [24, p. 13]
EV supply equipment	Conductors, including the phase, neutral and protective earth conductors, the EV couplers, attachment plugs, and all other accessories, devices, power outlets or apparatuses installed specifically for the purpose of delivering energy from the premises wiring to the EV and allowing communication between them if required [29, p. 10]
In-cable control box	Device which is incorporated in the cable assembly and which performs control function [24, p. 10]
Off-board charger	Charger connected to the premises wiring of the AC supply network (mains) and designed to operate entirely off the vehicle. In this case, direct current electrical power is delivered to the vehicle [29, p. 10]
On-board charger	Charger mounted on the vehicle and designed to operate only on the vehicle [29, p. 10].
Plug	Part of a plug and a socket-outlet integral with or intended to be attached to one flexible cable connected to the electric vehicle or to a vehicle connector [24, p. 12].
Plug and socket-outlet	Means enabling the connection at will of a flexible cable to fixed wiring [24, p. 11].
Socket-outlet	Part of a plug and a socket-outlet intended to be installed with the fixed wiring or incorporated in equipment [24, p. 12].

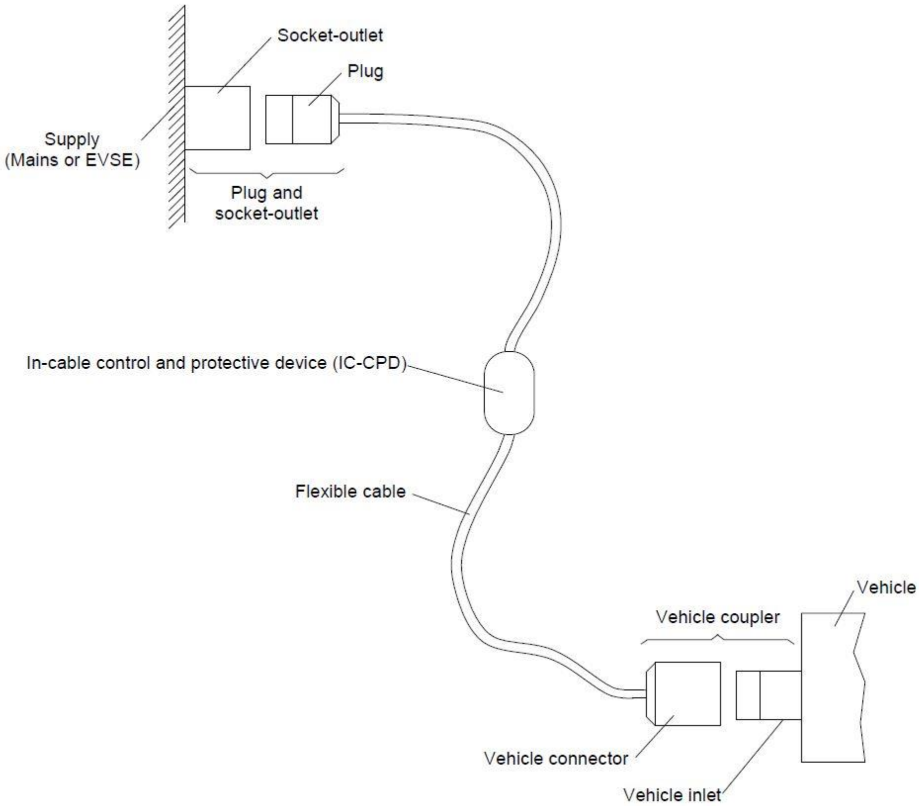

Figure 5: The equipment needed for charging an EV [24, p. figure 1].

Charging the EV is done by transferring power from the supply (mains or EVSE) to the EV. To enable a power transfer a connection is required, which can be done using the equipment shown in Figure 5 [24, p. figure 1]. The appearance of the supply varies from an ordinary household or industrial socket outlet to a dedicated charging station [26, p. 440]. Charging through an ordinary household socket requires extra safety functions in the charging cable in form of an in-cable control and protective device referred to as “the control unit” in the report, whereas a dedicated charging station provides all safety functions needed for charging an electric vehicle [29, p. 10]. The thickness of the cable depends on the current running through [24, p. 24].

A dedicated charging station is also called the electric vehicle supply equipment (EVSE) and can be with or without a fixed charging cable [29, p. 10]. The EVSE includes all EV couplers, plugs, power outlets or apparatuses that are installed specifically in order to deliver energy from the grid to the EV and allowing communication between them. It may or may not include a fixed charging cable, and can be either stationary or installed on a wall [22, p. 10]. Most charging stations provides either AC or DC charging with one type of plug, but some charging stations can provide a both AC and DC charging though several plug types suitable for different EVs [30]. Since regular household sockets only provides AC, most home charging stations charges through the mains [26, p. 440].

The EV coupler enables the connection between the electric vehicle and the charging cable [24, p. 13]. Included in the EV coupler is the EV connector and the EV inlet [24, p. 13]. These two parts will further be referred to as “the connector” and “the EVI”. The connector is attached to the charging cable and the EVI is fixed to the EV. Attaching the connector to the EVI enables the possibility of energy transfer and battery charging. The EVI is protected by a charging door that varies in form regarding on the brand [24, p. 13]. The door can be opened in different ways, both mechanical and electrical.

Connector types

There are many different types of EV connectors both for AC charging and DC charging [24, p. 22] and they can be found in Figure 6. There are different types of connectors and the types can briefly be sorted in to where in the world the vehicle is used. The most common connectors for vehicles used in Europe is Type 2 and are called the “Europe plug”. Three different charging systems are standardised around the world in IEC 62196-2 [31] and they are not compatible with each other without an adapter [32]. Type 1 is common in USA and are related to SAE J1772 [33] and type 4 is common in Japan and related to Japan Electrical Vehicle Standard G105 -1993 [34]. Some of the connectors have buttons on the handle to lock the connector to the EVI, for example Type 4 and Type 1 [24, p. 53].

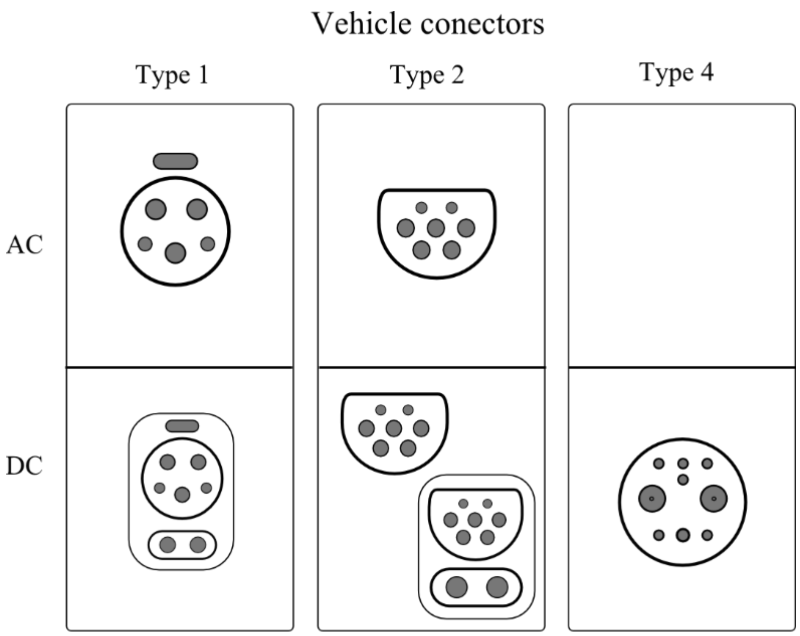

Figure 6: Vehicle connectors

EVI types

Every connector has a fitting EVI. There are many brands that have a so called COMBO EVI which allows the user to both charge AC in the upper inlet and DC if both the upper and lower inlets are used [24, p. 46]. For all inlets see Figure 7.

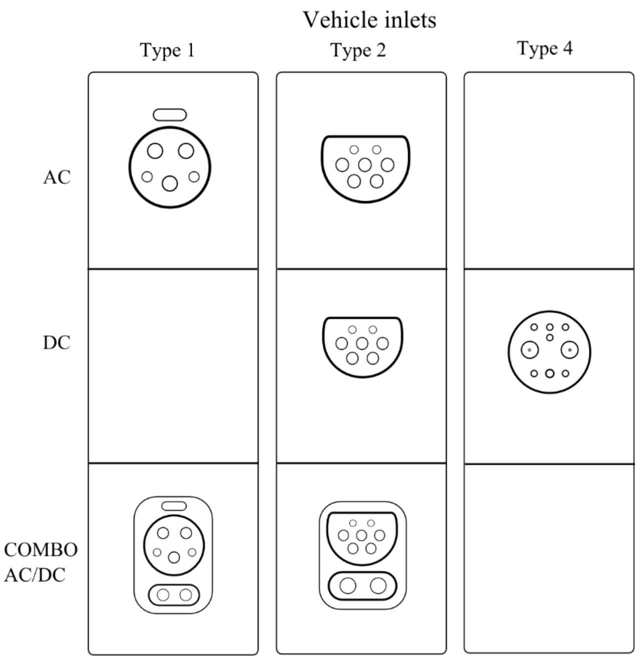

Figure 7: Vehicle inlets (EVI)

Charging modes

Charging a battery is quicker in the beginning, and slows down when the battery gets closer to fully charged. It can be compared to pouring water into a glass, faster in the beginning and then slower for better precision [25, p. 32]. Charging the electric vehicle can be done in several different ways. In the standard IEC 62196 maintained by The International Electrotechnical Commission (IEC) four charging modes are explained, see Figure 8 for details [24, pp. 6-7].

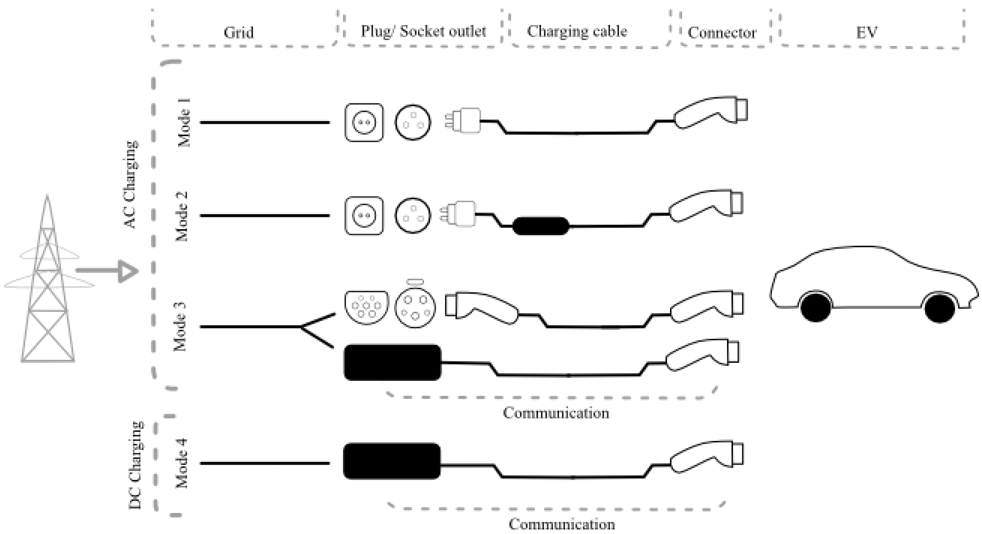

Figure 8: The four different modes described

Mode 1 and mode 2 charging is done through standard household sockets-outlets and is therefore both charged using AC [26, p. 440]. The difference between the two modes is the charging cables that are used. Mode 1 charging uses a charging cable without a control unit, and mode 2 uses a charging cable with a control unit. The control unit is a protection device that ensures that the connection between the grid and the vehicle is safe. The device controls and breaks the current in case of potential errors. [35, p. 70]

Mode 1, 2 and 3 uses AC charging and the current is adjusted to a preferable form by the electric vehicle on-board charger and then transferred to the battery [26, p. 440]. Mode 4 instead uses DC charging and the current can be transferred directly to the battery. The AC/DC conversion is done inside the charging station and this enables charging the battery faster than with the other three modes. [35, p. 70]

Mode 3 and mode 4 charging, both referred to as “fast charging”, is done using special electric vehicle charging stations [26, p. 441]. The electric vehicle charging stations has integrated functions for monitoring and protection, which means that the charging can be done with a cable without a control unit [35, p. 70]. Unlike the three other modes, mode 4 does not charge via the on-board charger. Another attribute is that the charging cable is fixed on the charging stations for mode 4, but mode 3 charging stations can have both fixed and detachable cables. [26, p. 441].

Concept of charging

There are different ways to charge an EV. It can be done through the mains with a charging cable, with a wallbox or with a fast charger that can be found at super markets and restaurant along the highways. Many companies are working with a new way of charging the EV with help of induction plates, but in the future it can be a solution to have inductive roads [13]. Experts in the area believes that the inductive charging will not be a standard way of charging the EV in the next 5-10 years, the charging cable or wallboxes will still be the most common way [13] . Tesla has own superchargers that has several DC chargers that works parallel with each other. This results in an output of up to 120 kW direct to the EV battery which shortens the charging time [36]. Another way is to remove the battery and replace it with a fully charged battery, which have been tested in Japanese electric taxis [25, p. 83]. Tesla has also showed a prototype of an automatic charging arm finding its way into the EVI [37]. Fisker Karma is talking about having solar panels on the vehicles roof to charge the battery [38].

4 Methods

This chapter briefly describes all the different methods used in the project and divides the methods into where they were used. It does not show how the methods were implemented in the work, this can instead be found in each phase chapter. Instead the chapter covers theory about the methods and why they were used based on their pros and cons. The project was divided into two phases with the purpose of identifying and evaluating parameters. The results from these two phases were used to present recommendations and user scenarios and investigating the best way to evaluate the user experience with help of these parameters. This division has been made to structure the work and also to facilitate for the reader. In Figure 9 the different methods used in the project were structured into where they were used. The aim with this project was not to develop a product, rather to evaluate existing ones and establish guidelines for future products. This project did therefore focus on the first and last steps of the interaction design process, which was evaluating and establishing requirements/guidelines. In this case it was evaluating and establishing guidelines for the user experience during the charging procedure of an EV.

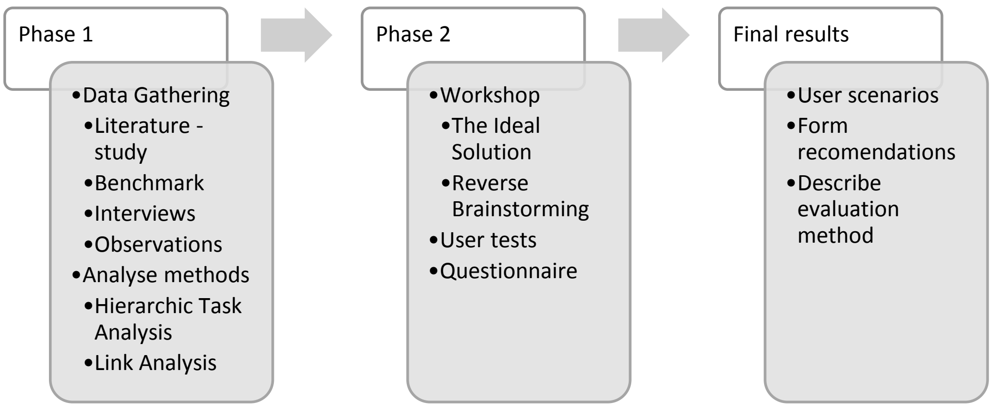

Figure 9: The different methods used, structured into where they are used.

4.1 Methods used in phase 1

The first phase, investigate charging procedure, had the purpose of collecting information about the charging procedure and the gadgets needed for charging with the help of a literature study and a benchmark. The result from the literature study can be found in chapter 3, background. Another aim was to identify the parameters that are affecting the charging procedure for the user, and the first phase therefore contained methods for gaining knowledge about the users and how they are using their EVs. The main purpose of data gathering is to get unknown information about a specific topic. To ensure that the right data is gathered it is important to plan the sessions carefully [15, p. 227]. It is also important to use methodological triangulation which means to validate data using several different gathering techniques. Unfortunately it is hard to achieve true triangulation due to that different kinds of gathering methods may result in different kinds of data. [15, p. 230]. Methods that were used were observations and interviews, and the data was analysed with the help of the two methods Hierarchic Task Analysis, HTA, [6, p. 496] and Link Analysis, LA, [6, p. 497].

The interviews in the first phase were primarily structured ones due to that data from a structured interview is easy to analyse [6, p. 486] thanks to closed questions which means that the interviewee just can choose from a predetermined set of alternatives [15, p. 234]. There are both pros and cons with interviews as a data gathering method [6, p. 487]. The pros is that it is a subjective and flexible method which minimizes the risk of misinterpretations and it results in a representative basis from the selection group due to that participants is chosen by the interviewer. One con is that the interviewer might influence the interviewee with their personality, attitude or position. Another con is that the answers from the interviewee might not be representative of what the person really does in a scenario. Because of that, interviews should be complemented by other methods, such as observations for more reliable data [6, p. 487]. Observations are therefore a good way to cover missing parts of the whole story. It is an objective method to gather information about how a person acts in a specific factual situation [6, p. 484] and fits well in the first phase. Observations are a good way to capture a user’s behaviour in a real scenario without interruption moments. It is a good way to develop knowledge in an unknown area. However the method does not tell the underlying causes of a behaviour which entails that the analysation of the data might be hard. [6, p. 485]

Hierarchic Task Analysis is a way to, in detail, describe the steps a user must go through to accomplish a task and fulfil a goal. The data needed for performing the analysis was gathered from observations, interviews and manuals [6, p. 496]. As a complement to the HTA a Link Analysis is good way to define how a user moves when performing a task [6, p. 497].

4.2 Methods used in phase 2

In the second phase, the identified parameters were analysed and evaluated in order to find out which the most critical ones are and to gain quantitative and qualitative data about how they should be formed to achieve the best user experience possible. The data was also used as a basis in the different user scenarios. The data was gathered through a questionnaire, a workshop with EV users and different user test. It showed how to form the parameters in the EV to facilitate the charging procedure for the user. A questionnaire was good in this case due to the need to get a lot of participants for quantitative data when circumstances like time or distance complicates the work [15, p. 244]. The questionnaire was also a good way to verify the data that already had been collected from the first phase [6, p. 488]. The pro with a questionnaire is that you can reach a larger amount of persons than with an ordinary interview. The persons cannot be affected by the interviewer's personality, status or mood and are often anonymous which may result in more reliable data which also is good. Cons with questionnaires are the risk of misinterpreted questions and if the answering rate is less than 50 % the answers are not representative [6, p. 489]. To analyse and illustrate some of the answers regarding how satisfied the drivers are with different parameters Net Promoters Score, NPS, [39] was used to show the satisfaction. This method focuses on showing how satisfied the customers are by letting them answer how likely it is that they will recommend the product/service to a friend on a scale from one to ten [39].

The workshop contained an alternative brainstorming method called the ideal solution [40] and also the method negative brainstorming [41]. To help the participants to generate ideas they got scenarios to work with. A scenario describes when a persona, which puts a face on a possible user [42, p. 11], is inserted into a story [16, p. 69]. It is a way to understand the users' values and needs and also a structured way to present the findings from the data gathering [13, p. 494]. A workshop with at least six people captures the overall comments that one can expect from users thanks to associations to different treated subjects [6, p. 489].

The different user tests captured qualitative and quantitative data and the participants evaluated the identified parameters. A user test is an experimental method allowing real users to interact with a product by performing different tasks [6, p. 525] . In the two user test in this study the participants got the task to test different concepts and grade them after interacting with EVs. The test can both be performed in a lab environment or in the real life, for instance at a workplace but should with advantage not last more than 30 minutes [6, p. 525]. If there are at least five to six participants in a user test, 75-80% of all user problems will be discovered [6, p. 526].

4.3 Methods used for final results

To illustrate different users in the target group both today and in the future, user scenarios were conducted. The user scenarios are also called written scenarios which aim to tell a story about a user in a situation [43, p. 99]. According to the same author the story can both show an existing user interaction and the possible future interactions for the user. The scenarios are based on information about real users and interactions which was gathered from the user tests and the literature study. A written scenario can be used for many purposes and in the final results the aim was to illustrate the user's interaction with different parameters depending on their habits and needs. It is a way to specify interactions that the different charging procedures must support to ensure a good user experience.

When forming the recommendations, no special method was used. Based on how the user had evaluated the parameters the recommendations were formulated and conducted into a list. It can be seen as a checklist that tells how the identified parameters should be designed for the best user experience. A checklist is used as way to map and review different factors [6, p. 491]. It is often formulated in way so the user easily can check if a statement is true or not [6, p. 491]. The recommendations that were formed do not have statements that the user can check, they are only describing how the parameters should be designed. Sometimes they are in form of a concept and sometimes by just describing how the characteristics of the parameters should be designed. The evaluation method was formed with a heuristic evaluation method as a foundation. Theory about heuristic methods together with other methods is presented in chapter 2, Theory. To ease the use of the method and to involve the users' opinions, guidelines in form of design principles were added.

5 Phase 1 – Investigate charging procedure

This chapter covers the first phase, where the aim was to identify the parameters affecting the charging procedure for the users. This was done by a literature study, different data gathering and analytic methods. The phase was ended with a discussion supported by the literature study and with the first results, the identified parameters.

5.1 Phase 1 - Implementation

The first part of the project involved getting familiar with electric vehicles, charging concepts, charging behaviours, international standards, methods for data gathering and for data analysis. The data gathering was initiated with a literature study in order to get a deeper understanding of the subject. Most of the information was found in vehicle owner's manuals, articles and international standards. Even though a literature study is an effective way to gather information about a subject, a decision was made to benchmark different EVs in reality to get an even deeper understanding.

The benchmark was performed on several BEVs and PHEVs by interacting with different kinds of charging stations. It was carried out on several different EVs, brands and models and was implemented to capture possible parameters that affect the user experience during the charging procedure. One test was to start and stop charging the EV, including all steps to achieve the desired result. In order to further be able to analyse the charging procedure, each test charging was recorded with a video camera. Something that also was investigated during the charging was different charging modes and charging stations. Since it is important to use methodological triangulation, several methods where used while performing the data gathering. Through the literature study and the benchmark study a brief understanding was acquired of the possible problems and parameters that may affect the charging procedure. The next step was to validate these insights, which was done through user studies including observations and interviews.

5.1.1 **Observation**

In an early phase in the project, information about the user and the charging procedure was gathered with the help of an observation. The goal was to gain knowledge about how users charge an EV and to observe which modes, types and connectors that was common to use. At first an observation protocol was made which was based on previously identified parameters through the literature study and the benchmark. 13 EV users participated in the test and they were divided into two skill levels: expert (four participants) and ordinary users (nine participants). The task the 13 participants got was to both start and stop charging a PHEV with the EVI placed over the left front wheel and the charging cable storage in the trunk over the load floor. The charging was done with a charging station without a fixed cable situated in front of the EV. The flow around the EV was documented with a video recorder and all steps of the charging procedure was written down in the performed order in the observation protocol, see appendix B. In order to investigate the user interaction during the charging procedure done at fast charging stations with a fixed charging cable, observations were performed in public parking lots.

5.1.2 **User interview**

The observation captured the user interaction during the charging procedure of an EV, but to capture the 13 participants' habits with their own EV charging procedure a structured interview was held after the observation. It was the same participants as in the observation. They all drive different EVs, work at Volvo and volunteered to participate in the studies. With the literature study as a foundation there were a number of concrete questions that needed to be answered, and a structured interview was therefore the most suitable method to use. It had standardized questions and every participant answered the same questions. The questions covered technical info about the participants' EVs and charging gadgets. They also answered questions regarding where and how often they charge their EV and what they think about different parameters. Questions regarding the charging habits and reasons for acquiring an EV were asked in order to collect data for the user scenarios. For all questions see appendix C.

5.1.3 **Expert interview**

An interview was held with an expert in charging, working at Volvo Cars. It was an open interview where the goal was to investigate what the expert thought about how the charging procedure might look like in the future. Subjects that were treated were wired/wireless charging, requirements regarding safety and how the user experience might look like.

5.1.4 **Hierarchic Task Analysis (HTA)**

In order to get an overall understanding of the different steps of the charging procedure, the conducted data from the observation was analysed with help of a HTA. Four different scenarios were analysed, “Start/Stop charging the EV with/without a fixed cable”. It was decided that all types of tasks should be presented in the HTAs and not just the tasks for a specific type of vehicle.

5.1.5 **Link Analysis (LA)**

The user flow describes how the user moves and interacts with the EV during the charging procedure, and is important to investigate in order to be able to optimize the user experience. With help of the HTA, based on the observation, four Link Analyses were conducted to show the user flow around the EV when charging.

5.2 Phase 1- Results

In this chapter results from the benchmark, observation, interviews and analytical methods will be presented.

5.2.1 **Benchmark**

The results from the benchmark are presented below in Table 2.

Table 2: Results from benchmark

Brand	**BEV/PHEV**	**Charging possibilities**	**EVI placement**	**Cable storage**
Audi A3 e-tron	PHEV	Mode 1-3	Front	Bag in trunk
Audi Q7 e-tron	PHEV	Mode 1-3	LHS back	Bag in trunk
BMW i3	BEV	Mode 1-4	RHS back	Front trunk
Chevrolet Volt	PHEV	Mode 1-3	RHS back	Side panel trunk, net
Mitsubishi outlander	PHEV	Mode 1-3	RHS back	Under load floor
Nissan Leaf	BEV	Mode 1-4	Front	Bag in trunk
Renault Zoe	BEV	Mode 1-4	Front	Bag in trunk
Tesla Model S	BEV	Mode 1-4 + Supercharging	LHS back	Frunk, Side panel trunk
Tesla Model X	BEV	Mode 1-4 + Supercharging	LHS back	Frunk
Toyota Prius	PHEV	Mode 1-3	RHS back	Under load floor
Volvo C30 Electric (Gen 2)	BEV	Mode 1-4	Front	Trunk
Volvo S90 Twin Engine	PHEV	Mode 1-3	LHS front	Side panel trunk
Volvo V60 Twin Engine	PHEV	Mode 1-3	LHS front	Under load floor trunk
Volvo XC90 Twin Engine	PHEV	Mode 1-3	LHS front	Under load floor trunk

Volvo V90 Twin Engine	PHEV	Mode 1-3	LHS front	Under load floor trunk
VW e-Golf GTE	BEV	Mode 1-4	RHS back	Under load floor trunk
VW Passat GTE	PHEV	Mode 1-3	Front	Side panel trunk

5.2.2 **Observation**

The observation resulted in a deeper knowledge about the user flow around a PHEV with the EVI placed over the left front wheel and the charging cable storage in the trunk over the load floor. The most common way to start and stop the charging of the EV for the 13 participants can be seen in Table 3.

Table 3: The common order of the charging procedure for the participants

Start Charging (nine of 13 participants)	**Stop Charging (12 of 13 participants)**
Get the charging cable	Unlock the vehicle
Connect to grid	Unplug the connector
Open EVI door	Close the EVI door
Plug in connector	Unplug from grid
Check feedback	Leave charging cable in trunk

Of these 13 participants four of them checked the ampere settings and three of them also changed the settings. Seven of the participants checked the charging status at some point during the observation, four of them looked at the control unit, two of them at the EVI and one checked both the EVI and the control unit. Problems that arose are found in Table 4 below.

Table 4: Problems that arose for some participants when charging during the observation

Problem to pull out connector from EVI (three participants)
Problem to open EVI (two participants)
Forget to take off lid of connector before trying to attach connector to EVI (one participant)
Problem to find the charging status (one participant)

5.2.3 **User interview**

The answers from the interviews were compiled and are presented below.

The expert users have more knowledge about EVs than an ordinary user, due to that they have worked with or developed EVs. The total numbers of EVs were 14 since one of the participants owns two EVs, one BEV and one PHEV. Out of these 14 EVs, five are BEVs and nine are PHEVs. The car models can be seen in Table 5.

Table 5: The participants' vehicle models

Brand and model	**BEV/PHEV**	**Plug type**	**EVI Placement**	**Quantity**
Volvo V60 Plug-In Hybrid	PHEV	Type 2	Front Left	7
BMW i3	BEV	Type 2	Back Right	2
Volvo C30 Electric (Generation 1)	BEV	Type 1	Front	2
Volvo C30 Electric (Generation 2)	BEV	Type 2	Front	1
Toyota Prius Plug-In Hybrid	PHEV	Type 1	Back Right	1
Chevrolet Volt	PHEV	Type 1	Front Left	1

All of the participants live in villas and have a private parking with access to a charging outlet. None of the participants have a dedicated charging station installed at home, but instead charges through a standard household socket. Everyone does charge at home, ten of them charge at work and five of them charge at other places like supermarkets.

Do you adjust the ampere settings?

The participants were asked if they ever adjust the ampere settings when charging their EV. Only one of the participants adjust the settings every time, to as low ampere setting as possible due to possible overload on the household grid otherwise. The participant in question drives a PHEV which means that the battery can be charged with a lower feed and still be fully charged over the night. Five participants answered that they rarely adjust the settings, if they do it is because of limitations in the grid. Such limitations could be that the washing machine is running at home, or that several other EVs are connected to the same feed. All participants that always or sometimes adjust the setting does this on the control unit. The rest of the participants, seven participants, do not adjust the settings at all.

Do you check the charging status?

The participants were asked if they confirm that the charging procedure has begun by observing any of the status indicators present on the vehicle or charging equipment. The participant that owns two EVs acts different with the two vehicles and the result below will therefore appear to involve 14 participants rather than 13. 12 of the EV owners do check the charging status and does this in the EVI (seven participants), the LED light in the windshield (four participants) or the drivers display (one participant).

The two remaining vehicle owners do not check the charging status after plugging in the EV to the grid. The reason that they do not check is that they assume that everything works, because it actually works almost every time. Another reason is the long response time, around 5 seconds, of the status indicator. The need to stand next to the vehicle and wait for the status indicator to light up is experienced as frustrating and a waste of time.

EV ownership

The reasons for driving an EV varied between the participants. For the different reasons, see Table 6.

Table 6: The reasons for driving an EV

Environment	Technology	Economy	Status	Other	
X					Environment. Could pay even more for a hybrid vehicle if needed.
X					Environment at first, but then realised that it is really nice to drive on electricity in queues.
X	X				80 % for the environment, also technically cool.
	X				Technically interested
	X				Electrification is the future, a good compromise to have a hybrid, it is hard to have a 100% electrified vehicle due to range.
	X				Responsible for the development of the C30. Never wants to buy a fossil fuelled vehicle again.
	X	X			The first vehicle I bought where 80 % for the economics and 20 % for the environment. The second vehicle (present) is 50/50 environment and economics.
	X	X			Technically interesting and for economic reasons
	X	X			Have been working with the development of hybrid vehicles. Thinks it nice to drive on electricity. Economically good.
		X			Lower cost, use it as a commute vehicle.
			X		"I was first", second-hand company vehicle, curiosity.
				X	Have driven a BEV in 15 years, but felt limited by the range and therefore bought a hybrid instead. Thinks that his vehicle is good looking.
				X	Fun with an electric vehicle, good range that is good enough to take me to work.

The most common reason for driving an EV among the participants is technological interest, which is not surprising since all EV owners today can be seen as early adopters. One can also conclude that buying an EV in many cases is a combination of several different aspects. As commented earlier, four of the participants are labelled as experts. The reason that these experts chose to buy an EV varies just as much between each user as it does for the ordinary users.

Driving habits

Eleven of the participants have additional vehicles in the household that are fossil fuelled. The five participants that drive a BEV have one or more either purely or partly fossil fuelled vehicle in the household. In two of the participant households the EV is the only vehicle. In those two cases the EV is a PHEV. All of the participants drive their EV every day and everywhere, which means that they do not choose their destination due to the range of the battery or the charging possibilities at the destination. They charge their EVs every time they park, at home, work and at the store.

Charging cable storage

The participants have different ways of storing their charging cable. Eight of the participants do not store the charging cable at the dedicated storage in the EV. In seven of these cases the dedicated storage is under the load floor in the trunk. Instead, five of them store the cable over the load floor, one stores it in the back seat and one does not store the charging cable in the vehicle at all, but instead leaves it at home in the garage. The last of the eight participants that do not store the charging cable at the dedicated storage should store it in the front trunk, also referred to as "frunk", but instead stores is over the load floor in the trunk. Examining the answers further, one can also see that five of these eight participants do not know that there is dedicated cable storage in their EV.

What do you think about the charging cable?

In seven cases a portable cable is always plugged into the household socket, whereas in six cases the charging cable is unplugged and put in the vehicle when driving away. Three participants that have the charging cable plugged in at home all the time has bought an extra charging cable that is stored in the vehicle. The participants where asked about their opinions on the EVs charging cable. The most common answer was that the cable feels stiff, especially in the winter time when it is cold outside. Another thing that was commented on was the control unit, that it feels heavy/clumsy and has a bad placement on the charging cable. The bad placement causes the participant to hold the charging cable with two hands in order to keep the cable off the ground. Other negative answers were: dirty cable, clumsy, feels fragile and that the contact is not good enough for frequently use. Positive answers were: works good, likes the bright colour and no comment.

EVI accessibility, feedback and visibility status indicator

The EVI placement affects the way that the EV is parked. The EVs with the EVI in the front part of the vehicle are parked with the front in, and the EVs with the EVI in the back of the vehicle are reversed in. The participants were asked about their thoughts about the accessibility of the EVI, the feedback when plugging the connector into the EVI and the visibility of the status indicator in the EVI. The comments on the accessibility and how many that has said each comment can be seen in Table 7.

Table 7: Answers about EVI accessibility, feedback and visibility status indicator

Accessibility	**Quantity**
Good placement	6
Bad with extra lid	3
Good overall	2
Bad placement if the charging station is at another place	2
Would like illumination in the EVI	2
Door easy to open	1
Sometimes freezes and cannot open EVI door	1
Unnecessary big EVI for a hybrid	1
Feedback	
Light	5
Sound	4
Not thought about that	2
Drivers display	1
Latch on a connector	1
Visibility status indicator	
It is well visible	4
Illumination, good	2
Has to bend in to see	1
Checks it subconsciously	1
LED windshield, great	1
Does not look at the lamp in the EVI	1
Good visibility when it’s dark	1

Feedback

The feedback is delivered in different ways depending on the vehicle. The most common feedback is light, either inside the EVI, on the control unit or a LED light in the windshield. Another frequently used feedback is through sound, or more of a “click”-noise. This is the sound of the locking mechanism inside the EVI that emits a click-noise when the connector is locked into the EVI.

Grade the UX when charging your vehicle

The participants were asked to grade the user experience when charging their own EV. A five graded scale was used, where 1 is really bad and 5 is really good. The result is shown in Table 8.

Table 8: Grade for UX when charging your vehicle

Grade	Quantity
1	0
2	1
3	3
4	9
5	1

The average grade for the user experience is 4. Some of the participants commented on why they did not give a higher grade, and those answers are compiled below in Table 9.

Table 9: Comments on why some participants did not give a higher UX grade.

An integrated cable would have been easier to bring.	Lower grade since the charging procedure is an extra step every day.
The push function on the EVI door is bad and sensitive.	Remove the lid on the EVI.
Thinks that the fast charging cable is clumsy.	The button on the connector is quite hard.
The charging procedure would have been even better with inductive charging.	Hard to charge when it’s dark and cold.
Due to problems with some charging stations.	The control unit on the charging cable is heavy.
Stiffness of the charging cable in wintertime.	

As one can see the comments regards both parts of the charging equipment and the charging concept overall. Some of the participants did mention other comments, which are listed below in Table 10.

Table 10: Other comments

Charging station
Drives further at work to find a charging station with a fixed cable.
Has put a cord from inside the house to the parking space.
Charging cable
Only has one charging cable that he takes with him. But he does not take the cable with him if he knows that there is a fixed cable at his destination.
Leaves the Mode 1 and Mode 2 cable at home and only stores the fast charging cable in the vehicle.
Uses an extension cord.
Has several charging cables: one ordinary and one for fast charging.
Rarely brings the cable, so it is "fixed" at home.
EVI & Connector
Does not like the lid on the EVI.
Can open the EVI with one hand, which is good.
Thinks that the EVI light is bad.
Overall
Thinks the charging procedure is easy, releases the relay - starts charging, has a residual current devices.
Uses the vehicles app a lot, there one gets information about the charging and if the charging is interrupted in some way.
Positive that there is a dedicated place for the charging cable.
Clear information about the charging in the drivers display.
Has no problem overall to charge with a cable. Think that it's part of having an EV.

5.2.4 **Expert Interview**

The expert thought that the charging cable will remain for at least five to ten years from now. During this time the wireless inductive charging will slowly be integrated into the infrastructure but the charging cable will remain as a backup, almost like a spare wheel. The expert said that vehicle brands with EVs in their product range will release an inductive charger during the coming two years. The problem with inductive charging today is that it is expensive and the components are large.

The expert thinks that the first ones will just be customized to home use and the second generation for public places. On the question about how the user will interact with the inductive charger the expert said that all interaction will be inside the vehicle. The future flow will therefore differ from the user flow when charging with a cable. The first ones will probably demand that the drivers will position the vehicle over the inductive plate with help of guidelines in the display. This interaction, the expert thinks will be a big part of the user experience along with how the feedback will be perceived. Another interaction with the inductive charger will be the start and stop of the charging and the expert thought that the vehicle will start charging directly after a successful docking between the vehicles plate and the chargers plate. On how to stop the charging he expert thought it will work as today, when unlocking the vehicle or when it is fully charged. [13]

5.2.5 **Hierarchic Task Analysis (HTA)**

To see the four different HTA for “Start/Stop charging the EV with/without a fixed cable” see Figure 10, Figure 11, Figure 12 and Figure 13. The scenario that the users experienced most trouble with is start charging the EV without fixed cable due to that scenario contained most time consuming tasks.

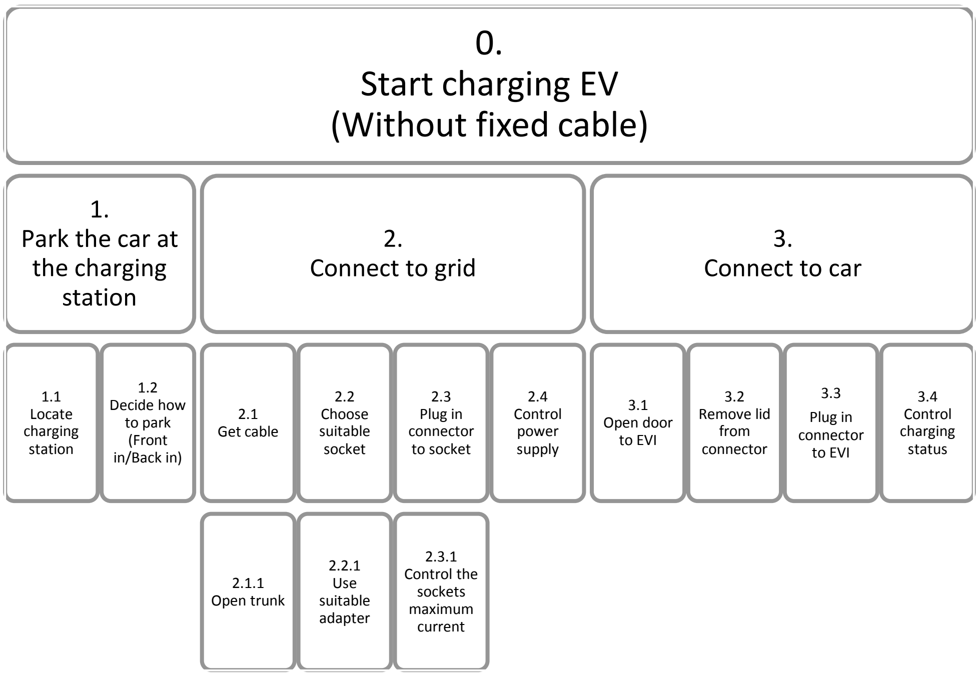

Figure 10: Start charging the EV without fixed cable

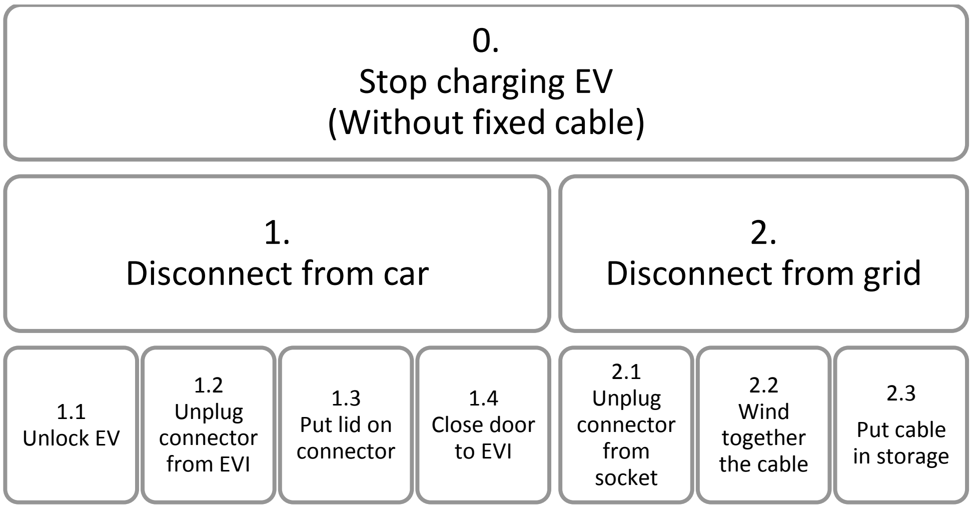

Figure 11: Stop charging the EV without a fixed cable

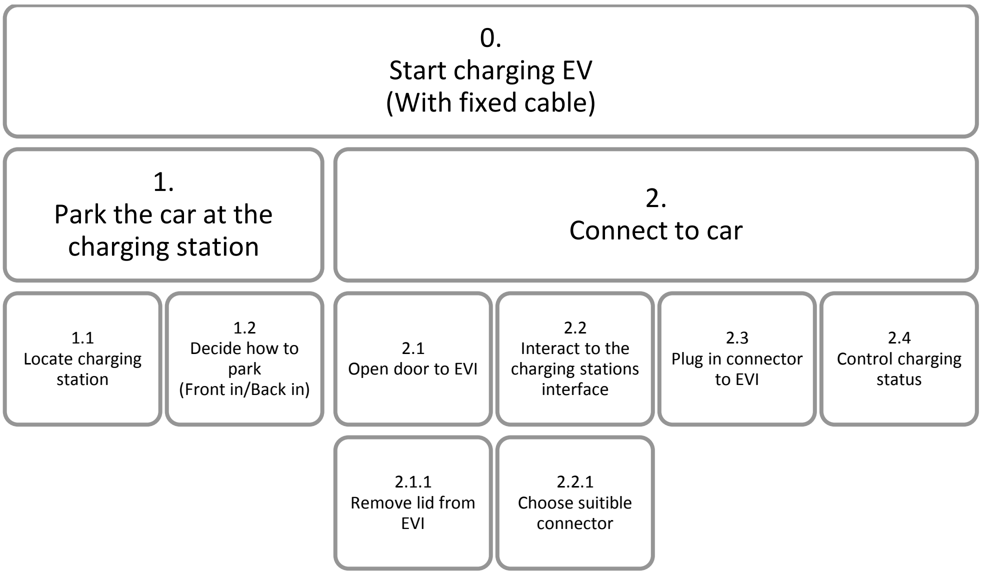

Figure 12: Start charging the EV with fixed cable

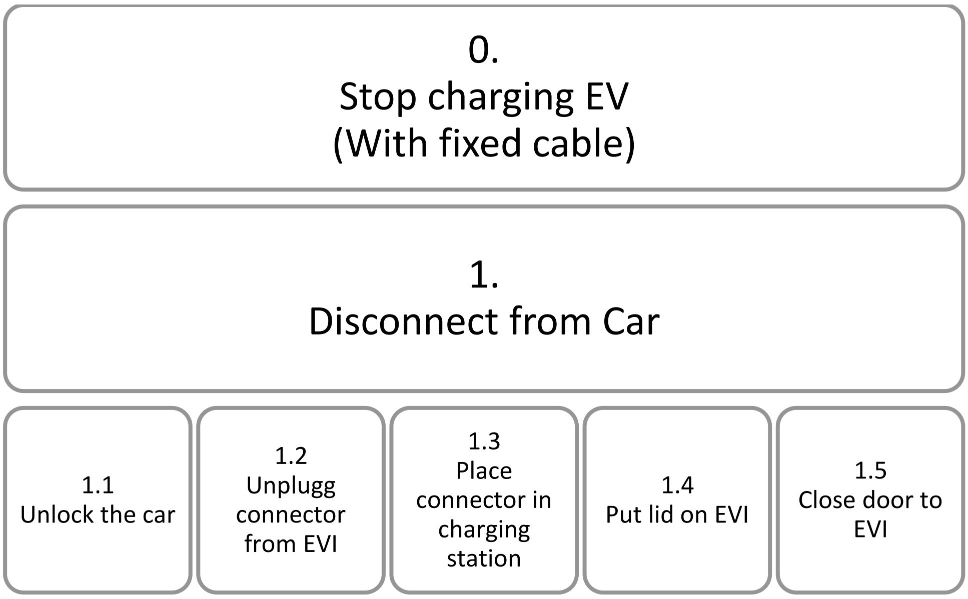

Figure 13: Stop charging the EV with fixed cable

5.2.6 **Link Analysis (LA)**

Below in Figure 14 the LAs are shown for start and stop charging without fixed cable and in Figure 15 the LAs for start and stop charging with a fixed cable are shown. The different tasks are numbered in accordance with the HTAs.

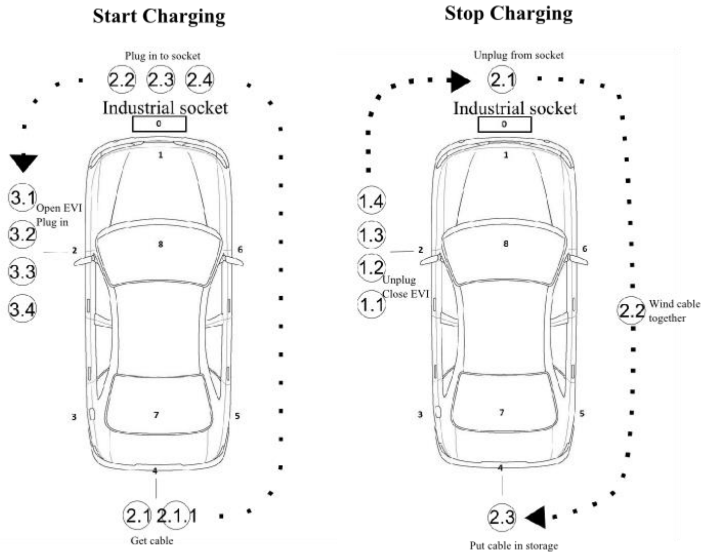

Figure 14: LAs for start and stop charging the EV without fixed cable.

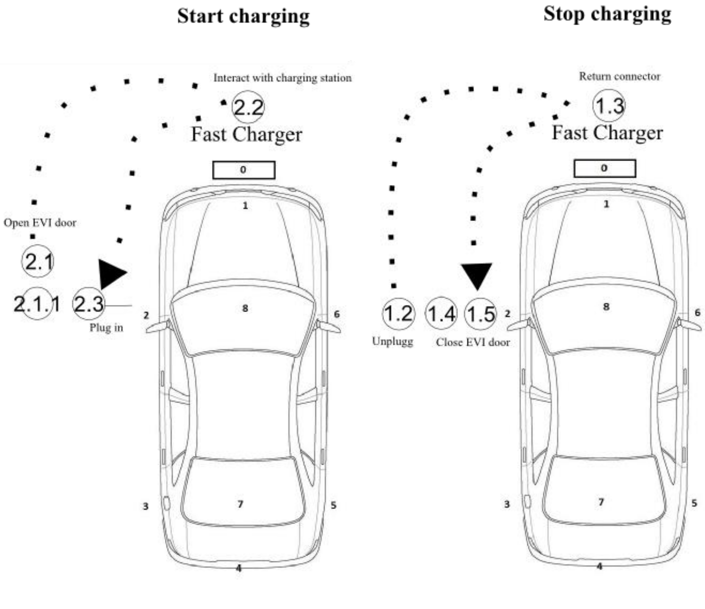

Figure 15: LAs for start and stop charging the EV with fixed cable.

5.2.7 **Identified parameters**

The identified parameters after the first phase are for wired charging the ones in Table 11. They are not listed in any specific order. For wireless charging the only identified parameter is feedback.

Table 11: Identified parameters for today's charging

Parameters for today's charging
Placement and design of EVI
Storage charging cable
Feedback charging
Charging cable

5.3 Phase 1 - Discussion

The literature and benchmark study resulted in parameters that needed to be confirmed with data from our own user study. The result from the observation and the interview matched with our first insights from the literature and benchmark study. This results in that the identified parameters comes from more than one source and hopefully reflects all things that might affect the user experience when charging an EV. The parameter that was most commented by the participants after this step was the storage of the charging cable which is cumbersome according to our study but also according to others, for example Franke and Krems [10, p. 81]. According to an expert at charging systems, charging cables will be the most common way of charging the EV in the nearest future [13]. The charging cable and its storage may therefore be an important critical parameters and the storage of the charging cable is therefore something that needs to be investigated further. Other parameters affecting the charging procedure according to the participants and the literature are the handling of the charging cable, placement and design of the EVI and the charging status feedback. This is something that must be investigated further in the work to get knowledge about how these parameters should be designed to optimize the user experience.

From the observations and the benchmarks HTAs and LAs were conducted which presented the tasks needed for charging and the users flow around the EV when charging. To streamline the charging procedure the task should be able to be performed in an effective way that demands as few touchpoints as possible for the user. The user tests were conducted on an EV with the EVI located over the left front wheel and with a cable storage in the trunk. This can result in an ineffective flow that will lead to a time-consuming interaction with the EV. According to Scott et al. the fewer touchpoints there are with the charging gadgets, the more satisfied the user is with the procedure [1]. So a convenient charging flow may result in that the users are more satisfied with the charging procedure. If comparing charging an EV with refuelling an ordinary ICE there are according to Scott et al some differences depending on the design of the EV [1]. Users with a Tesla has fewer charging touchpoints than a user who is charging a Nissan leaf and Scott et al and the Tesla drivers think that charging the BEV is as easy as refuelling an ICE which the Nissan Leaf users do not agree on. This study by Scott et al shows how important it is to have an easy charging procedure and this is something that the next phase will investigate further.

The participants in the observation and interview were a homogeneous user group all of whom works at Volvo Cars. All of our participants are early adopters according to Everett M. Rogers acceptance model [14] and the main reason for almost everyone to drive an EV is the interest in new technology which is a common reason in previous studies as well [9]. The future users, the early and late majority [14] will probably differ from today’s users which is one of the bigger challenges in this project. This user study with early adopters does only represent a small segment of the future EV users but it is assumed that the factors influencing the charging behaviour should not differ in the future. One has to consider not only today's users and their experiences but also the future users and therefore need to take the preferences and interests of the future users into account as well as todays. Some of the participants in the study where experts in the area and some answers may for that reason be of a professional kind rather than personal.

5.3.1 **Wireless charging**

The future of EV charging will probably be within inductive charging. But due to that one delimitation in this project is that it will not cover any interaction with digital displays inside the vehicle, which is the main interaction for the concept inductive charging, the only parameter that will be focused on is the feedback. Since no charging cable is used during inductive charging the HTA and LA will differ and the user flow will just be inside the vehicle. As the physical interaction is decreasing with this concept, it demands less of the future users which is an advantage since the future users will be early and late majority and not early adopters as today. These users will probably not accept the handling and storage of the cable as it is today and the inductive charging will hopefully easier be accepted by them.

5.4 Phase 1 – Conclusions

The data gathering and tests in this first phase resulted in the identification of several parameters that may affect the user experience during the charging procedure. These will be investigated further in the next phase. Table 12 describes how the identified parameters will be evaluated in the next phase so that the charging procedure can improve the user experience. The future of EV charging will probably be with inductive charging. The parameter that will be focused on affecting the inductive charging procedure, the feedback, will be evaluated in the next phase with help of a workshop.

Table 12: How the identified parameters will be evaluated in the next step.

Identified parameters	**Appropriate evaluation method**
Placement and design of EVI	Questionnaire, user test
Storage charging cable	Questionnaire, user test
Feedback charging	Questionnaire, user test
Charging cable	Questionnaire, user test

6 Phase 2 – Evaluate charging procedure

The second phase aimed to evaluate the effect that the identified parameters have on the user experience and to further investigate user habits and future charging concepts. The result includes which parameters are the critical ones and how they should be formed to achieve the best user experience possible. It includes results about user habits which can be used to later form user scenarios and results about the future of EV charging.

6.1 Phase 2 - Implementation

The data gathering and tests in the first phase resulted in the identification of several parameters that may affect the user experience during the charging procedure. The next step and also the goal with phase 2 were to further investigate the effect that each identified parameter has on the user experience. Depending on the identified parameter, different investigation methods were used to achieve the best possible result. The data gathering and parameter evaluation were performed by using a questionnaire and user tests. To further investigate the users' charging experiences and requests for the future, a workshop was held with EV users.

6.1.1 **Questionnaire**

The data analysed in the first phase were collected from a limited number of users. In order to obtain a greater quantity of data from a larger amount of users a questionnaire was created. The goal with the questionnaire was to compare the results found in previous studies, find focus areas for future user tests and to find user patterns which can be used when defining the user scenarios. The questionnaire investigated the users charging habits and the effect that the identified parameters from phase 1 has on the user experience. Compared to the questions asked during the interviews in phase 1, the questions in the questionnaire investigate the root cause and how the user is experiencing the effect of the parameters.

The questions were a combination of simple check box questions, grading scales and free comments. Whenever a grading question was asked, a following question was asked about what would be required to achieve a higher grade. These motivations are extremely important since it investigates the root cause of the user experience of the identified parameters.

In order to get in touch with as many users as possible the questionnaire was distributed to 226 Volvo Cars employees that drive a Plug-In Hybrid as a company car. It would clearly be best if the questionnaire was distributed to that quantity of BEV users as well, but the amount of BEV owners are fewer than PHEV owners and therefore harder to find.

6.1.2 **Workshop**

A workshop was conducted with the goals of identifying problems with today's EV charging and generating ideas for future charging concepts. The areas that were highlighted were mainly problems and solutions for the cable storage, charging cable, EVI and the charging procedure overall. The workshop participants consisted of 13 EV users, all of whom are employees at Volvo Cars. When initiating the workshop, a clarification was made to leave the professional opinions outside the workshop and instead participate as EV users. The agenda for the workshop can be seen in Figure 16.

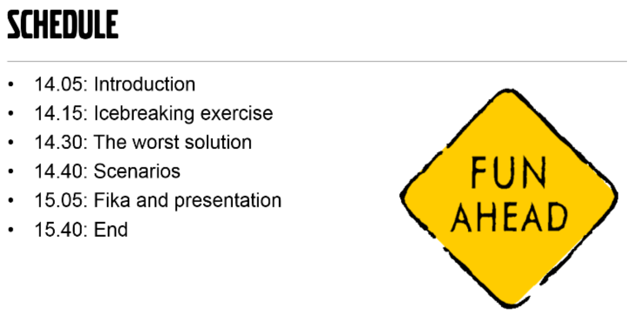

Figure 16: Agenda for the workshop "The future of EV charging".

The goal with the introduction and the icebreaking exercise was to begin to find one's feet and to brief the participants about the purpose and structure of the workshop. The participants were divided in to three groups in which they together would work with the different tasks. First up was an exercise called "The worst solution" and in this exercise the groups where put into the following scenario:

"You are working in a project that is developing the first EV for the company Bad Cars Corporation. The EV is going to be charged using a charging cable. The thing is, that you are actually working for a competitor and wants to sabotage the

development of the vehicle. How would you design the charging procedure to make the user experience as bad as possible?"

The participants were asked to describe which characteristics that would be present in an EV designed to achieve the worst user experience as possible when it comes to the charging procedure. The goal with this exercise was to start the idea generating process of the participants. This method is called negative brainstorming and was used since it often can be easier to come up with bad attributes of a product rather than good [41].

In the next exercise the participants were given three different scenarios describing different EV users and performed the exercise "The ideal solution". The goal was to identify possible problems and ideal solutions for the personas in the scenarios. The participants then investigated which of these solutions that were realistic and could be implemented today and which could be implemented in five to 15 years.

Scenario 1 describes a 40 year old business woman that drives an EV for environmental and status reasons. She lives in an apartment in the city and uses her EV to commute and go to meetings. Money is not an issue for this user, she always wears nice clothes and does not want to get dirty when interacting with the EV. Scenario 2 describes a 50 year old family father that drives an EV for economic reasons. He uses his EV to commute to work and drive his children to their sports activities on evenings and weekends. It is important that the EV is charged enough after work in order for the user to drive his children to their activities. On weekends the parking lots often have limited charging possibilities. He often has a lot of equipment in the trunk and has no problem getting dirty when interacting with the EV. Scenario 3 describes a 30 year old woman that lives in an apartment in the city and drives an EV for environmental reasons. She is a carpool member and tries to choose an EV in the carpool if possible, and it can be a new EV interface every time. She uses the EV to go on weekend trips, to the store or to visit friends on the country side.

6.1.3 **User test - Charging cable handling and storage**

After analysing the results from the questionnaire and workshop it was decided to further investigate the parameters that arose many opinions and comments from the participants. A user test was conducted with the goal of evaluating the handling and storage of the charging cable. The test was performed by different BEV and PHEV users who got to evaluate different concepts by using a scale from one to ten and by motivating the grading.

The participants started with evaluating different charging cable concepts followed by charging cable storage concepts. Grades and comments were collected from each concept to be able to identify which concepts were preferred by the participants. The charging cable evaluation included different concepts regarding the stiffness, wrapping mechanism, control units, connectors and cords, see Figure 17.

Figure 17: Different concepts of the charging cable

The stiffness concepts included one thinner and one thicker cable. Two different wrapping mechanisms concepts were evaluated, one where the cable is attached using touch fasteners and one where the cable is wound around the control unit. Three concepts of control units were evaluated, one where the control unit is situated in the middle of the charging cable, one where it is situated on the socket part of the cable and one cable without a control unit. The connector concepts included one connector with a latch, one without a latch and one with a touch button. At last the participants were asked how the ideal charging cable would look like according to their preferences.

The test was performed in a PHEV with a dedicated storage for the cable under the load floor. The storage evaluation included concepts of storage over and under the load floor in the trunk, when taking both an unloaded and loaded trunk into account. Five concepts for storage over the load floor in the trunk were presented: loose, in a soft big “weekend bag”, a small hard bag, in a plastic box, in a container with a hook in the side panel, under load floor with and without a net and a net in the side panel. See Figure 18 for the different storage concepts. As for the cable, the participants were asked where in the vehicle and how they ideally would prefer to store the cable.

Figure 18: Different storage concepts

6.1.4 **User test - EVI placement and feedback**

Another user test was performed with the goal of evaluating different concepts of placements, opening/closing mechanisms, lids and feedbacks of the EVI. Different EVs with different solutions were used to present the different EVI and feedback concepts to the participants. This test also included different BEV and PHEV users and they got to score different concepts using a scale from one to ten and also motivate why they chose the grade. After evaluating each concept area the participants were asked about how the ideal solution would look like if they could wish.

To evaluate the placement of the EVI the participants were asked to think about the places where they charge their EV, and from that conclude where they would prefer the EVI to be placed on the EV. Six different concepts regarding the opening mechanism of the charge door were evaluated: a physical or a touch button inside the vehicle close to the driver's seat, pushing on the charge door, a button on the key, a button on the connector and by turning and sliding the door open. Two lid concepts were evaluated, one where there is an extra protective lid inside the EVI and one where the protective function is integrated in the EVI. Four feedback light concepts were evaluated, see Figure 19.

Figure 19: Feedback light concepts

Three concepts for sound feedback were presented to the participants, one with a low sound and quick feedback, one with a high sound and quick feedback and one with a low sound and slow feedback. Next the participants evaluated four different concepts of unlocking the connector from the EVI: a button on the key, using keyless and touching the door handle or opening a door, a button on the connector or with an app. At last, the participants evaluated five concepts of closing the EVI door: closing manually and then pushing, closing manually without pushing afterwards, sliding and turning a knob, a button on the connector and closing automatically three seconds after pulling out the connector.

6.1.5 **Interaction design**

The gained information from the different user studies and the literature study helped answer the three questions regarding interaction design presented in the theory chapter; who is the user, how is the product used and where is it used? The questions were not answered by participants but by the authors of the report.

6.2 Phase 2 – Results

In this chapter results from the questionnaire, workshop and user tests will be presented as well as the answers on the interaction design questions.

6.2.1 **Questionnaire**

The questionnaire was sent out to 226 Volvo employees who drive a Plug-In Hybrid as a company car. This resulted in 131 responses which is a response rate of 58 %. The participants were asked a series of questions regarding, among others, reasons for acquiring an EV, driving habits and their opinions about the charging cable, charging cable storage and the EVI. The result in the following section is going to be presented both in figures and text and is a compilation of the results from the questionnaire. The complete result can be found in appendix D.

The participants' main reason for acquiring an EV was the preferential price, and 48 % of the participants indicated that the preferential price was a parameter that affected them very much. Other parameters with a high influence were that an EV is environmental friendly and the future of automotive. Some parameters with a lower influence were the low noise level, positive driving experience and good performance.

Driving habits

The majority of the participants, 70%, own an additional car in addition to the Plug-In Hybrid. The type of car varies between fossil fuelled, EVs and bi-fuelled. 76 % of the participants use their EV for all kinds of journeys, both daily and on the weekends. A question was asked regarding how far the participants drive each day and 69 % of the participants indicated that they drive 50 km or more on a regular day.

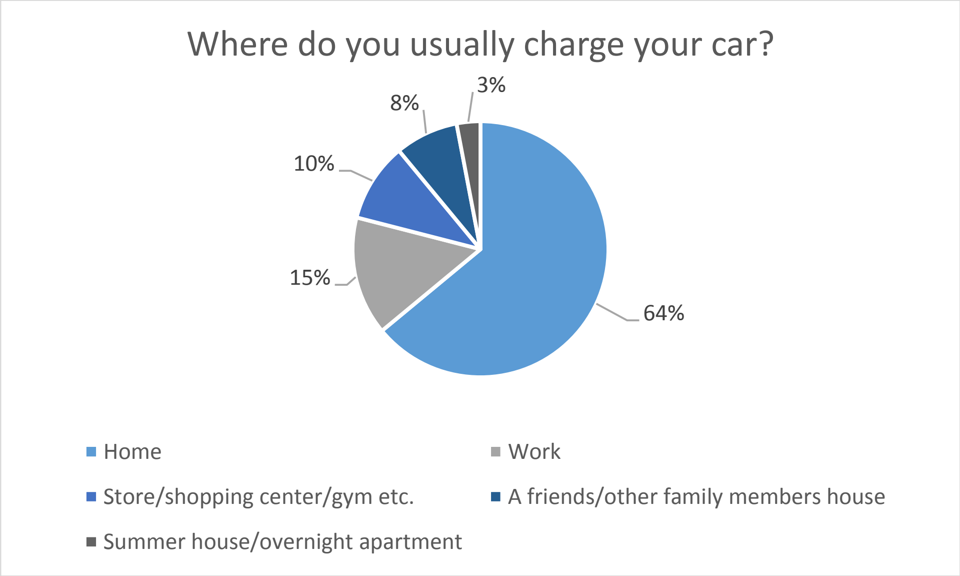

Figure 20: Where do you usually charge your car?

The participants were asked about their charging habits including how often, where and how they charge their EV. 90 % of the participants charge their EV at least once a day and this is mostly done at home, which can be seen in Figure 20. Other common places to charge is at work and at the store/shopping centre/gym. When charging at home 92 % of the participants use the charging cable that came with the EV. After the charging is completed 60 % plug it out and store it inside the EV, whereas 32 % leave the charging cable plugged into the household socket. Only 1 % of the participants have installed a wallbox at home. The 32 % that leave the charging cable plugged in may, however, also be seen as using a wallbox since it can be compared to a fixed charging cable.

Cable storage

A majority of the participants indicated that there is no dedicated place to store the charging cable in their EV. This is not correct since there is dedicated charging cable storage under the load floor in the trunk of the specific PHEV used by the participants. When asked where they store their charging cable inside their EV the answers were over the load floor in the trunk (56 %), does not store the charging cable in their EV (31 %) and in another place in the car for instance on the floor behind the driver's seat (13 %). Among the 33 % who stated that there is dedicated cable storage, 56 % does not store it in that dedicated storage due to that they believe it is not easy enough to store it there. Some of the reasons are compiled in Table 13. Instead of storing it in the dedicated storage 62 % store the charging cable over the load floor in the trunk, 21 % in another place in the car while 17 % does not store the charging cable in their EV.

Table 13: Reasons for not storing the charging cable in the dedicated storage.

One cannot access the dedicated cable storage when the trunk is loaded
Too cumbersome, difficult and takes too much time
The storage is small and the charging cable is stiff so it's hard to wind the cable together as tight as needed to fit the storage
It's easier to put the cable on the floor behind the driver's seat or loose over the load floor in the trunk
Does not bring the charging cable in the car

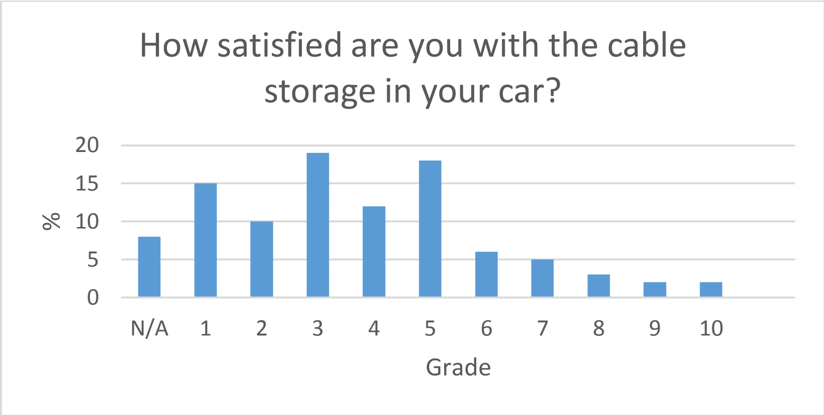

Figure 21: How satisfied are you with the cable storage in your car?

The participants were asked to grade how satisfied they are with the cable storage in their EV, which by looking at the grades in Figure 21 can be interpreted as not so satisfied. Analysing the grades with NPS it is visible that only four percent of the participants are promoters, eight percent are passive and 88 percent are detractors. The NPS for the charging cable storage is -84. The participants were also asked where in the EV they would like to store the charging cable if they could wish. One of the two most popular answers, which were proposed by 34 % of the participants, was to have a core winder, similar the solution as in a vacuum cleaner, where the charging cable is fixed to the EV and extensible. The other answer which was also proposed by 34 % of the participants was to have some dedicated storage over the load floor, for instance in a bag, a box or a net pocket in the side panel. The common factor for the majority of the suggestions was to have storage with easy access and enough space in order to reduce the time and effort it takes to get the cable into the storage.

EVI and feedback

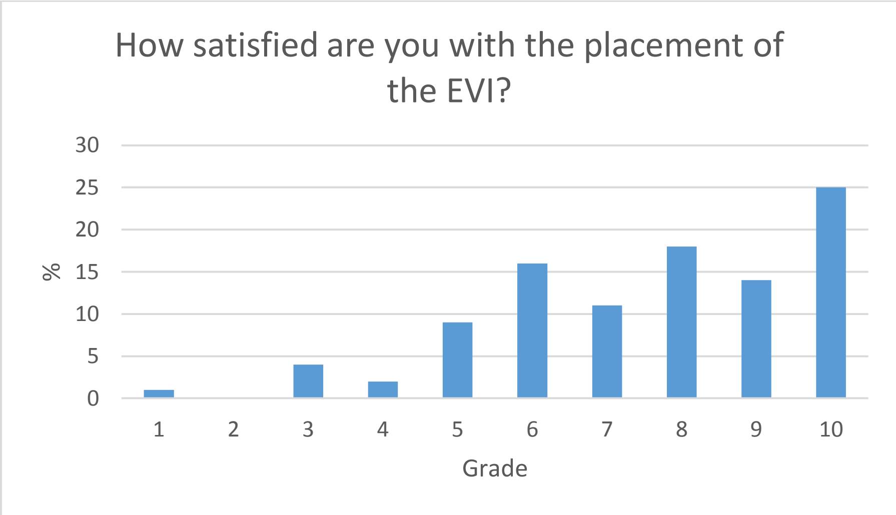

Figure 22: How satisfied are you with the placement of the EVI?

Figure 22 shows how satisfied the participants are with the placement of the EVI. 68 % of the participants have graded seven or higher. In the PHEV driven by the participants of the questionnaire the EVI is situated over the left front wheel. A question was asked about what would be required for a higher grade and the most frequent answer, proposed by 20 % or the participants, was to place the EVI in the front of the vehicle. Other less frequent answers were that the vehicle should have several different EVIs, a core winder or a hidden EVI. The NPS value for the placement of the EVI is seven. It is 39% that are promotors and have graded nine or ten, 29% passives and 32% detractors.

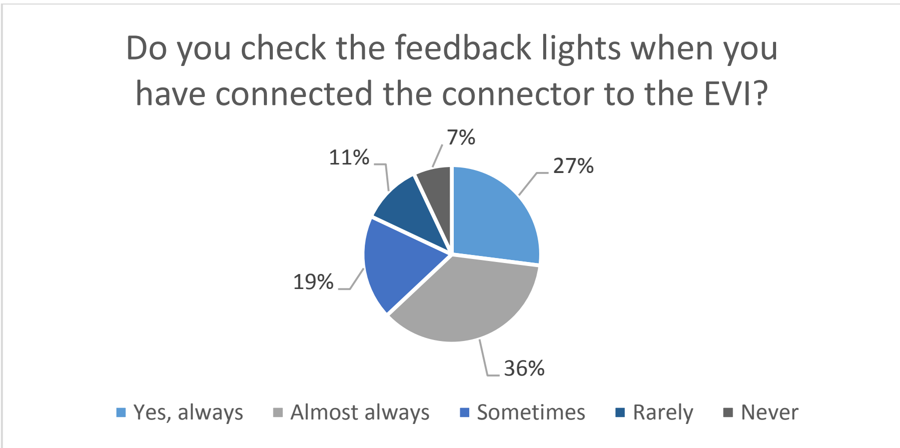

Figure 23: Do you check the feedback lights when you have connected the connector to the EVI?

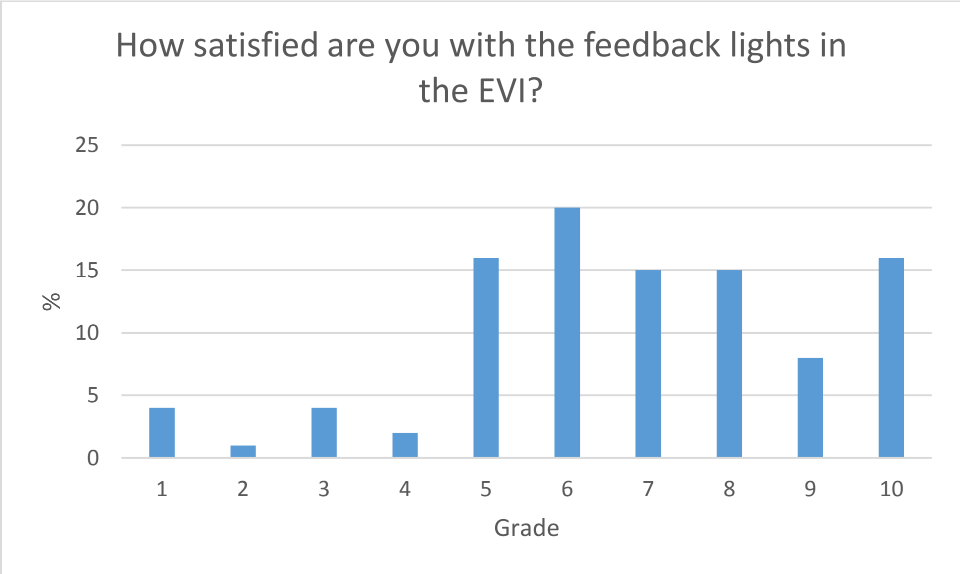

Figure 24: How satisfied are you with the feedback lights in the EVI?

The participants were asked if they check the feedback lights inside the EVI that shows the charging status when they are charging their vehicle. As can be seen in Figure 23, 63 % of the participants check the feedback light every time or almost every time they connect the connector to the EVI. 18 % answered that they rarely or never check the feedback lights, and the reasons for this are among others that they instead control the charging status in the EV's associated mobile application or that they trust that the charging is working without any problems. The participants were then questioned about how satisfied they are with the feedback lights inside the EVI. Observing Figure 24, the participants are satisfied overall and that 54 % of the participants has graded seven or higher. When asked about what would be required for a higher grade regarding the feedback lights, the most frequent answer was to get a better explanation of the different feedback colours and what they mean. Another comment was that one would like a faster feedback, since one does not want to stand next to the EVI and wait for the feedback lights to show the charging status. The NPS value for the feedback lights in the EVI is -22 and there were 24% promoters, 30% are passives and 46% detractors.

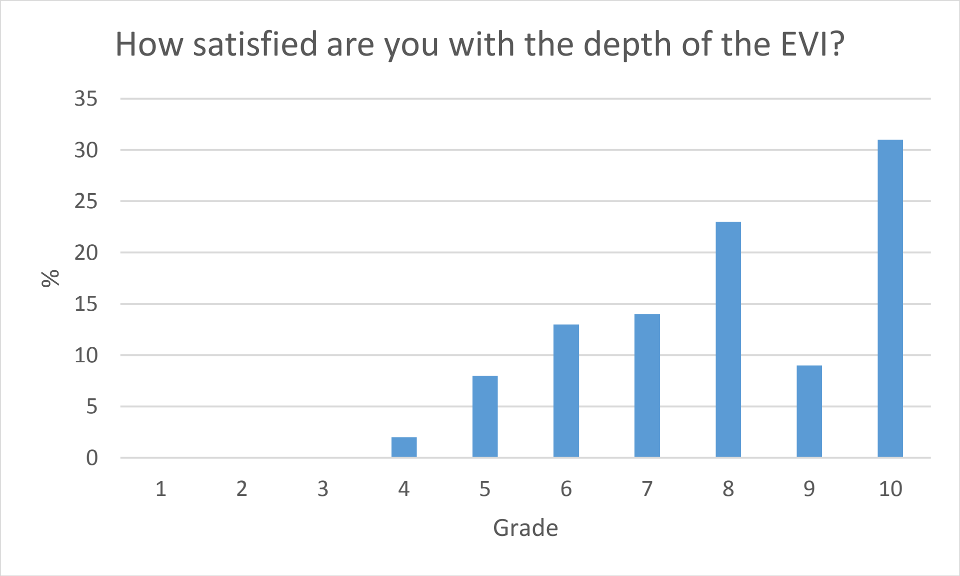

Figure 25: How satisfied are you with the depth of the EVI?

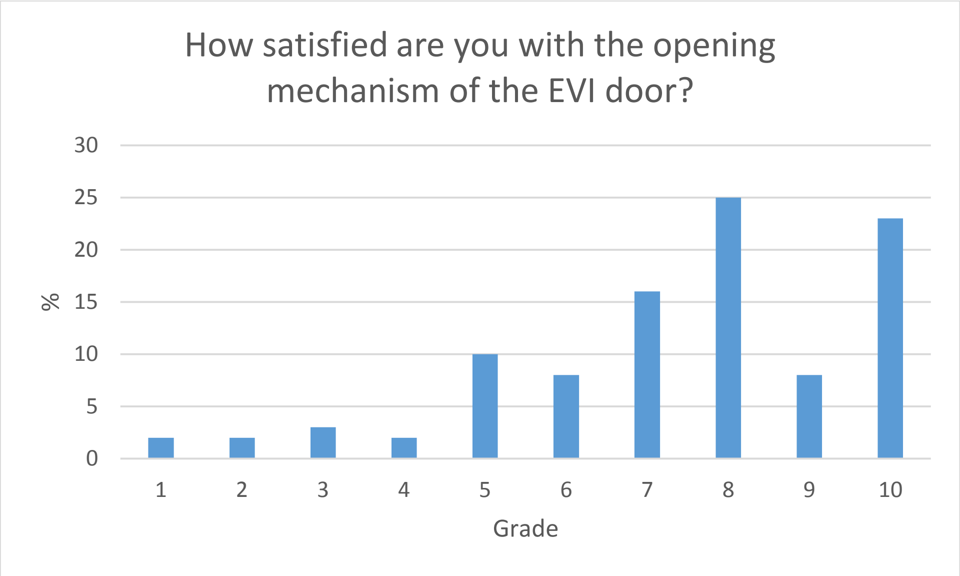

Figure 26: How satisfied are you with the opening mechanism of the EVI door?

The participants were asked about the different parameters regarding the EVI. Figure 25 illustrates the satisfaction of the depth of the EVI. 77 % of the participants have graded 7 or higher which indicates that they are overall satisfied with the depth. The NPS value is 17 where 40 % have graded nine or ten, 37 % seven or eight and 23% one to six. The participants were also asked about how satisfied they are with the opening mechanism of the EVI door. The EVI door in the PHEV driven by the participants of the questionnaire is opened with a push mechanism. It can be read that 72 % of the participants have graded seven or higher, see Figure 26. The NPS value is four with 31% promotors, 41% passives and 27 % detractors. When asked about what would be required for a higher grade the most frequent answer was that the door should be easier to open and close especially when it is cold, be more robust and be opened and closed automatically and electrically.

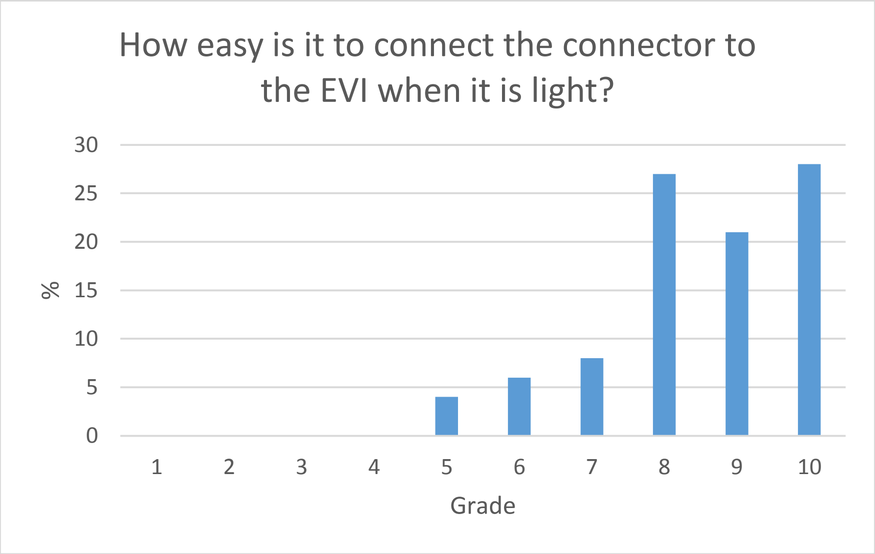

Figure 27: How easy is it to connect the connector to the EVI when it's light?

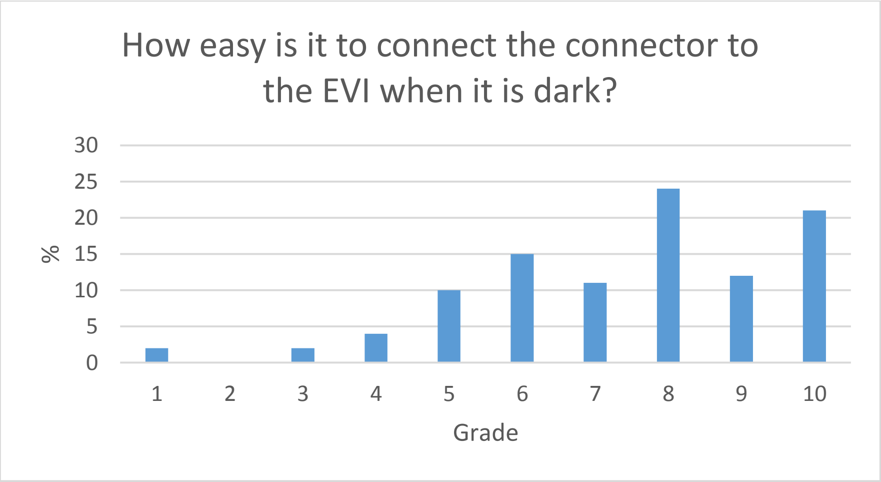

Figure 28: How easy is it to connect the connector to the EVI when it's dark?

Comparing the results in Figure 27 and Figure 28 it can be seen that the participants think it is easier to connect the connector to the EVI when it is light outside compared to when it is dark. Overall the participants think it is easy both when it is light and dark outside. The NPS value for connecting the connector to the EVI when it is light is 41 compared to a NPS value of zero when it is dark outside. In order to give a higher grade when it is light outside the participants would like the extra lid on the EVI to be removed and ensure that it is easy to fit the connector to the inlet. To improve the satisfaction when it is dark they would like better illumination in the EVI and better feedback that the connector is fitted correctly into the EVI.

Overall

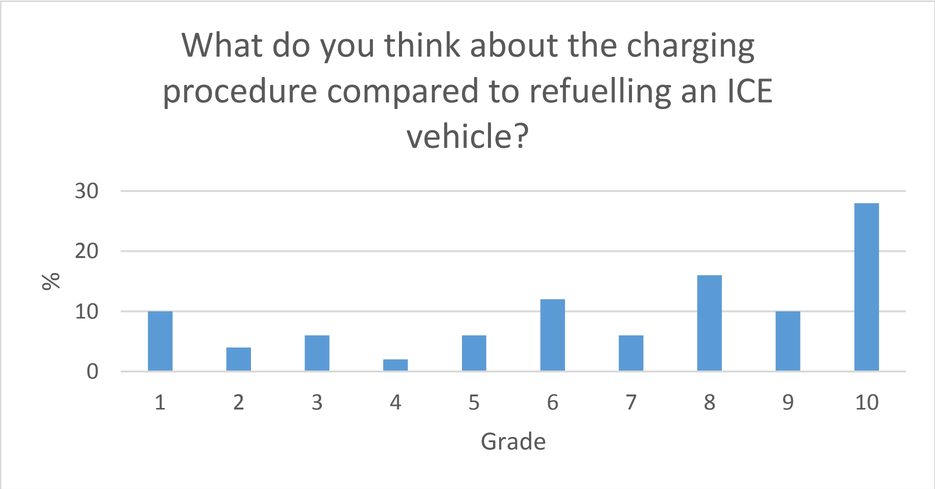

Figure 29: What do you think about the charging procedure compared to refuelling an ICE vehicle?

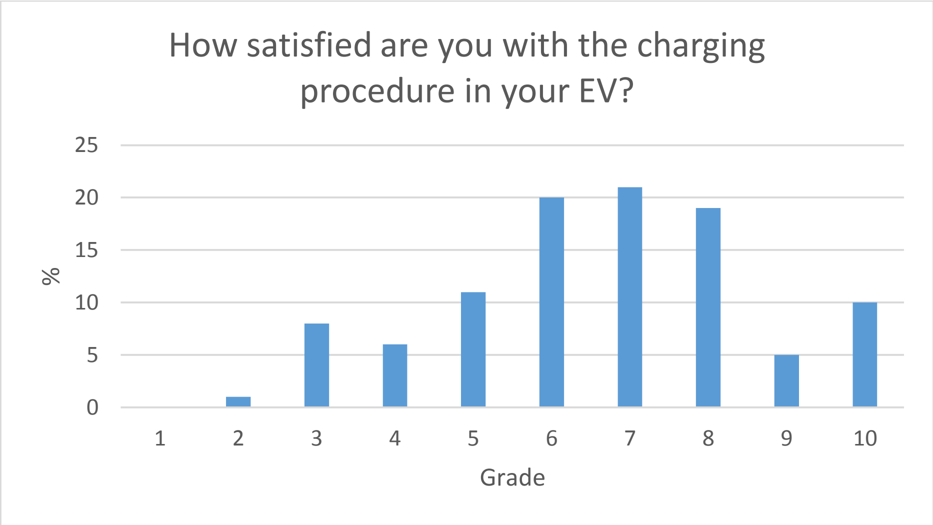

Figure 30: How satisfied are you with charging procedure in your EV?

At last the participants were asked what they think about the charging procedure compared to refuelling an ICE vehicle and how satisfied they are with the charging procedure overall. The question regarding the comparison between the charging procedure and refuelling was sent out later than the rest of the questionnaire and therefore only represents 50 responses. Grade one means that charging is much worse than refuelling, and grade ten means that charging is much better than refuelling. In Figure 29 it can be seen that the opinions vary a bit between the participants, but 72 % thinks that charging is as easy, or easier than refuelling. Regarding the satisfaction with the charging procedure the average grade was six point seven, which can be seen in Figure 30, and 55 % of the participants have graded seven or higher. There are more detractors, 45%, than promotors, 15%, which gives a NPS value of -30. Table 14 shows some comments about what the participants would require to set a higher grade regarding the charging procedure.

Table 14: What would be required for a higher grade regarding the charging procedure overall?

Charging cable
More flexible cable
No control unit
Charging cable storage
Core winder
Not having to handle a dirty cable
EVI
Longer time period before unlocking the vehicle and auto-locking the connector to the EVI
Better opening mechanism of the EVI door
Other
Wireless charging

6.2.2 Workshop

The major conclusions from the workshop are summarized below and the complete result can be found in appendix E.

The worst solution

Characteristics were discussed regarding the charging cable, plug, EVI, feedback and overall charging procedure. In order to be as bad as possible for the user the charging cable should among others be too short/long, easily become entangled, be heavy/clumsy/stiff, stored under the vehicle, separable, static and covered in white fabric. When it comes to the plug one should always need to use an adapter when charging, the plug should be hard to plug into the EVI and have different standards everywhere. The EVI should have a really bad positioning, for instance at the b-pillar doorstep on the right hand side of the vehicle or under the vehicle, it should be hard to open preferably mechanically with a tool or a separate key and the packing should be poor resulting in ice in the EVI during wintertime. There should be bad or no feedback when the user starts the charging and the control unit should communicate in Morse code to make it difficult for the user. In order for the overall charging procedure to be bad the charging should take really long time and be initiated by using a poorly designed app that does the opposite of what the users want.

The ideal solution

Two problems were identified for the user in scenario one, which was that the user does not want to get dirty and lives in an apartment with limited access to a parking space with charging possibilities. The ideal solutions would be to have an EV with a large battery capacity that needs to be charged less often, install a wallbox close to the parking spaces at home and at work, wireless charging to reduce touch points and avoid getting dirty, strategic placement of the EVI to reduce collection of dirt and to make use of some kind of portable charging service vehicles. The realistic solutions that can be implemented today are to optimize the position, visibility and illumination of the EVI, improved battery capacity and develop a suspension device for the cable to avoid touching the ground. The realistic solutions that can be implemented in five to 15 years are wireless charging, to have solar cells on the roof for charging the battery and to use a smart grid that transfers energy between EVs depending on the current battery status.

When focusing on the user in scenario two the participants identified two problems, that the user has a lot of equipment in the trunk which makes it hard to access the charging cable if it is stored under the load floor in the trunk and bad access to fast charging. The ideal solutions would be to have inductive, solar or wind charging, automatic charging stations, not having to bring your own charging cable, transfer energy between EVs, core winder for the charging cable storage, only have DC charging everywhere and to standardize the charging plugs and charging stations. The realistic solutions that could be implemented today are to have a softer charging cable, move the control unit from the cable and into the vehicle and move the EVI to the front of the vehicle. The realistic solutions that could be implemented in the future are automatic, inductive or solar cell charging.

Five problems were acknowledged for the user in scenario 3 which were the limited battery capacity, the need for several different charging stations subscriptions, possible limitation of charging cable variety in each EV, new interface each time and the uncertainty of the presence of fast charging possibilities in each EV. Suggestions of realistic solutions were to improve the battery capacity, develop a drone service that delivers fully charged batteries, charge via solar cells, rain water generators or induction, standardize the EV interface, have self-cleaning paint on the car to avoid getting dirty, include the opening of the EVI in the keyless solution and to implement a “Pony Express” solution where the user can change to a fully charged EV if needed at a specific carpool location. Realistic solutions that can be implemented today were to design the carpool’s booking system so that it always offers fully charged EVs, that the carpool company acquire EVs with only one interface and to remove the control unit from the charging cable and instead adjust the ampere settings on a display inside the EVI door. A realistic solution that could be implemented in five to 15 years is to have one plug standard in Europe for all EVs to eliminate the need of different charging cables and adapters.

6.2.3 **User test - Charging cable handling and storage**

The grading for the average score for each concept can be found in Table 15 and the grading for each participant can be found in appendix F. Most of the concepts were graded quite low and the participants were not so happy about how the charging cable is designed today. The biggest problems according to their comments were the placement of the control unit and were it should be stored when not used.

Table 15: Grades for the different charging cable concepts

Cable stiffness	**Average**
Concept 1: Yellow Mode 3	**6,6**
Concept 2: Red Mode 3	5,1
Wrap the cable together	**Average**
Touch fasteners mode 2	**5,3**
Portable "Wallbox"	4,2
Control Unit	**Average**
Control unit middle of cable	5,1
Control unit on schuko	5,1
No control unit	**6,2**

Connector release	Average
Type 1 connector with button	5,7
Type 2 connector without button	6,2
Type 2 connector with a touch button	**7,8**
Cable handling	**Average**
Yellow mode 2/3	5,9
Coiled cable	**6,5**
Cable storage	**Average**
Yellow mode 2/3	5,6
Coiled cable	**6,8**

The participants answered the question about how the ideal charging cable would look like according to them. The answers can be seen in Table 16 and one participant can have said more than one preferable attribute. The number shows how many participants that mentioned the attribute. As seen in Table 16 nine of the 13 participants wished to remove the control unit from the charging cable and that it should be integrated in the EV with a core winder. Eight of the participants also thought that the charging cable should be straight unlike the five that thought that it should be coiled. Some of the participants stated that they would like to get rid of the cable and suggested wireless charging as an alternative.

Table 16: How the ideal charging cable would look like

How the ideal charging cable would look like	Quantity
No control unit	9
Core winder	9
Straight cable	8
Coiled cable	5
Touch button on connector	4
Adjust ampere settings inside EVI	2
The car adjusts the ampere settings automatically	2

The grades regarding the placement of the control unit show that the concept with no control unit got the highest grade. But when looking at specific grades and comments there are some negative answers as well. Some participants think that removing the control unit from the cable just results in more places to be in, because then the control functions would be moved to for instance the centre display instead, as seen in Table 17. There were also two participants that came up with a new concept in not having the control unit on the charging cable and instead be able to adjust the ampere settings with an app.

Table 17: Comments regarding the control unit

Comments regarding the control unit	Quantity
If moving the settings inside the vehicle, it would result in more places to be in	5
Rarely adjust the ampere settings, would be nice to have it inside the vehicle	4
Would be nice to be able to adjust with an app	2
Good to get rid of the control unit	2

The participant also graded the different storage concepts and the results are presented below in Table 18. The best concept according to the participants both for an unloaded and a loaded trunk was to have a net pocket in the side panel.

Table 18: Grades for the different storage concepts for both unloaded and loaded trunk

Storage unloaded trunk	Average
Lose	4,4
Container with a hook	5,4
Soft weekend bag	5,1
Small hard bag	5,0
Net on side	**5,9**
Plastic box	4,4
Under load floor with net	4,8
Under load floor without net	4,4
Storage loaded trunk	**Average**
Lose	3,5

Container with a hook	5,5
Soft weekend bag	5,2
Small hard bag	5,6
Net on side	**5,8**
Plastic box	3,8
Under load floor with net	4,0
Under load floor without net	3,6

The participants described how the ideal charging cable storage would look like and the answers can be seen in Table 19. Many of the participants did also mention that they would like to have inductive charging and that this would solve the storage problem.

Table 19: Comments on how the ideal cable storage would look like

How would the ideal cable storage look like?	Quantity
Integrated, core winder	4
Net	4
Like today, loose in the trunk	2
In the side panel in the trunk	2
Good with a bag for dirty/wet	2

6.2.4 **User test - EVI placement and feedback**

The average grades for the different EVI and feedback concepts can be found in Table 20. The participants' individual grades can be found in appendix F. The best way to open the EVI door is according to the participants with a push solution and to close they prefer an automatic solution that closes the EVI door three seconds after pulling out the connector. To unlock the connector from the EVI most of the participants would like to have a button on the connector that shuts the current and makes it able to pull out the connector. This concept works when the car key is present in the area. The best light feedback concepts according to the participant are either a big light beside the EVI or a LED light in the windshield. A "click" sound after approximately two seconds is the best sound feedback. However, many of the participants mentioned that they never listen to the sound when plugging in the connector in their everyday life.

Table 20: Grades of different EVI and feedback concepts

Opening EVI door	**Average**
Concept 1: With a button inside the vehicle	4,2
Concept 2: With push	**8,2**
Concept 3: With key	4,9
Concept 4: With connector	7,6
Concept 5: With touch button	3,6
Concept 6: Turn and slide	4,4
Feedback in form of lights	**Average**
Concept 1: One big light beside the EVI	**6,9**
Concept 2: Three lights on the side of the EVI	6,7
Concept 3: Light inside the EVI	5,1
Concept 4: LED windshield	**6,9**
Feedback in form of sounds	**Average**
Concept 1: A "buzz" after 5 sec	5,0
Concept 2: Click sound after 2 sec	**5,2**
Concept 3: A direct low "buzz"	**5,2**

Unlocking the connector	Average
Concept 1: With the key	6,5
Concept 2: Keyless, touch door handle	7,2
Concept 3: Button on connector	**8,2**
Concept 4: With an app	3,1

Closing EVI door	Average
Concept 1: Push	7,3
Concept 2: Electromagnetic	8,5
Concept 3: Slide and turn	2,5
Concept 4: Connector	7,2
Concept 5: Automatic, 3s after pulling out	**8,8**

The participants answered a question about where they would prefer the EVI to be placed on their EV and the answers differed a lot. The most common answer was though at the front of the vehicle, either left/right hand side over the wheels or at the grille which ten participants answered. It was only two participants that would prefer to have the EVI placed in the back of the car but one of them answered that it could be placed in the front as long as it is on the left side. One of the participants said that it is a habit and that anything would do.

6.2.5 **Interaction design**

The three questions that are important to answer when designing and evaluating an interactive product are who the user is, how the product is used and where the product is used. The answers to these questions are a generalised compilation of the collected data from the literature study, user tests and questionnaire.

Who is the user?

Today’s EV users are innovators or early adopters and have a larger technological interest than an ordinary vehicle user. It is quite costly to buy an EV today which limits the amount of persons that have the ability to buy an EV. On the other hand an EV is cheap to drive and can be a better alternative economically if leasing a vehicle. Today’s EV users need to accept that having an EV comes with more procedures than an ICE vehicle, for example handling a charging cable and finding a parking space with charging possibilities.

Tomorrow's EV users should not differ from ordinary vehicle users. There should be as little difference between an EV user and an ICE vehicle user as between a diesel vehicle user and a petrol vehicle user.

How is the product used?

The use of EVs differs depending on the EV type. To generalise PHEV users use their vehicle for all kinds of journeys. They are not dependent on the battery range when deciding a destination since they can rely on the ICE if the battery runs out. BEV users on the other hand are more dependent on the charging infrastructures especially when traveling a further distance.

EV users have a higher interaction frequency with the vehicle during the charging procedure compared to refuelling an ICE vehicle. An ICE vehicle is fuelled approximately two times a month whereas for instance a PHEV is charged up to two times a day, that is 60 times a month. It is not only the frequency of the interaction that is higher for EV users but also the interaction itself. The flow around the EV during the charging procedure includes among others getting the charging cable from the storage, plugging in the cable to the charging station and EVI and checking the feedback.

Tomorrow's EV users should not need to choose their destination any differently compared to a user which is driving an ICE vehicle. The interaction itself and the frequency of the interaction should also be lower in order to attract a wider range of users.

Where is the product used?

Charging an EV can be done either via a charging station, a household socket or an industry socket. These can be found in parking lots close to stores, at work or at home. The most common way for users to charge their EV is at home through a household socket. This requires the users to have a private parking space with access to electricity and most EV users therefore live in houses with a garage, carport or private parking space. Charging EVs can be done anywhere and is only depending on the infrastructure and availability of both slow and fast charging stations.

6.3 Phase 2 – Discussion

The second phase included a questionnaire, user tests and a workshop with the aim of evaluating the effect that the previously identified parameters have on the user experience.

6.3.1 **Questionnaire**

The questionnaire was sent to 226 PHEV drivers and had a response rate of 58%, 131 responses, which is a great rate. The amount of responses gave us reliable data and made us comfortable drawing conclusions about how some parameters should be designed according to today's users. But even though some parameters have a strong result, others do not and more evaluations need to be done in order to gain more knowledge about what the users prefer. The 131 participants that answered the questionnaire all work at Volvo Cars and drives a PHEV as a company car. It was for this reason important for the participants to set their professional opinions aside and answer the questionnaire as an EV user. This was something that was stated clearly not only in the questionnaire, but on all occasions when the participants expressed their opinions. In all our tests the participants have been mostly PHEV drivers and not so many BEV drivers. This is because the employees at Volvo that have been participating in the tests drive PHEVs and not BEVs. Our opinion is that the hybrid owners might be the critical users since they have to charge the EV more often than the BEV owners. Hopefully the needs of the BEV users will be captured as well if the charging procedure is improved for the PHEV users.

6.3.2 **User tests**

The questionnaire was followed by user tests that focused on the charging cable and the storage of it as well as the design of the EVI and different feedback solutions.

The purpose of the tests were to let the participants grade different concepts which demanded physical interaction and real user tests were the best way to do it. After analysing the answers from the questionnaire it was concluded that some of the parameters could be excluded from further user tests. For some parameters it was decided that the data was enough in order to draw conclusions for recommendations and user scenarios. Other parameters that were thought to be critical actually turned out to be not so critical and were for that reason excluded. One example of a parameter that was decided to let be was the depth of the EVI since the responders did not experience a trouble with it. The responses that pointed at different opinions or were graded very low by many participants were decided to be evaluated further during the user tests. One source of error in the last user test regarding the EVI and feedback was that one of the EVs that had many of the tested concepts was broken and not present during five of the 14 tests. The participants that performed the test without that EV had to imagine the concepts after an explanation and in some cases, they got to view a video showing the concepts.

Another source of error could have been how the participants interpreted and used the scale from one to ten. Some of them graded some concepts with the highest grade possible, ten, but others did just use the eight fist grades in the scale. Is this because they reserved score ten to a concept not out on the market yet, for example inductive charging, or did they just think that the presented concepts were not good enough for a higher score? Another difference seen in the participants' results is that some have used the two lowest scores with the comment that they never would use the concepts and other have graded concepts they would not use with a higher score. This might have affected the average score and for the best result the information about how they should grade the concepts could have been clearer. The best would have been if all participants graded with regard to their own opinion about if they would use the concepts or not.

With help of the questionnaire and the user tests the things that were already known were verified and a few new opinions were found regarding the user experience during the charging procedure. When it comes to the answers to the questions regarding how to design an interactive product, the answers are quite generalised. Generalisations were done in order to briefly and concisely describe who the user is, how the product is used and where the product is used. The more detailed and broader answers are instead going to be represented in the uses cases.

6.3.3 **Workshop**

The workshop was really successful, the participants were very engaged and happy to help us, and they had many ideas based on their experiences with EVs. The result from the bad solution can in most cases be translated to the opposite and help us formulate guidelines. One part of the workshop was the ideal solution where the participants got to identify possible problems and solutions for three different scenarios. The scenarios were based on the collected user habits from the previous tests and covered three common and interesting scenarios. Besides the advantage of generating different solutions the scenarios were also a good way to help the participants to generate ideas. The scenarios did also verify everything that was identified during earlier tests, benchmarks and the questionnaire. Some of the most common solutions were as few touchpoints as possible, consistency and inductive charging. It felt like all participants really believed in the inductive charging solution. The ideal solution exercise also resulted in some new solutions, like the concept "The Pony Express" for carpool users. Instead of stopping to charge your borrowed EV you can change it to a fully charged one. This together with the solution about a consistent interface were really good inputs for the car sharing scenario. Since this project also focuses on the future of charging these solutions were really helpful. Other more futuristic but yet realistic solutions were smart communicative grids and the core winder that really would help to improve the user experience.

6.3.4 **Parameters**

As mentioned earlier, when designing a product or a system it is important that the user's mental model match with the designer's mental model. All EV users have most likely refuelled an ICE vehicle at some point. The mental model of how to refuel a vehicle is something that the user translates to an EV when charging its battery. If the reality does not match with the expectation, the user might feel frustrated or confused. Since there are several more steps included when charging an EV compared to refuelling an ICE vehicle it is important to facilitate as much as possible for the user during the charging procedure. An example is that an EV user has to store the charging cable in the vehicle and take it out to be able to charge the EV. ICE vehicle users do not bring a hose to the gas station when refuelling, which creates a mismatch in the mental model. This was something that a lot of participants commented on both in the questionnaire and during the user tests, the problem of having the need to go through an extra step. It is therefore no wonder that when the participants were asked about the ideal charging cable storage they answered that they want a solution that is integrated in the vehicle, with a core winder.

Charging cable storage

Another important issue is the visibility of the charging cable storage in the specific vehicle that was evaluated in the questionnaire. 67 % of the participants stated that there is no dedicated charging cable storage in their vehicle, when there actually is one. It is obviously not clear enough that the storage under the load floor is meant for the charging cable. When analysing the answers from the questionnaire and the user test it is clear that the participants are overall dissatisfied with the charging cable storage in their vehicle. The different storage concepts were graded very low in the user test, none with an average grade over six on a scale from one to ten, and none of the storage solutions satisfied the participants fully. This is therefore something that needs to be investigated further. We think this is reason enough to consider the charging cable storage as one of the critical parameters affecting the user experience. Solutions that might increase the satisfaction is to not have a charging cable to store but instead have wireless charging or a core winder. The grades from the charging cable storage concepts were also analysed using Net promoter Score, NPS. This confirmed the dissatisfaction of the participants since only four percent of the participants are promoters, eight percent are passive and 88 percent are detractors. We are well aware of that the NPS is traditionally a way to calculate customer experience based on the question "How likely are you to recommend our product / service to a friend or colleague?" and that is not the question the participants got. But still, the questions regarding how satisfied the drivers are to different parameters were answered at a scale from one to ten which means that the NPS could be an interesting way to illustrate the satisfaction.

EVI

The consistency is really important to consider when designing a product and is something that affects the user experience. This could be if the opening mechanisms of the charge door and the fuel tank door differ from each other. One example is when the charge door is opened by pushing and the fuel tank door is opened by a button in the instrument panel. How does the user know which door is opened which way? Should the user need to think about this? The answer is clearly no on the second question. The design should be consistent to enhance the user experience.

One problem that arose during the EVI user test was regarding the affordance of the charge door. A common opening mechanism both for charge doors and fuel tank doors are by pushing on it. When pushing it is important to push on the right spot, otherwise the door does not open. A problem that arose for some participants in the user test was that they did not manage to open the door when pushing, even if they pushed on the right spot. They then tried to push on another spot and still failed to open it. Here is when the users got confused. Is it not supposed to be opened by pushing? It is clearly not obvious where on the door one should push in order to open it. If one fails to open the door it is reasonable to try pushing on another place. As for all products if there is an error done by the user it is never the user's fault, it is a problem with the design. This might not be a big problem when the user is interacting with a familiar vehicle but the problem might arise for users driving EVs from carpools.

A variation in the results was noticed when evaluating the placement of the EVI. It turned out that the preferred placement is depending on the individual and the situation. Some users prefer to reverse in when parking their vehicle and some prefer to park with the front in, and the charging stations are also situated in different places. To generalise most participants prefer to park with the front in and most charging stations are situated in front of the parking space. This means that the placement of the EVI preferably should be situated in front of the vehicle or over the left front wheel.

Feedback

The charging feedback light was something that was evaluated during one of the user tests. As mentioned earlier, the goal with using feedback is to help the user understand that a control has been used and to determine the new state. When charging an EV it is important that the user receives information about the status of the charging procedure. The charging status is presented inside the vehicle in the combi instrument, the screen behind the steering wheel, and in lights situated close to the EVI. Different concepts of EVI light feedback were evaluated during one of the user tests and several important aspects were noticed by the participants. It is important that the feedback is clear so that the charging status is easy to interpret and that the feedback comes immediately after the control is used. It has to be obvious for the user what the different colours of the feedback light mean, for example the light should be yellow when waiting to start charging, green when the EV is charging and red when there is a problem. It is also important that the feedback comes immediately since the users may want to move on to other activities after starting the charging procedure. The importance of the feedback light was something that also was noticed by the participants in the questionnaire who drive vehicles where the EVI feedback lights are blue instead of green when charging. Several participants reacted to this and want the meaning of the feedback colours to be clearer.

Another aspect of the charging feedback light is the importance of the placement and visibility of the light which can also be connected to the cognitive aspect called mapping. Mapping describes the importance of having the feedback close to the control that is used in order for the user to understand what the feedback represents. As a solution to the issue regarding the slow feedback discussed above, some participants stated that they would prefer the feedback to be visible when standing at another place near the vehicle. One example could be to place a LED light in the instrument panel or close to the trunk to enable the user to check the feedback without needing to stand close to the EVI. Though this solution might interfere with the cognitive aspect of mapping since the feedback light then is situated far away from the control that is used. Another problem that was observed was the bad visibility of the EVI feedback light in the concept where the light was situated at the upper bottom of the EVI. On one hand many of the participants thought the concept had good mapping but on the other hand they had to lean forward to be able to see the feedback light. This shows that there are several different aspects to consider when designing a solution.

In addition to the feedback light different concepts of sound feedback were also evaluated. The concepts evaluated in the EVI user tests contained sound feedback in terms of locking the connector to the EVI. These sounds are not designed to be used as sound feedback, but we wanted to investigate if this might be something that the participants take into account when charging their EV. It turned out that few participants listen to the locking sound to control that the charging has started, but that they do not mind that there is a feedback sound. If it still has to be some kind of feedback sound it should be clear and immediate just like the feedback light.

Charging cable

The cognitive aspect mapping can also be connected to where the control unit and its functions should be situated. Today most control units are situated on the charging cable approximately 30-100 cm away from the wall plug part of the cable. Many of the participants in the questionnaire complained about the control unit and wanted it to be removed from the charging cable. This was therefore something that was investigated further in a user test. The hypothesis when starting the user test was that the users would like the functions of the control unit to be removed from the charging cable and placed in the centre screen inside the vehicle instead. This was not totally the case. The participants that often charge at new places and therefore often have to check the capacity of the socket outlet and adjust the ampere settings, prefer to have the control unit on the charging cable. The ampere settings can be changed when standing beside the socket outlet and controlling the ampere limitations of the outlet. If the ampere settings instead were to be adjusted inside the vehicle, the user has to go back to the vehicle and sit down in the driver's seat in order to change the ampere settings. This creates an extra step for the user and deteriorates the user flow. The participants that charge at the same place almost every day and rarely adjust the ampere settings prefer to remove the control unit from the charging cable. Options suggested by these participants were to add the possibility of adjusting the ampere settings in the associated mobile application, or to adjust it on the centre screen inside the vehicle.

One of the expectations when performing the user tests was to find out how the charging cable should be designed in order to satisfy the users. The answers varied overall between the participants and the conclusions that are drawn about the design come from the concepts that got the highest grades. Even though these concepts were the best ones in the user test, it does not mean that they are good concepts. None of the concepts had an average grade above six on a scale from one to ten. The parameter could be investigated further in order to find a design that is preferred by more users. Though the problem can be more about having a charging cable at all and not the design of it as discussed earlier.

6.3.5 **Wireless charging**

The inductive charging concept has been a regular problem solver for many dilemmas according to our different users. With this concept they will not have to handle or store the cable, nor have to plug in the cable and the flow will be better. The whole physical user experience would probably be better. Today's users are not satisfied with the handling and storage of the charging cable but it was also seen that they are not willing to buy a wallbox which should solve some of their daily strugglers. Only one of 131 users that answered the questionnaire had a wallbox, and if they not are willing to buy something that today can help them, will they be willing to buy something even more expensive? Hopefully when the technology is more mature and the prices have decreased this concept will appeal to today’s users. A reason that might affect the participants’ interest of buying a wallbox is that they all drive a PHEV as a company car. The length of the contracts for the company cars vary between one to two years which might not be enough time to be willing to invest in expensive charging equipment. When looking at the future user’s we think that they might buy an inductive charger, mostly because they will not accept handling the cable even if it is still the most common way to charge the EV.

Due to the lack of inductive concepts that have been able to be tested the feedback for wireless charging has not been evaluated with different concepts as done with the feedback for wired charging. But in accordance with previously discussed interaction design factors and what the users expect from a charging system we will try to formulate different concepts regarding how the feedback might look like. As well as the feedback for wired charging it should be direct and according to mapping the feedback should be perceived were the driver is located when the charging begins. If the charging starts immediately after docking the feedback should be perceived from inside the vehicle. But if it is possible to start charging the vehicle when not sitting in it the feedback should also be perceived from outside the vehicle. Some examples to start the charging from outside can in accordance with previously evaluated concepts from the user test be when the vehicle is locked, with the key or with an application. The feedback should be in form of both light and sound in accordance to previous findings. Depending on if the inductive charging will work with a smart grid, where the users do not have to adjust the ampere settings by themselves, or not it might be required to manually adjust it. This can then be done from inside the vehicle and with a mobile application. Due to the user flow the best concept would be to have it inside the vehicle in accordance with mapping. Ending the charging might be done when unlocking the vehicle or with an application.

6.4 Phase 2 – Conclusions

The goals with phase 2 were to evaluate different characteristics for the identified parameters and to conclude which of the parameters are critical for the user experience. The characteristics are included in the concepts presented below. The characteristics presented are from the concepts that got the highest grades in each user test. In the final results it will be evaluated if the result from this phase regarding the characteristics has credibility enough in order to formulate recommendations on how to design the parameters.

6.4.1 **Wired charging**

Placement and design of EVI

The placement of the EVI is overall depending on the individual and the situation. According to the EVI user test the most preferred placement of the EVI is over the left front wheel. This is also visible in the results from the questionnaire where the participants are overall satisfied with the current placement of the EVI, which is situated over the left front wheel.

According to the EVI user test the EVI door should preferably be opened with a push solution and closed with an automatic solution that closes the EVI door three seconds after pulling out the connector.

The connector should be unlocked from the EVI by using a button on the connector, along with a keyless solution, that shuts the current and makes it possible to pull out the connector.

Storage charging cable

According to both the questionnaire and the user test evaluating the charging cable and storage, the ideal storage solution is a core winder where the cable is fixed and integrated in the EV. The best storage concept evaluated in the user test was to have a net in the side panel in the trunk.

Feedback charging

The best feedback light concepts according to the participant in the EVI user test are either a big light beside the EVI or a LED light in the windshield. A “click” sound after a maximum of two seconds is the best feedback sound.

Charging cable

According to the user test evaluating the charging cable and storage the charging cable should be as stiff as it is today and be wrapped together using touch fasteners. The control unit is preferably removed from the charging cable and the ampere settings are instead adjusted inside the vehicle. To ease the handling and storage of the charging cable it should be a coiled cable.

6.4.2 **Wireless charging**

Feedback

As well as the feedback for wired charging it should be direct and according to mapping the feedback should be perceived were the driver is located when the charging begins. If the charging starts immediately after docking the feedback should be perceived from inside the vehicle and if the charging starts when not sitting inside the vehicle the feedback should be perceived from outside the vehicle. The feedback should be in form of both light and sound in accordance to previous findings.

7 Final results – Recommendations, user scenarios and evaluation method

In this chapter recommendations, user scenarios and a designed evaluation method based on the results from previous phases are presented. The recommendations can be used as guidelines when designing the critical parameters and are also described in the user scenarios. The evaluation method aims to evaluate the user experience during the charging procedure of EVs and was based on the identified critical parameters.

7.1 Recommendations

Based on the conclusion in phase 2 recommendations for how to design the critical parameters were formed. The recommendations for wired and wireless charging can be seen in Table 21.

Table 21: Recommendations for how to design the critical parameters.

Wired charging	
Parameter	**Recommendation**
Placement and design of EVI	
Placement EVI	Over the left front wheel or in front of the vehicle
Opening mechanism EVI	Push solution
Closing mechanism EVI	Automatically after pulling out the connector
Unlock connector	Button on connector together with a keyless solution
Storage charging cable	Integrated solution or net in the side panel in the trunk
Feedback charging	Both light and sound

Placement	Close to the EVI and additional feedback visible standing further away from the EVI
Colours	Yellow, green and red lights. Clear and strong lights.
Response time	Immediate after plugging in the connector
Sound	A “click” sound immediate after plugging in the connector
Charging cable	
Stiffness	Easy to handle and wrap together in order to fit in storage
Control unit	No control unit on the cable
Cable type	Coiled
Wireless charging	
Feedback	Both light and sound
Placement	Located close to where the driver is located when the charging begins
Response time	Immediate after the charging is started

7.2 User scenarios

The user scenarios were formed based on the information regarding today's users collected from the literature studies and user tests. The user scenarios cover different users, parameters and habits. The words and phrases in bold type in the scenarios highlight the characteristics affecting the user experience during the charging procedure.

7.2.1 **Scenario 1 – Family father**

Figure 31: Hans' family [44]

Hans, see Figure 31, is driving a PHEV as a company car. He chose to have a **PHEV** thanks to the **good benefit value** and to **decrease the diesel consumption**. The vehicle has a **range of 60** km in pure electric drive. Hans is this morning packing the kids' school bags and his computer bag into the trunk. He checks the charging status by looking at the **led-light in the windshield** that **shines steady green** which indicates that the vehicle is **fully charged**. His child Sara, who is 10 years old, steps out of their townhouse and **unplugs the charging plug** from the household socket. The **integrated coiled cable** easily fits in the designed area at the front of the vehicle and Sara has no problem putting it back there. She closes the port protecting the cable with **an easy touch and it closes itself**. Sara's two year younger brother, David, and mother, Livia, have now stepped into the car and the whole family drives to the morning's first destination, the nearby school. After leaving the children at school Hans and Livia drive to their common workplace which is situated 40 km away from the school. At work they have the ability to charge their EV and since they prefer to use the ICE as little as possible in their daily driving, they **always charge at work**. Livia opens the port to the integrated cable by **pushing it** and thanks to that the **cable is coiled it never touches the dirty floor** in the parking house when she connects it to the socket. She looks at the **feedback light**, located in the **same area as the cable storage**, which directly after she has plugged in the cable is **flashing slowly in green and a "click" is sounding, which indicates that the vehicle is now charging**.

Later that afternoon Hans in normal order unplugs the fully charged vehicle, which **the well visible feedback light** indicates by now **constantly shining in green**, and drives with Livia to the school to pick up the kids. Back home they charge the PHEV while getting ready for tonight's activities. David is going to a friend's house, Sara is having a soccer practice and Hans and Livia is going to the supermarket. After leaving the children they drive the short trip to the supermarket. Livia looks at the **centre stack** and sees that they still have a range of 50 km left so they park in an ordinary parking lot. When finishing the grocery shopping they pack the many bags into the trunk. Hans is so happy that he has an **integrated cable** that **does not need to be stored in the trunk** as in his last PHEV. After picking up the children they drive home and connect the vehicle so they can drive on the electric engine tomorrow as well.

Later that evening Hans is starting the washing machine and is not even giving a thought about if the **ampere adjustment** from the socket is right. The vehicle does by **itself regulate the ampere** and Hans **does not need to worry** about that a fuse might blow up.

7.2.2 **Scenario 2 – Friend of the environment**

Figure 32: Mary [45]

Mary, see Figure 32, is a young woman that has a **big interest in the environment**. She is the member of a **carpool** that only offers BEVs. On weekdays Mary always travels with public transportation, but on weekends she uses a car from the carpool in order to **travel longer distances**. This Saturday she is going windsurfing with a friend 200 km down the coast and therefore needs to use a car from the carpool.

A carpool park is located in Mary's neighbourhood and she **checks in her app** if there are any cars available that **are fully charged**. She chooses a BEV that is available with **300 km battery range** and walks to the car park to get the car. Mary has driven a lot of BEVs before so even though this specific BEV is new for her she feels comfortable using it. When she gets home she grabs her windsurfing equipment including a wetsuit, surfboard and sail and loads it into the trunk of the car. On the way to the surf destination she is picking up her friend Tom. Mary enters both the final destination and Tom's address into the cars navigation system. It **suggests the best route based on available charging stations** in order to get battery range enough to go to these destinations and home again, which includes a stop along the way since there are no charging possibilities at the surf destination. After picking Tom up, which is 50 km from the final destination, they drive to a resting stop with a **fast charging station** and a restaurant. Since Mary has not driven this BEV before she is unsure where the EVI is placed. By navigating to the **charging page in the centre display** she can read about the charging characteristics of the car. It shows that the car is charged using a **type 2 plug, the EVI is placed over the left front wheel, the cable storage is under the**

load floor in the trunk and that fast charging is possible. They park with the **front in** since the charging station is located in front of the parking space. Mary gets out of the car, approaches the charging station and takes the charging cable suited for her car. With the **connector in one hand** she **easily pushes the EVI door** and connects the connector into the EVI. The **feedback light**, which is formed as a **circle around the EVI**, lights up first in **yellow to confirm that the connector is plugged** in and then in **pulsating green when the charging has started**. No further interaction is needed with the charging stations since it **recognises the car's ID and automatically sends an invoice to the carpool company**. Meanwhile the car is charging they buy coffee at the nearby restaurant and Mary gets a **notification in the carpool app** as soon as the **charging is finished**. Since the car uses **a keyless** solution the connector is unlocked using the **button on the connector if the key is close**. Mary unplugs the car, closes the **EVI door with a push**, docks the cable into the charging station and they can finally continue to the surf destination.

After spending a couple of hours at the surf place it is time to go back home, not home to Mary but to Tom. There is a household socket next to the parking space at Tom's house. According to the car's **navigation system** there is range left for the entire trip but Mary still wants to charge the car since she is staying the night. When arriving to the house they park with the **front in** since the household socket is situated at the front of the parking space. She goes to the **trunk to get the charging cable**, but realises that the trunk is **fully loaded and that the cable is stored under the load floor**. After unloading the car she is happy that the load floor is kept up by **gas struts** so that she **has both hands available** to get the cable. She plugs the cable into the socket outlet and then into the car. It is almost dark outside but thanks to the **good illumination in the EVI** Mary has no problem connecting the cable to the EVI. There **is no control unit on the charging cable so the ampere settings are instead adjusted automatically**. Mary checks the EVI **feedback light** and feels happy about that the charging has started without any problems.

7.2.3 **Scenario 3 – Early adopter with technological interest**

Figure 33: Bo [46]

Bo, see Figure 33, is a middle aged man with a **great interest in technology**. This morning Bo is preparing for his day, he is packing his tennis bag at the same time as he **checks his app** and sees that his PHEV soon is fully charged. After eating breakfast he steps out from his house with his training bag and a bag with presents for his mother in each hand. He walks up to the trunk and with a **light kick with his left foot** the trunk flights open, with the **car key still in his pocket**, thanks to the **keyless solution** his car has. He leaves the bags so he has his hands free and walks to the **nearby EVI** which is situated on the **left hand side** in the **back of the car**. Bo sees that the **feedback light is shining green**, visualizing that the EV is **fully charged**. Since the car still is unlocked he just pulls out the connector and start wrapping it together while going to the **wallbox** located in the back of his carport. On his way over there he sees that the **EVI door is closing itself automatically**. He docks the cable in the wallbox and walks back to the trunk and closes it. In the trunk he has two bags for **his other two charging cables** that he uses when **not charging at home**. The sizes of the bags is so **big** that the **cables is easy to put in it with just one hand** but is **easy to store** together with the other bags **thanks to it softness**. He has one ordinary mode 2 charging cable **with a control unit on it** in one bag and in the other bag he stores his extra bought **mode 3 cable for fast charging station** as the one at the tennis court. The bags are located **on the loading floor** together with his tennis and gift bag and in a **net**

pocket in the side panel he stores his **different adapters**. Bo jumps into the car and drives to the tennis court. Well there he backs into the charging station and picks his **mode 3 cable** from the bag in the trunk and plug it into the charging station. He opens the **EVI by pushing on it** and plugs in the connector in the EVI, where the **feedback light immediately starts pulse in green**.

When he comes out after the tennis game he finds out that it has been raining. The **cable is now wet and a bit dirty** but thanks to the **charging cable bag** the other bags are **protected and separated from the wet cable.** The cable is **soft and flexible** which **facilitates the handling** of it. Bo is now on his way to his mother and father who lives 50 km south from the tennis court for a birthday party. Since his range with a fully charged battery is just **50 km** he feels a bit worried about if he is going to make it there on only the electric engine. After driving a while he gets stuck in a traffic jam which results in that the ICE starts with 6 km left to his parents' house. Bo is feeling a bit sad for this and thinks about how long he should charge the vehicle to make the journey of 35 km home again on the electric drive only. When arriving at his parents' house he collects the ordinary **mode 2 cable from its bag** and plugs it into a household socket. To increase the chance to make it home on electric drive he **adjust the ampere to the highest one** with some **easy presses on the control unit** and then opens the EVI with the **push function** and plugs in the connector. The feedback **light situated inside the EVI is now shining in orange**, showing that a **security check is running**, and after a while it **pulses in green**. Bo takes the bag with presents and walks into the party. After greeting everyone he finds out that his father is using the oven for the birthday cake and that both the dishwasher and the washing machine is running. Bo feels a bit worried about that a fuse might go off and **therefore adjust the ampere to a lower one in his app**. It is better that the party will be successful than me going home on pure electric drive he thinks while hugging his mother.

7.2.4 **Scenario 4 –Status**

Figure 34: Alexandra [47]

Alexandra, see Figure 34, is a business woman that drives a BEV for **environmental and status reasons**. She loves to drive a BEV since it is **quiet, has great performance and a long range of 500 km**. This is her first EV and she has only driven ICE cars before. She has always thought it is a struggle to refuel the car and is therefore happy that she does not have to refuel her new car. Alexandra often wears suits and nice clothes and **does not want to get dirty** when **interacting with the car**. The **physical interaction is almost eliminated** in her BEV since it is charged using **inductive charging** and **solar cells on the roof**. It is **possible to charge the car with a charging cable** but it is only done in special cases when **inductive charging is not possible**. The charging cable is situated **under the load floor in the trunk** and can almost be compared to a **spare wheel since it is rarely used**.

Alexandra lives in an **apartment in the city** and has recently installed an **inductive charging solution in her parking garage**. She has talked to her neighbours that also drive BEVs about **connecting the charging** plates in the garage and fix a **smart grid** like the ones in public parking spaces around the city. An ordinary morning when she is going to work she walks down to the garage and finds her BEV fully charged since it has been charging overnight. This can be seen by looking at the **LED light in the windshield that shines with a constant green light**. She gets into the car and drives off to work. After a full day at work she comes home and drives into the garage. The car notices that an **induction plate is nearby** and the **navigation panel shows a picture of the car in relation to the charging plate**. By using the **navigation panel** as a guide she can **easily park** the car in the right way to enable inductive charging. When the car is located at the right spot the **centre display and combi instrument informs** Alexandra that the parking is complete and that the **charging has started**. The charging **feedback is immediate** and she can turn off and get out of the car without having to wait for the charging to start.

7.3 Evaluation method

The method that was chosen to best suit this evaluation was a way of heuristic evaluation. A list of cognitive design principles evaluated for the charging procedure is described in Table 22. These principles were found in the literature and during the user tests. In addition to these cognitive principles, physical design principles were also evaluated such as effort, weight, stiffness, location and height. The evaluation method will in the future be used by an expert group within ergonomics.

Table 22: Cognitive design principles evaluated for the user experience.

Design principle	**Description**
Visibility	Is the function visible to the user? For instance visibility of the status indicator when standing at different places around the EV
Accessibility	The ability to access for instance the charging cable storage
Reachability	Is the function reachable to the user?
Clearance	Is there enough space to perform the specific task?
Discoverability	What is the control used for?
Flow	The different steps of the charging procedure creates a user flow around the EV
Affordance	How is the control used?
Feedback	Help the user understand that a control has been used and to determine the new state
Flexibility	Amount of possible ways to do an operation

Based on the HTA made in phase 1 the design principles described above were connected to each task in the charging procedure. The tasks for start and stop charging an EV and the related design principles can be seen in Table 23 and Table 24.

Table 23: Design principles for start charging an EV.

Operation	**Design principles**
0. Start charging EV	
1. Connect to grid	
1.1 Get cable	
1.1.1 Access charging cable storage	Accessibility, visibility, reachability, number of operations, effort and location compared to EVI (flow). If in trunk, take loaded and unloaded trunk into account.
1.2 Plug in cable to socket	
1.2.1 Adjust ampere settings	Location compared to socket (flow), effort, affordance and understanding of feedback.
1.3 Control power supply	
2. Connect to car	
2.1 Open EVI door	Location, height, opening mechanism, clearance, effort.
2.2 Remove lid from connector and EVI if present	Lid/no lid
2.3 Plug in connector to EVI	Illumination, effort, clearance, visibility and accessibility.
2.4 Control charging status	Visibility, location, colours, response time and flexibility.

Table 24: Design principles for stop charging an EV.

Operation	Design principles
3. Stop charging EV	
4. Disconnect from car	
4.1 Unlock connector	Number of operations, flexibility and location compared to EVI (flow).
4.2 Unplug connector from EVI	Effort, clearance and accessibility.
4.3 Put lid on connector and EVI if present	Effort.
4.4 Close EVI door	Effort, clearance and number of operations.
5. Disconnect from grid	
5.1 Unplug cable from socket	
5.2 Wind together the cable	Stiffness, handling, weight of cable and effort.
5.3 Put cable in storage	Accessibility, visibility, reachability, number of operations, effort and location compared to EVI (flow). If in trunk, take loaded and unloaded trunk into account.

The developed evaluation method follows the ordinary flow when charging an EV and each task is evaluated and graded on a scale from one to ten. In Table 25 the grades from each task are categorized into the critical parameters. The average grade is calculated for each parameter and for the charging procedure over all.

Table 25: Calculation of grades for each critical parameter.

Parameter	Grades
Storage of charging cable	
1.1.1 Access charging cable storage	
5.3 Put cable in storage	
Charging cable	
1.2.1 Adjust ampere settings	
5.2 Wind together the cable	

EVI	
2.1 Open EVI door	
2.2 Remove lid from EVI if present	
2.3 Plug in connector to EVI	
4.1 Unlock connector	
4.2 Unplug connector from EVI	
4.3 Put lid on EVI if present	
4.4 Close EVI door	
Feedback	
2.4 Control charging status	
Charging procedure overall	

8 Discussion

This chapter will discuss the final result and the method used in this project. It will also reflect upon criticism of sources, further work and ethical aspects.

8.1 Final results

This project resulted in the identification of and design recommendations for the critical parameters affecting the user experience in accordance with the research questions stated in the beginning. Since the results in this project have been verified in each phase it is an indication that all critical parameters have been found. It also resulted in user scenarios describing the user experience and the most effective evaluation method in order to evaluate this experience. We are for this reason very satisfied with the results of this project since it answered all our research questions and fulfilled our goals.

8.1.1 **Recommendations**

One of the goals with this project was to find out how the critical parameters affecting the charging procedure should be designed in order to satisfy the users. The conclusion in phase 2 presents the concepts that got the highest grades in each user test and are therefore the base when forming the recommendations. Even though these concepts were the best ones it does not mean that they are good concepts which are something that was taken into consideration. Regarding some of the parameters we do not consider us having enough data in order to set recommendations. Instead of being presented as a concept the recommendations for these parameters are presented in characteristics. One example is the feedback light which is recommended to be placed adjacent to the EVI and to be presented in yellow, green and red colour. It does not say anything about how it should be designed, rather what should be included in the design.

8.1.2 **User scenarios**

The scenarios are based on the results from the literature study, user tests, questionnaire and workshop. The stories presented in the scenarios are inspired by the participants' real life activities and habits. For instance the participants in the questionnaire shared their reasons for buying an EV, and the four most common reasons are the starting points for each of the four scenarios. They also shared their daily habits regarding how far and where they drive their EV.

The solutions presented in the user scenarios are a combination of the concepts that got the highest grades in the user tests and desires suggested by the participants. A lot of possible improvements and desires for the future were captured in the questionnaire, workshop and user tests. This includes among others improvements regarding charging concepts, opening/closing mechanism of the EVI, feedback, charging cable, cable storage and user flow. These suggestions were presented as existing solutions for the users in the user scenarios. For instance the integrated charging cable in scenario 1 was the desired solution suggested by 34 % of the participants in the questionnaire.

As mentioned earlier 67 % of the participants in the questionnaire answered that there is no dedicated charging cable storage in their EV. This despite that there actually is one. It is not clear enough for the users where the storage is and this is therefore not a reasonable solution. This was in the user scenarios solved by having an integrated solution in scenario 1, to have information about the charging characteristics in the centre display in scenario 2 and to have a wireless solution in scenario 4. Doing this the physical interaction when storing the cable is improved and limited, better informed or totally eliminated.

Scenario 1 – Family father

Hans that is presented as a family father in the first scenario represents an ordinary user in the near future. As discussed in phase 2 tomorrow's EV users should not differ from ordinary vehicle users. There should be as little difference between an EV user and an ICE vehicle user as between a diesel vehicle user and a petrol vehicle user. There should not be any extra effort to have an EV and anyone should be able to use it. For instance Hans's daughter Sara unplugs the charging cable from the socket when the charging is completed.

The coiled charging cable is a solution that is implemented in this user scenario since it got a higher grade compare to a straight cable in one of the user tests. A positive aspect that was brought up by some of the participants were that it is easy to handle, store and that it stays off the ground and therefore does not get as dirty as a straight cable. Since tomorrow's EV users probably will have a lower acceptance to the problems with the charging procedure the reduction of dirt on the cable is important.

Another problem that arose when talking to users were the problem that the grid sometimes get overloaded at home. This might happen when the EV is charging with a high ampere setting and the washing machine is running at the same time. To eliminate this problem the car adjusts the ampere settings automatically when it notices that the grid is about to be overloaded.

Scenario 2 – Friend of the environment

Mary represents a user that is going to be a common user in the nearest future. Carpool and car sharing companies are getting popular amongst people who use a car more rarely. Mary lives in an apartment in the city and does not have access to a parking space at home. She also commutes to work using public transportation which means that a carpool fits her perfectly.

The ability to control the entire charging procedure in an app has been desired by some participants. Most EV manufactures offer a mobile application that works together with the car, but the charging procedure features might be limited. In order to facilitate for the user, in this case Mary, the app for instance sends her notifications about the charging status. Some participants responding to the questionnaire said that they sometimes choose their destination depending on the charging possibilities at the destination. The planning procedure is optimized and simplified for the user by being integrated in the navigation system. This feature is also available in the app and the journey can therefore be planned before getting to the car. Moving on to the mobile application provided by the carpool, Mary can there easily see if there are fully charged EVs available. This feature was suggested by the participants in the workshop and has therefore been implemented in the scenario.

The problem that might arise when using new EV interfaces is solved by having an easy overview in the centre display informing about the charging characteristic of that specific EV. Another feature that was implemented in the scenario was that the charging station recognizes the car’s ID and sends an invoice to the owner. It removes a physical touchpoint and limits the interaction with the charging station.

The feedback light is an important parameter that affects the user during the charging procedure. According to the recommendations stated above it should be situated close to the EVI, immediate and shown in yellow, green and red colours in order to be as clear as possible for the user. The feedback light in this scenario is therefore designed as a big circle around the EVI that is clear and visible when standing close as well as further away from the EVI. It also gives feedback immediately and in the recommended colours.

A problem that was brought up by the participants was the limited access to the charging cable storage if the trunk is loaded, primarily when the storage is situated under the load floor. This problem occurred for Mary as well since we think it is an important issue to highlight. To ease the interaction with the storage the load floor is kept up by gas struts which make it possible to access the charging cable with only one hand available.

Scenario 3 – Early adopter with technological interest

Bo represents an ordinary EV user today. He is an early adopter and thinks that it is cool and exciting with new technology. A user like Bo does not mind the extra effort that it takes to have an EV and does not mind having several charging cables in the trunk. He knows that the charging procedure and charging cable are parts of having an EV today and has no major problem with it. Bo usually charges his car wherever and whenever he gets the opportunity since his goal is to drive on the electric engine as much as possible.

This scenario pays attention to the importance of having a keyless solution that works together with the charging equipment. As soon as he gets close to the car the key is recognised, he can easily open the trunk with a kick under the trunk and at the same time the connector is unlocked from the EVI. As well as for the previous scenarios this scenario also brings up the importance of being able to control the charging procedure in a mobile application.

As presented in the scenario Bo has several charging cables with accompanying bags. The mentioning of the wet and dirty charging cable highlights the importance of having dedicated charging cable storage. The user does not want the other things in the trunk to get wet and dirty and the ability to store the cable in a separate bag is therefore an important aspect.

Scenario 4 – Status

The last scenario is built upon the solutions that can be implemented in the further future five to 15 years from now. Alexandra represents a user that does not want the charging procedure to be an extra step, which probably represents the approach of many future users. Inductive charging was brought up by participants both in the questionnaire and the workshop. According to the expert interview this is a charging concept that is going to be a realistic future concept. The charging cable is still going to be present and included when buying an EV, but it is going to be used more as a spare wheel rather than the average way to charge the car.

Using wireless charging limits the physical interaction during the charging procedure and the critical parameters affecting the user experience are therefore also limited. The only parameter affecting the user experience that is not digital interaction is the feedback regarding the charging status. The design principles are the same for wireless charging as for wired charging, which means that the feedback should be immediate, clear and easy to understand.

The scenario additionally shows how the user experience during the charging procedure can be better than during the refuelling procedure of an ICE car. Alexandra has earlier experienced that it is a struggle to refuel her car but using wireless charging she does not need to physically interact with either a refuelling hose or a charging cable.

8.1.3 **Evaluation method**

During this project hour after hour have been spent planning and performing user tests. Including real users in every evaluation is extremely time consuming and inefficient for the people performing the evaluation. After reading about different evaluation methods it was found that an analytic method performed by experts in the area is one way to do it. But to evaluate the user experience and interaction without users in some way sounds insecure, even if the experts have knowledge in user experience. We then started to think about a way to take the users' experiences and opinions into account without having them physically there. The analytic method NASA Task Load Index is a subjective method to evaluate the workload, which can be done with just one user [6, p. 481]. This should decrease the number of user test to just one, but we do not think that this would capture the overall user experience but just one user's opinion and it is therefore not a good method to use in our case. The good thing with the NASA method is though that it divides the interaction into different dimension that might help to focus on one dimension at a time [7]. In the methods heuristic evaluation and standard inspection two to three experts evaluate the interface and experience with the help of predeveloped criteria [6, p. 523] [8]. Then we thought that if the predeveloped criteria are based on the data that was gathered from users in the different test we could have the advantage of both being time efficient in accordance to the heuristic evaluation [6, p. 481] and to include the overall thoughts about how the user experience should be according to today's users. In order to be as accurate as possible we decided to formulate a list of criteria based on the critical parameters which the experts can evaluate against. This evaluation method can therefore be seen as both objective and subjective with an indirect high grade of participation without having any real users present.

When developing the heuristics for the method the critical parameters and the results from the different tests were used as a basis in order to decide what was important to evaluate. It resulted in different design principles that the expert will evaluate against for each task in the charging procedure, see the previously presented Table 23 at page 87 for the heuristics. It was decided that the evaluation should follow an ordinary user flow in the charging procedure. With a foundation in the Hierarchical Task Analyses presented in phase 1 it was decided which tasks should be included. The experts will perform the tasks in the charging flow and evaluate the parameters after the design principles. Each task will be graded by the experts on a scale from one to ten. A ten grade scale has been used in the user tests and it was therefore easy to include it this method as well.

Our expectation of the method is that it should be able to cover the nearest future concepts as well as todays. For example if the storage solution in the future is an integrated charging cable, the same evaluation method can be used. The only difference is that some of the steps in the charging procedure is eliminated and therefore not evaluated. Regarding the inductive charging the physical interaction is going to be very limited. It will mainly be interaction with digital displays and the only physical interactions will be the manoeuvre of parking the car properly over the induction plate and to get feedback regarding the charging status. The interaction with the digital displays is not something that is included in the scope since limitations are taken from any screen based interfaces. The charging feedback will be evaluated in the same way as for the wired charging.

The benchmark study was quite big but could have included more EVs in order to capture all functions possible to evaluate. There might be some functions that were missed and are therefore not covered by this evaluation method.

The evaluation method was validated by three experts within ergonomics and they got the task to evaluate an EV with it. They all thought that the method worked very well and that it was a relief to have the design principles as guidelines. This method involved all important parameters and took less time than the previously one used at the company. The only thing that they requested was clearer instruction for some of the guidelines.

8.2 Methods

The division of the project into phases was a great way to clearly and effectively structure the work. It made it easier for us to focus on each part of the project and better get an overview of the different parts and conclusions. Since the phases are built upon the conclusions from the previous phase it was an effective way to organise the project.

The first part of the project involved doing a literature study to get an overall understanding of the usage of electric vehicles and to investigate if any research had been done in this area before. It was a great start of the project since the area was quite unfamiliar for us. It also helped us get an understanding of the user experience during the charging procedure and which parameters that might affect it. Having read a lot of articles covering the area it was great to get a feeling of how the facts are experienced in reality which was done by doing benchmarks on several different EVs. It is one thing to read about how a product is used and another thing to actually experience it yourself. The benchmark increased our understanding for the charging procedure and the parameters affecting the user experience. Through the literature study and the benchmark we learned a lot and also got an understanding of what could be investigated in the user observations and interviews.

Different data gathering methods were used in order to ensure methodological triangulation which means to use different data gathering techniques, something that Preece et al means is important [15, p. 230]. The observation was performed with 13 EV users on one specific EV. Looking back it would have been preferable to observe the participants when charging several different EVs. Considering that it was in the early data gathering phase of the project it would have been beneficial to get input from more EVs and not only one. The observations were held in a controlled environment which is one way to conduct observations according to Preece et al. [15, p. 252]. That might have resulted in that the participants acted a bit different from what they should have done in a natural environment when charging the EV. In accordance to the same author the observation session must be carefully planned to ensure that the right things are in focus [15, p. 252]. This is something that was successful in this observation. The observation covered charging a for the users unknown vehicle and if they had charged their own EV the result might have differed. Now the charging procedure of an unknown vehicle for experienced users has been covered. It would also be interesting to see how these users charge their own EV that they are familiar with. But thanks to the users being unfamiliar with exactly this EV they had to step out from their habits and comfort zone which covered the possible scenario about a car-sharing activity.

As well as the observation the interview was done with 13 EV users. To ensure that the right data was gathered the sessions were planned carefully in accordance to Preece et al. [15, p. 227]. The questions asked were mostly closed ones and with alternatives based on the literature study and the benchmark. The questions included all parts of the charging procedure since we were not yet sure about the direction of the project. Looking back the interviews would preferably have included more open questions to give the participants the opportunity of talking more open about the charging procedure. Having closed questions answers were obtained regarding the specific questions asked but this might also have resulted in missing out on some important information about the user experience. Considering that this was in the early phase of the project it would have been good to capture as much information possible about the user experience and doing the sorting of information afterwards instead. Overall it was suitable to have user interviews this early in the project instead of having a questionnaire or similar data gathering methods. In the interview the users' feelings and experiences could be captured in a better way since the questions were asked face to face.

The user observation and interview gave us input from a limited amount of users, and the next step in the project was to verify these findings with more users. A great way to collect quantitative data is to use a questionnaire which therefore was the next data gathering method used. To begin with the response rate from the questionnaire was higher than expected which gave us a trustful amount of user data. Since the loss from the selected group was smaller than 50 % the answers are representative [6, p. 489]. It was a useful way to gather data in this part of the project. The result gave us information about what to focus on and in which direction the project should continue. An important part was to find out which parameters that the users are satisfied with today and which parameters could be improved. It captured both user problems and possible solutions that were extremely valuable for our project. Another important part of the questionnaire was to capture the users' habits and reasons for acquiring an EV. This result was later used as a base when forming the user scenarios. Getting quantitative data about user habits is really important in order to cover all possible users and make the user scenarios as realistic as possible. Since the questionnaire contained quite many questions for several different areas we tried to implement as many closed questions as possible. Mainly in order to make the compilation of the result as easy as possible for us but also to get answers that could be interpreted in an appropriate way. In some of the questions it was more suitable to let the participant write freely in order to express their opinions in the best way. The only problem with having these kinds of open questions is as mentioned above that the answers are harder to interpret and that it is a risk that the answers are misinterpreted by us. The answers were interpreted as well as possible but some answers were hard to interpret due to unclear written comments. This problem would have been avoided if instead having interviews face to face, but the quantity of participants would have made that hard to implement.

As discussed in phase 2 the workshop was an effective way to get desires and comments from the users about the future of EV charging. It was a good complement to the data gathering methods and the users got the opportunity to reflect over how they would like to experience the charging procedure. The scenarios worked as well as thought and it generated many new ideas for the participants when having to think about another user than oneself. It was great to start with an icebreaking exercise and the first task, the worst solution, really got the participants in the right mood. It is much easier to find problems and things not working so well than great things about a product and all the participants found it easy to brainstorm around bad solutions. We are very happy about how engaged they were and can safely say that the overall solution must have been covered thanks to a great discussion. A workshop with at least six people captures the overall comments that one can expect from users thanks to associations to different treated subjects [6, p. 489] and since the participation in the test was more than six the data have a high credibility. Overall, the participants of all user tests in phase 2 were engaged and happy to help us with tests and to contribute to the development of EVs. The participants signed up for the workshop and user tests and were therefore really excited to generate new ideas.

The user tests were an appropriate way to evaluate different concepts for the critical parameters affecting the user experience. As discussed above it would be preferable to let the participants evaluate the concepts in a more natural environment to get as realistic results as possible. User test can be performed in a lab environment as ours but should with advantage not last more than 30 minutes according to [6, p. 525] and they did not. In each of these two tests the number of participants were 13 and 14 which according to [6, p. 526] is a lot more than needed to guarantee that 75-80% of all user problems will be discovered. Many of the concepts were introduced for the first time to the participants during the user tests which might have influenced the result. It might have been different if the concepts were used in a natural environment and during a longer period of time in order for the participants to get a better feeling of the concepts. The concepts in the user test evaluating the charging cable and charging cable storage were presented to the participants in two different ways. Some of the concepts were presented as existing solutions that the participants could interact with and some of the concepts were only presented by us in words. This might have had a negative effect on the result and was therefore considered and adjusted to the next user test. The concepts in the user test regarding the design and placement of the EVI were therefore presented almost entirely using existing solutions. Overall the grading of the different concepts worked really well and made it easy for the participants by being able to compare different concepts. It was also great that the participants got the opportunity to motivate each grade and make suggestions regarding desired solutions that had not been brought up. This made us sure about having captured all possible concepts and solutions that the participants might want to be included in the charging procedure.

Some of our users have been participating in more than one of our data gathering methods. For instance a few users participated both in the questionnaire and in one of the user tests. The downside of this is that there probably is overlapping in the gathered data and that more different opinions would have been collected if having new participants in each gathering method. The positive aspect is that the users are familiar with reflecting over the user experience from participating the first time and therefore might be more open and reflecting the next time. The users that answered the questionnaire before participating in a user test also got the opportunity to further express and explain their opinions in a more open way.

8.3 Criticism of sources

This project has both included sources in form of literature regarding used methods and theory about electric vehicles as well as human sources in form of user studies. Since a big part of our sources are in form of humans reflections needed to be done regarding how reliable these participants have been. The participants have been early adopters with a big interest in the subject. We feel that they all have been very keen to help us in best possible way and they have been accommodating in the study with the hope of supporting the development in this relatively new area.

Since this subject is relative new, it was quite difficult to find printed sources with a high academic reliability. Some definitions are therefore taken from different websites with EV drivers as targets. The information obtained from those sources has also been confirmed by experts within charging and from our participants.

There has not been that many studies performed regarding EV driver's habits and the ones that have been found do not reflect the Asian market. Asia is a big market for Volvo Cars Corporation and it would have been interesting to compare if the habits differ depending on were in the world the user is. Since Asia has a large EV market it would also have been interesting for the whole project to gain more information about the EV drivers from Asia, the articles found are from Europe and USA. Once again, due to this quite new area the studies in Europe and USA are not that many and it would have been preferable to find even more information. The articles that have been found do not have a main focus on the user experience and the charging procedure. The focus is more on the drivers and their habits and has a more general approach than this project which is more specific. We still think that the articles have been a good source for us, mostly to help us create the user scenarios. They confirm the habits of our users and together they make a good foundation for the user scenarios.

The printed books regarding interaction design do all have a focus on digital interaction and not physical interaction design. Despite this, these sources have been used but only the information that can be applied both on digital and physical interaction.

Almost all definitions regarding different EV terms are taken from different international standards which have a very high reliability. The standards have been the foundation in the background chapter and have often been used alone due to that we do not think that another source is needed thanks to the high reliability.

Theory about many of the methods used in the project comes from the book "Arbete och teknik på människans vilkor". It is a book written by experts and teachers from different universities in Sweden and describes both data gathering methods and evaluation methods. The information has also been established by many other similar sources. We have in the highest possible way tried not to use only one source and that is something that strengthens the credibility of the presented theory. Overall we do think that all our sources have a high grade of credibility.

8.4 Further work

The different storage concepts were graded very low in the user test, none with an average grade over six on a scale from one to ten, and none of the storage solutions satisfied the participants fully. This is therefore something that needs to be investigated further. The design of the charging cable was graded very different by the participants and no clear result could be seen. How it should be designed is therefore something that also needs to be included in further work.

When the expert group validated our guidelines they wished for instructions for how different solutions should be graded instead of just grade by themselves from one to ten. This is something that we do not have time for and is not in our scope but we strongly recommend Volvo Cars Ergonomic department to include more specific guidelines for how the grading should be done. It is important to base the grading on our user studies and how the participants graded different concepts.

8.5 Ethical reflections

All participants of the user tests have been participating voluntarily and no intrusion has been done to their privacy.

Generally a lot of ethical reflections can be done regarding the manufacturing of EVs for instance concerning the material used for the batteries. Though this aspect is not involved in our scope and will therefore not be discussed any further.

9 Conclusions

This chapter presents the answers to the research questions stated in the beginning of the report.

- **Which methods can be used for evaluating the user experience for the charging procedure in electric vehicles for a car company?**

The user experience can be evaluated using empirical methods, involving users, or analytical methods, involving experts in the area. A method involving users is a user test where the user gets to interact with the product similar to the tests performed during our project. Methods involving experts are for instance NASA Task Load Index and heuristic evaluation which are subjective methods not involving any real users.

- **Which of these is the most effective method?**

The most effective evaluation method is to only involve experts by using a heuristic evaluation method with guidelines formed from user tests. The guidelines should be added in order to include the users' opinions without having to involve the users in the evaluation. This evaluation method is both objective and subjective with an indirect high grade of participation without having any real users present. This makes it the most effective method regarding both accuracy and time.

- **Which are the critical parameters that are affecting the user experience around the charging procedure in electric vehicles, both today and prospective?**

Table 26 describes the critical parameters that affect the user experience during the charging procedure of EVs. The future of EV charging will probably be with inductive charging. The parameter that will be affecting the inductive charging procedure is the feedback.

Table 26: Critical parameters affecting the charging procedure today and in the future.

Critical parameters	Charging concept
Placement and design of EVI	Wired charging
Storage charging cable	Wired charging
Feedback charging	Wired and wireless charging

Charging cable	Wired charging

- **How should these critical parameters be designed to optimize the user experience?**

The recommendations for how the critical parameters should be designed to optimize the user experience during the charging procedure can be seen in Table 27.

Table 27: Recommendations for how to design the critical parameters

Wired charging	
Parameter	**Recommendation**
Placement and design of EVI	
Placement EVI	Over the left front wheel or in front of the vehicle
Opening mechanism EVI	Push solution
Closing mechanism EVI	Automatically after pulling out the connector
Unlock connector	Button on connector together with a keyless solution
Storage charging cable	Integrated solution or net in the side panel in the trunk
Feedback charging	Both light and sound
Placement	Close to the EVI and additional feedback visible standing further away from the EVI
Colours	Yellow, green and red lights. Clear and strong lights.
Response time	Immediate after plugging in the connector
Sound	A “click” sound immediate after plugging in the connector
Charging cable	
Stiffness	Easy to handle and wrap together in order to fit in storage

Control unit	No control unit on the cable
Cable type	Coiled
Wireless charging	
Feedback charging	Both light and sound
Placement	Located close to where the driver is located when the charging begins
Response time	Immediate after the charging is started

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Appendix A Work distribution and time plan

A.1 Work distribution

The work has been distributed equally between the members of the project group. Even though we have different specializations, we have been united within the area of interaction design. All tasks within the project have been planned and performed together. Both of us were always present during all user tests, interviews and observations and we have been contributing equally to the project.

The only time the work has been divided was when Lisa was compiling the results from the questionnaire while Karin made illustrations for the report.

A.2 Project plan and outcome

The project plan with the planned activities, the outcome and the differences between them are presented below.

A.2.1 Project plan

The project plan and the included activities are presented in Figure 35 and Table 28.

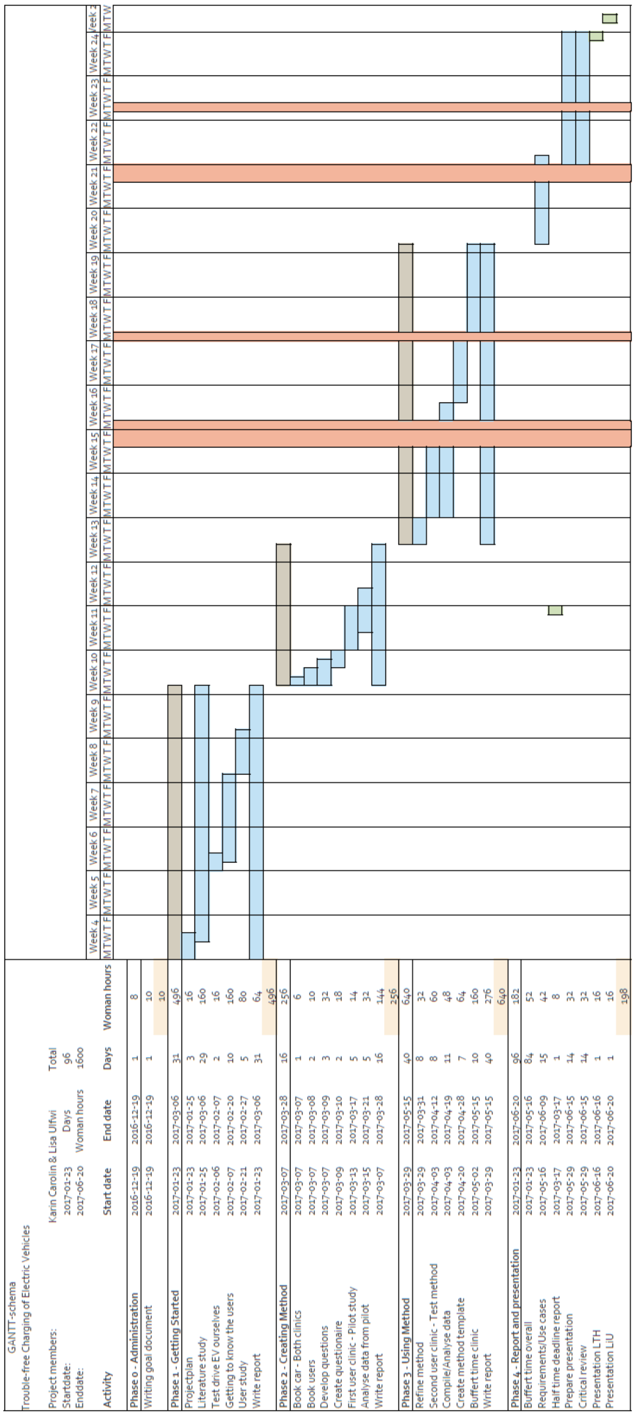


Figure 35: Project plan

Table 28: Activities in project plan

Activity	Start date	End date	Days	Woman hours
Phase 0 - Administration	2016-12-19	2016-12-19	1	8
Writing goal document	2016-12-19	2016-12-19	1	10
				10
Phase 1 - Getting Started	2017-01-23	2017-03-06	31	496
Project plan	2017-01-23	2017-01-25	3	16
Literature study	2017-01-25	2017-03-06	29	160
Test EVs ourselves	2017-02-06	2017-02-07	2	16
Getting to know the users	2017-02-07	2017-02-20	10	160
User study	2017-02-21	2017-02-27	5	80
Write report	2017-01-23	2017-03-06	31	64
				496
Phase 2 - Creating Investigation Method (IM)	2017-03-07	2017-03-28	16	256
Book car - Both clinics	2017-03-07	2017-03-07	1	6
Book users	2017-03-07	2017-03-08	2	10
Develop questions	2017-03-07	2017-03-09	3	32
Create IM	2017-03-09	2017-03-10	2	18
First user clinic - Pilot study	2017-03-13	2017-03-17	5	14
Analyze data from Pilot	2017-03-15	2017-03-21	5	32
Write report	2017-03-07	2017-03-28	16	144
				256
Phase 3 - Using IM and Creating Evaluation Method (EM)	2017-03-29	2017-05-15	40	640
Refine IM	2017-03-29	2017-03-31	8	32
Second user clinic - Test IM	2017-04-03	2017-04-12	8	60
Compile/Analyze data	2017-04-03	2017-04-19	11	48
Create **EM** template	2017-04-20	2017-04-28	7	64
Buffer time clinic	2017-05-02	2017-05-15	10	160
Write report	2017-03-29	2017-05-15	40	276
				640
Phase 4 - Report and presentation	2017-01-23	2017-06-20	96	182

Buffer time overall	2017-01-23	2017-05-16	84	52
Requirements/Use cases	2017-05-16	2017-06-09	15	42
Half time deadline report	2017-03-17	2017-03-17	1	8
Prepare presentation	2017-05-29	2017-06-15	14	32
Critical review	2017-05-29	2017-06-15	14	32
Presentation LTH	2017-06-16	2017-06-16	1	16
Presentation LiU	2017-06-20	2017-06-20	1	16
				198

A.2.2 Outcome

The project plan and the activities described were followed during the whole project. The amount of hours for each activity was used as planned, with minor changes regarding the dates they were performed.

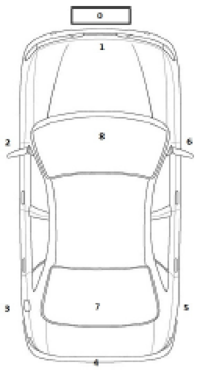
One of two differences between the project plan and the performed activities was that the “Second user clinic – Test IM” was moved to phase 2 and divided into two user evaluation tests instead. The other difference was that the activity “Requirements/Use Cases” was moved to phase 3, in the report called “Final results”, and renamed to “Requirements/User Scenarios”.

Appendix B Observation Protocol

Date:
Location:
Number:

Observation Protocol - Trouble-free Charging

Charging station: ☐ Mode 1 ☐ Mode 2 ☐ Mode 3 ☐ Mode 4 and ☐ Type 1 ☐ Type 2 ☐ Type 3 ☐ Type 4
Brand:______________ Brand:______________
Fixed charging cable: ☐ Yes ☐ No
Parking: ☐ Front in ☐ Back in ☐ Other Comment:______________
Car model: ☐ BEV ☐ PHEV ______________
Plug type car: ☐ Type 1 ☐ Type 2 ☐ Type 3 ☐ Type 4 Adapter: ☐ Yes ☐ No
Brand:______________ Brand:______________



User flow: ☐ Start charging ☐ Stop charging

Comments:

Adjusting ampere/voltage: ☐ Yes ☐ No How?:______________
To what?______________
Checking charging status: ☐ Yes ☐ No How? ☐ Charging station
☐ EVI
Lid on EVI: ☐ Yes ☐ No ☐ Control unit
Lid on cable: ☐ Yes ☐ No ☐ Displays inside vehicle
☐ LED windshield
Opening charging door: How?______________ ☐ Other: ______________

Problems:

Other comments:

Figure 36: Observation protocol from the first user test

Appendix C Interview protocol – User interview

Date: Number:
Location:

User interview - Trouble-free Charging

Car model: ☐ BEV ☐ PHEV ______________________

Plug type car: ☐ Type 1 ☐ Type 2 ☐ Type 3 ☐ Type 4 Adapter: ☐ Yes ☐ No

Brand:__________ Brand:__________

How do you live? ☐ Villa ☐ Townhouse ☐ Apartment Private parking lot: ☐ Yes ☐ No

Charging station: ☐ Mode 1 ☐ Mode 2 ☐ Mode 3 ☐ Mode 4 and ☐ Type 1 ☐ Type 2 ☐ Type 3 ☐ Type 4

Brand:__________ Brand:__________

Fixed charging cable: ☐ Yes ☐ No

Parking: ☐ Front in ☐ Back in ☐ Other Comment:______________________

Adjusting ampere/voltage: ☐ Yes ☐ No How?:______________

To what?______________

Checking charging status: ☐ Yes ☐ No How? ☐ Charging station

☐ EVI

Lid on EVI: ☐ Yes ☐ No ☐ Control unit

Lid on cable: ☐ Yes ☐ No ☐ Displays inside vehicle

☐ LED windshield

Opening charging door: How?__________ ☐ Other: __________

EV ownership

Why did you buy your car?______________________

Which gadgets where included in the purchase?______________________

Did you get an intro when you bought the car? ☐ Yes ☐ No

Does your household have more cars?______________________

Driving habits

How often do you drive your car?______________________

Where do you drive your car?______________________

Choice of destination due to charging procedure?______________________

Charging cable

Is there a dedicated cable storage? ☐ Bag ☐ Net ☐ Loose ☐ Over load floor ☐ Under load floor ☐ Frunk

How do you store the charging cable? ☐ Bag ☐ Net ☐ Loose ☐ Over load floor ☐ Under load floor ☐ Frunk

What do you think about your charging cable?______________________

____

EVI

Accessibility?______________________

Feedback?______________________

Visibility status indicator?______________________

Charging habits

Where do you charge your car? ☐ Home ☐ Work ☐ Store ☐ Friends house ☐ Other

How often do you charge your car? ☐ Everytime I park ☐ Once a day ☐ Other __________

Grade the UX when charging your car, 1-5 (hard-easy)? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Can we contact you for further tests and interviews? ☐ Yes ☐ No

Figure 37: Interview from the first user test.

Appendix D Complete results from questionnaire

1. How long have you been driving an EV?

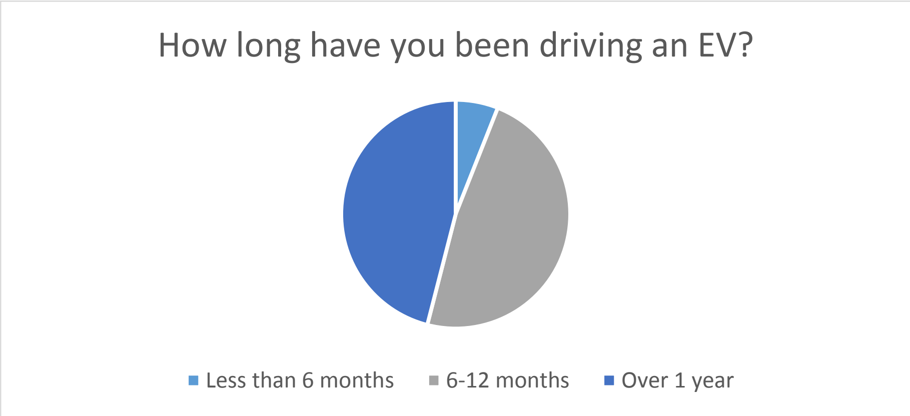


Figure 38: How long have you been driving an EV?

2. How much did the following parameters affect your choice of acquiring an EV?

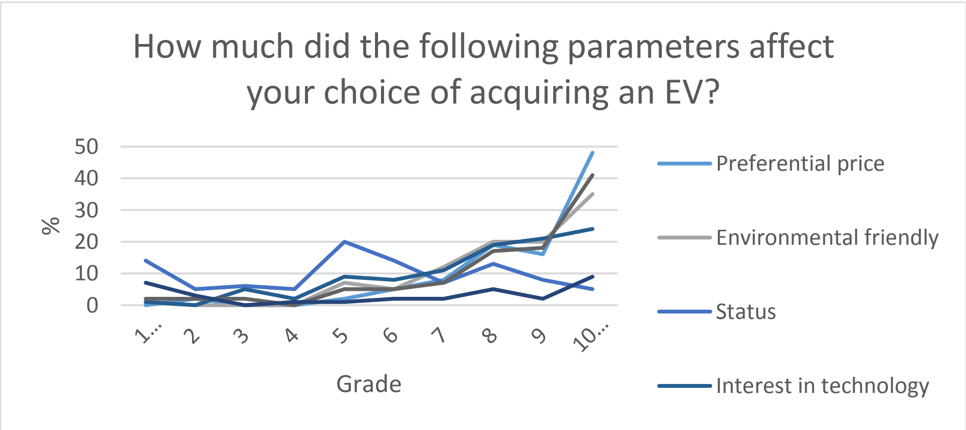


Figure 39: How much did the following parameters affect your choice of acquiring an EV?

3. If your answer on the above question was "Other", which parameter do you refer to?

Table 29: If your answer on the above question was "Other", which parameter do you refer to?

Parameter	Quantity
Taxable benefit	5
Sound level	5
Operating cost	4
Positive driving experience	4
Good performance	4
Interior design, comfort	1
New technology	1
Can charge at home	1
Work-related	1
Generally drive short distances	1
No exhaust gases	1
Solidity	1
Refuel less often	1

4. Do you have any additional car in your household?

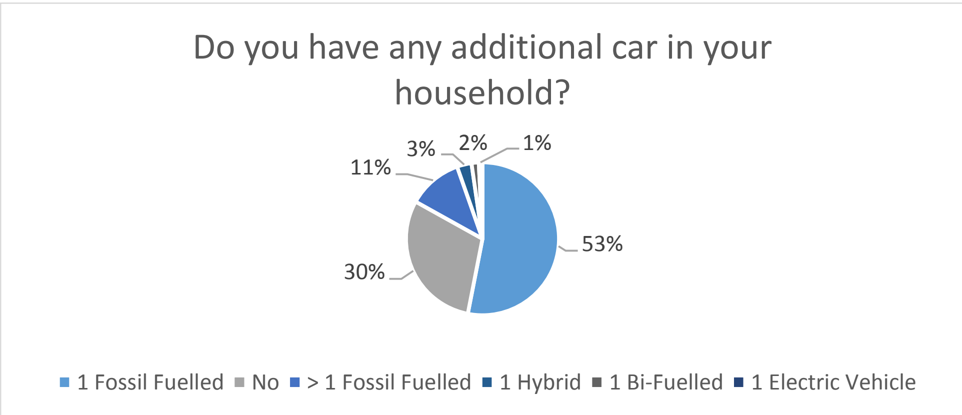


Figure 40: Do you have any additional car in your household?

5. What kind of journey do you do with your EV?

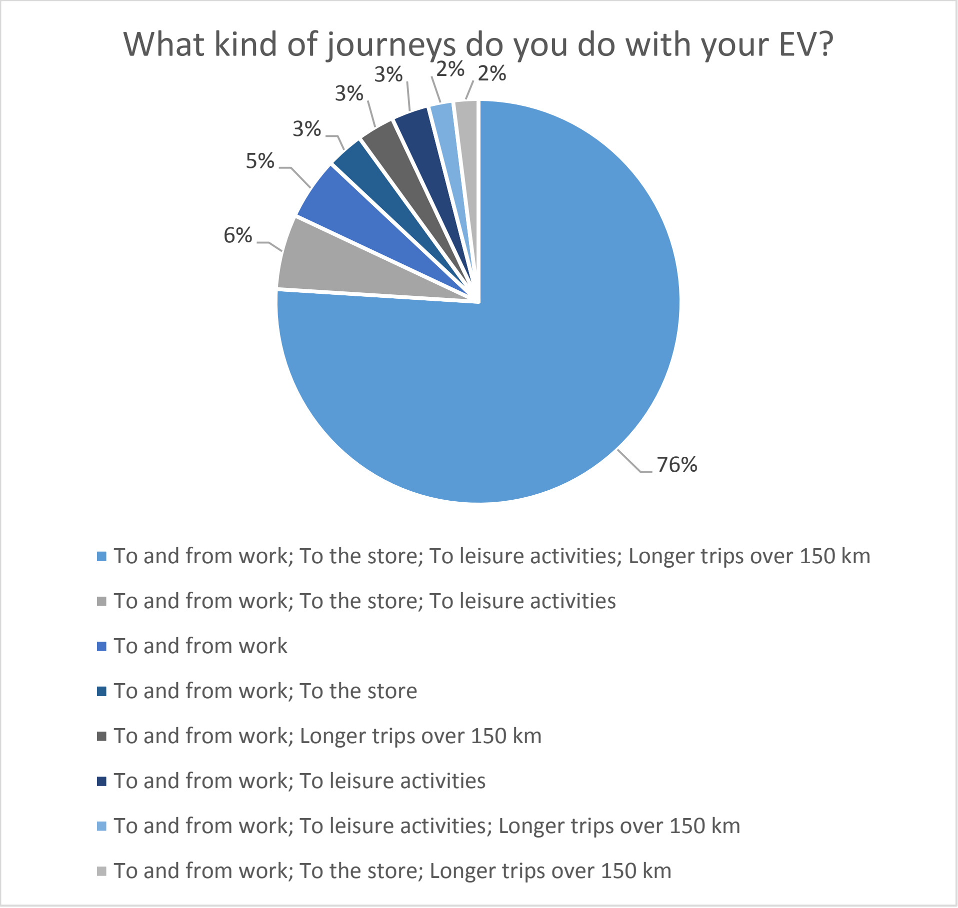


Figure 41: What kind of journey do you do with your EV?

6. How often do you drive your EV?

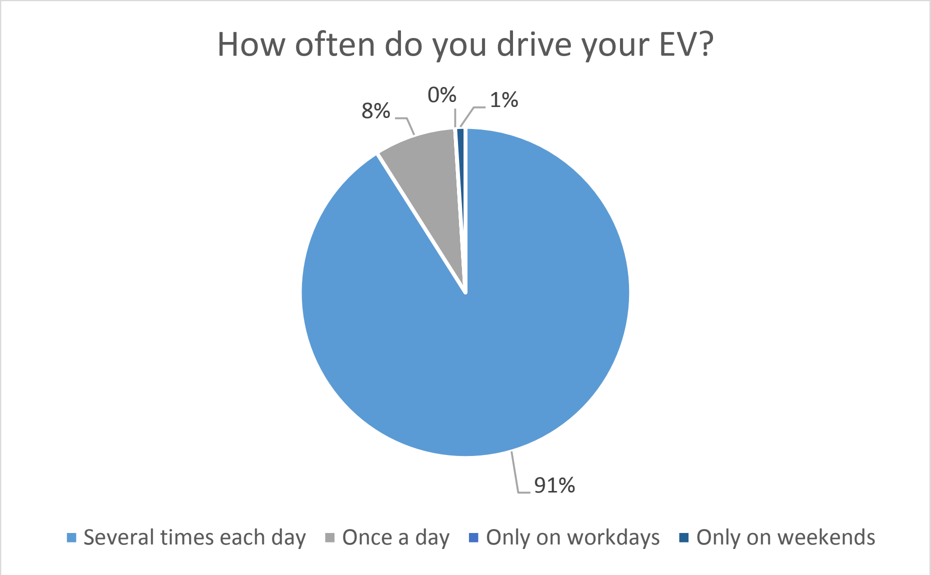


Figure 42: How often do you drive your EV?

7. How far do you usually drive during one day?

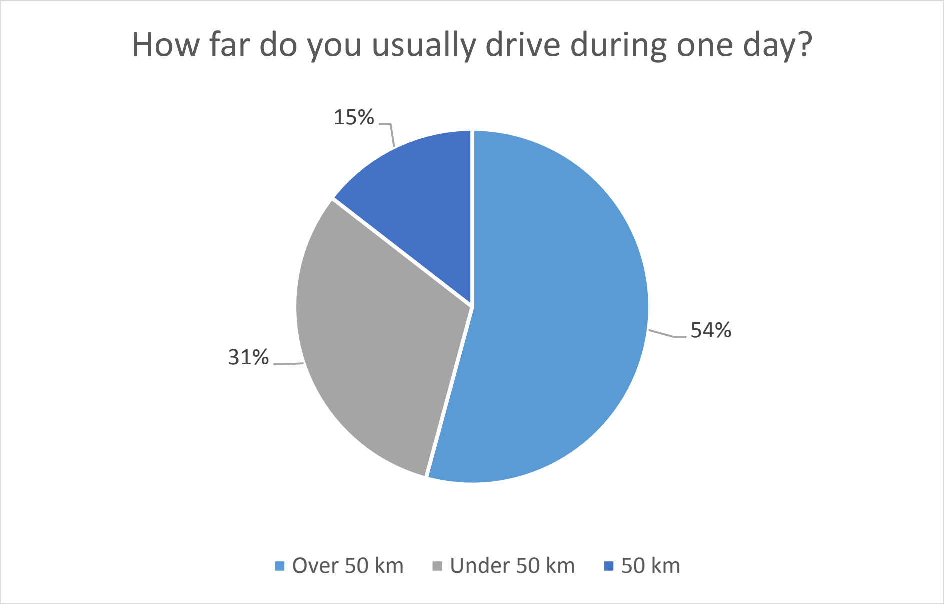


Figure 43: How far do you usually drive during one day?

8. Where do you usually charge your car?

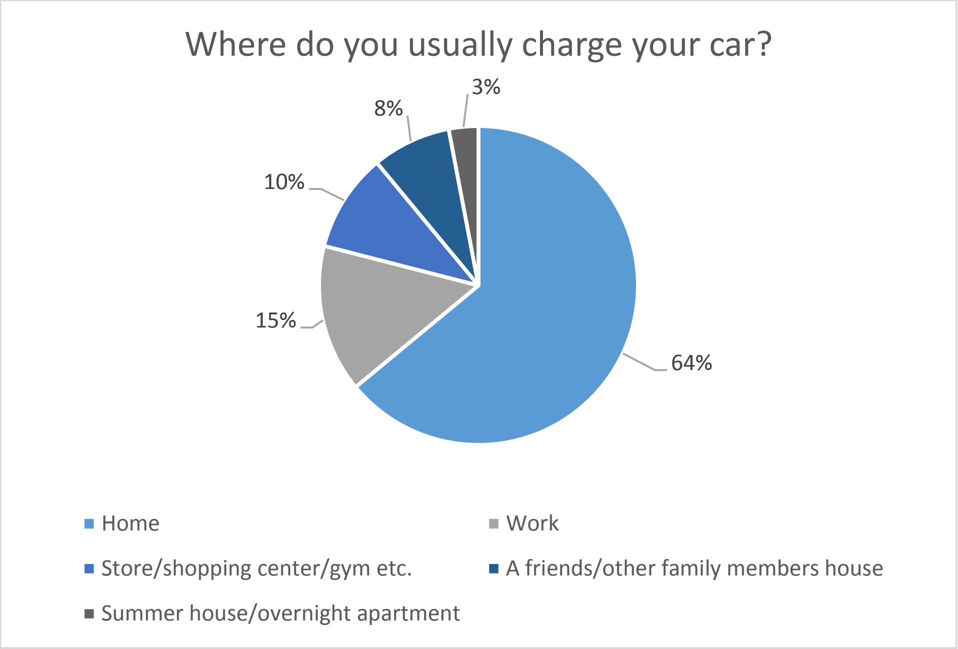


Figure 44: Where do you usually charge your car?

9. How often do you charge your car?

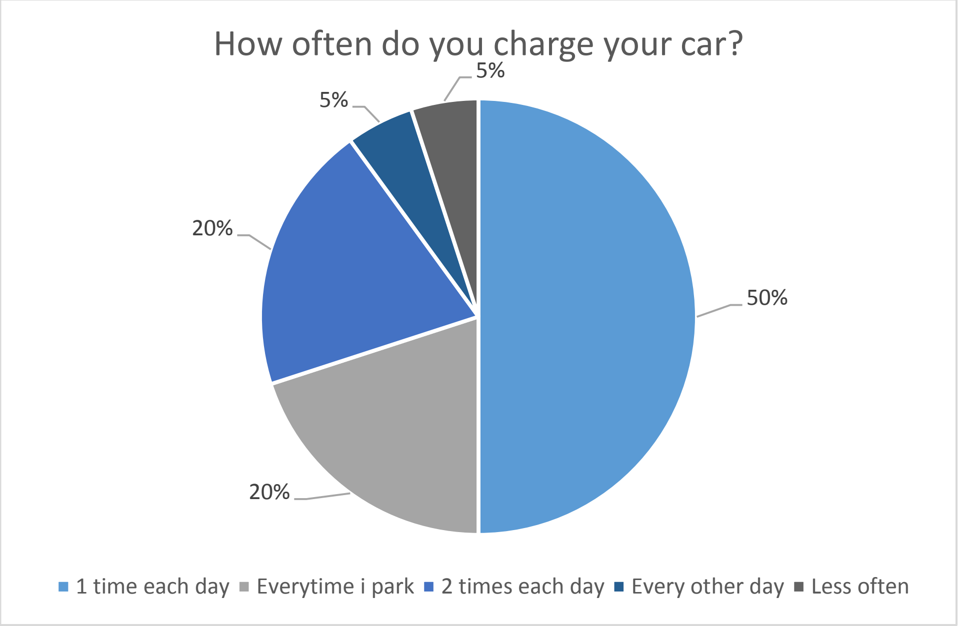


Figure 45: How often do you charge your car?

10. How do you live?

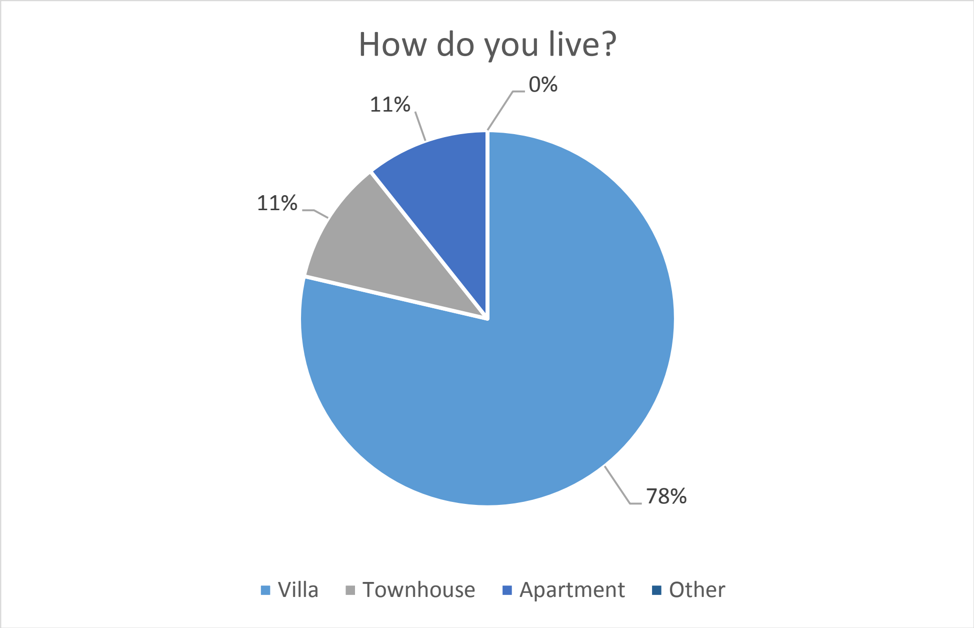


Figure 46: How do you live?

11. What are your parking possibilities for charging where you live?

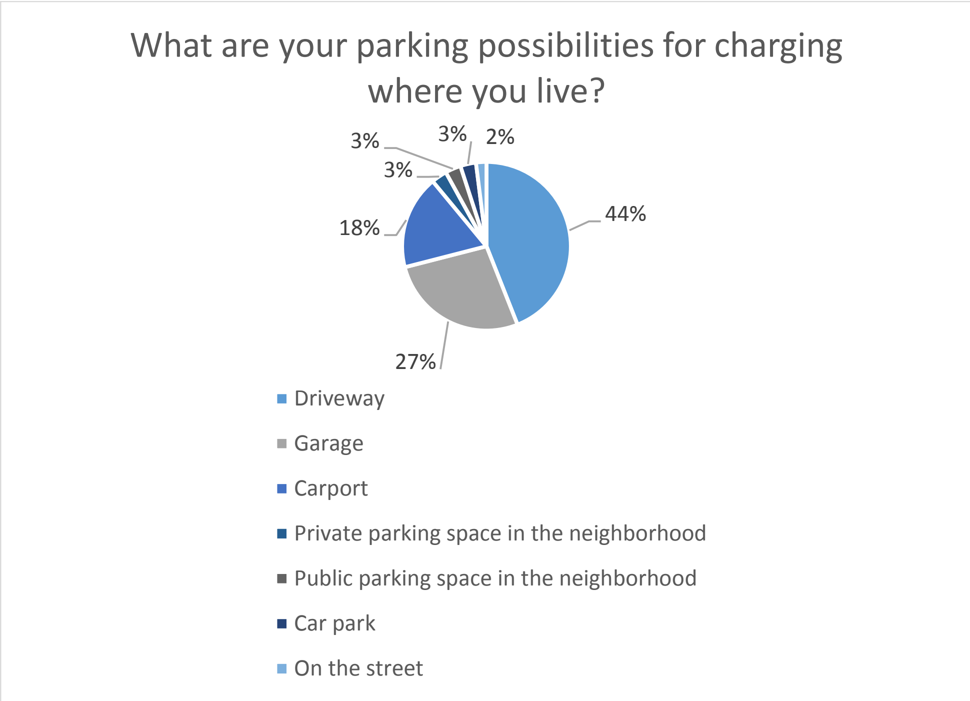


Figure 47: What are your parking possibilities for charging where you live?

12. How do you charge your EV at home?

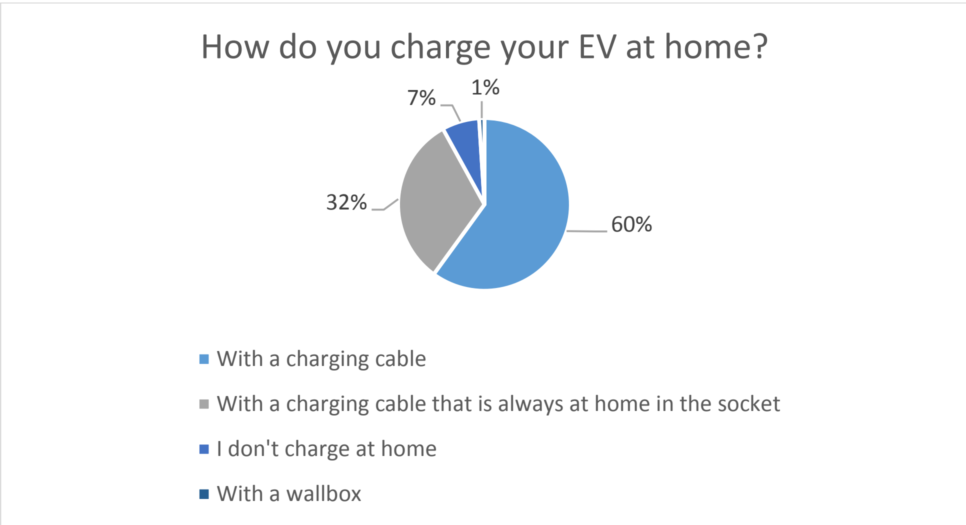


Figure 48: How do you charge your EV at home?

13. Do you charge your EV at work?

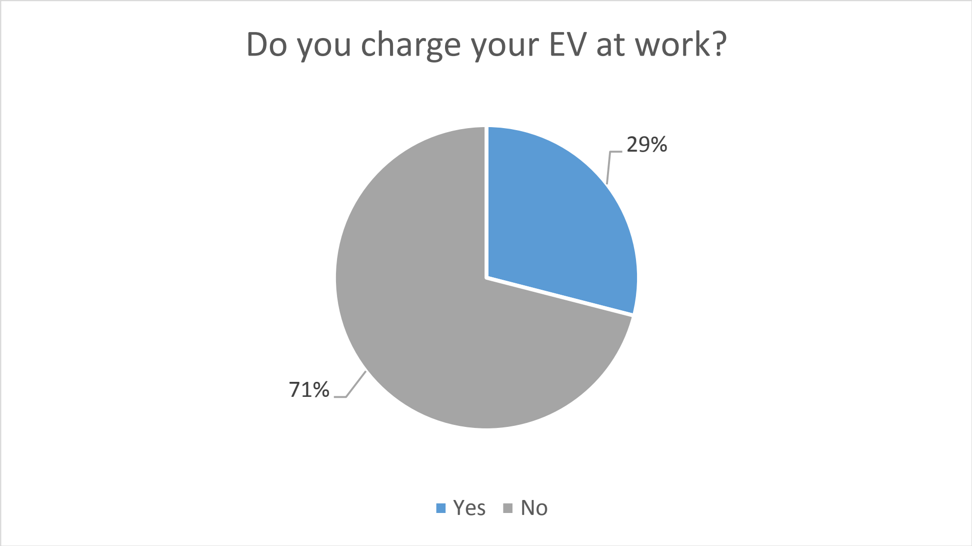


Figure 49: Do you charge your EV at work?

14. How do you charge your EV at work?

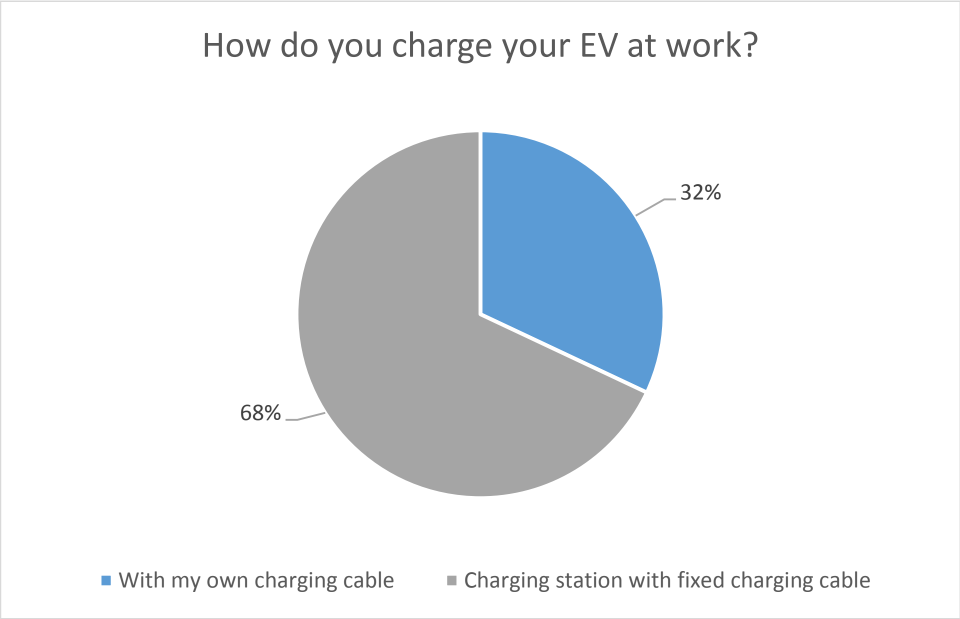


Figure 50: How do you charge your EV at work?

15. Do you ever choose your destination based on the charging possibilities at the destination?

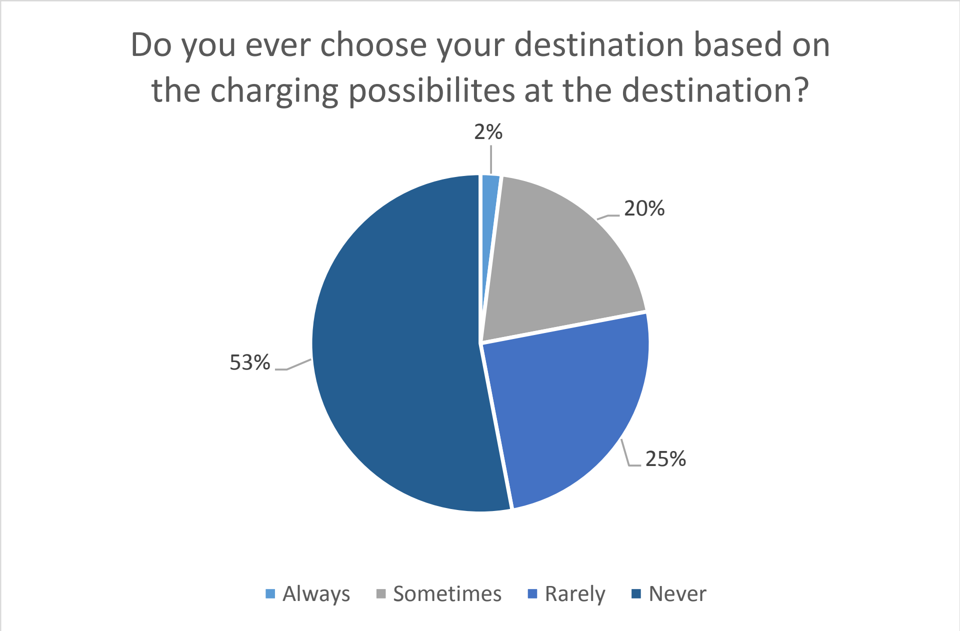


Figure 51: Do you ever choose your destination based on the charging possibilities at the destination?

16. Is there dedicated cable storage in your EV?

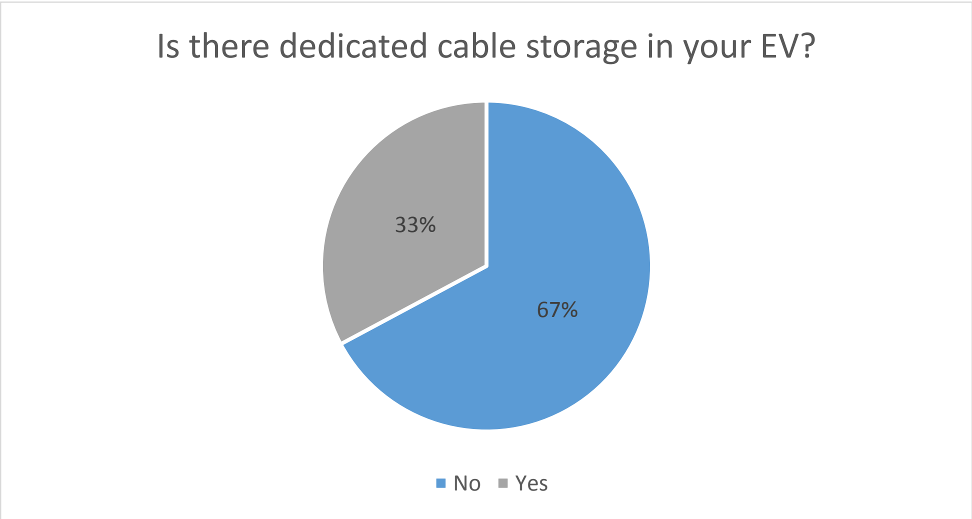


Figure 52: Is there a dedicated cable storage in your EV?

17. Do you store the cable in the dedicated storage?

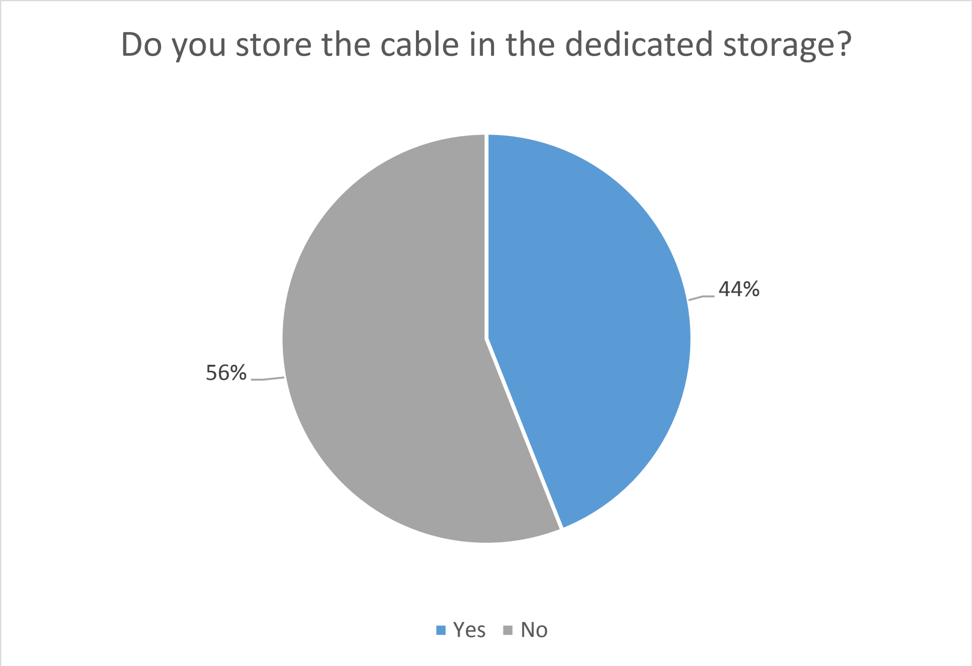


Figure 53: Do you store the cable in the dedicated storage?

18. If no on the previous question, why not?

Table 30: If no on the previous question, why not?

Comment	**Quantity**
Too complicated	4
Leave it plugged into the socket at home	4
Cannot access the storage if the trunk is loaded	3
Hard to wrap it together as tight needed to fit in the storage	3
Easier to put it in the backseat or loose in the trunk	3
Takes too much time	2
Tediously	2
Laziness	1

19. Where do you store your charging cable?

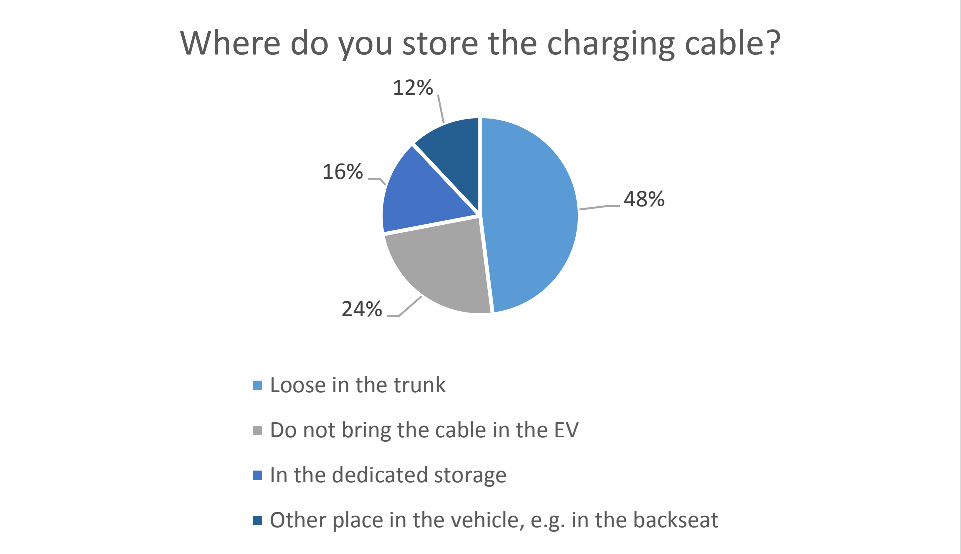


Figure 54: Where do you store your charging cable?

20. If you could wish, where would you like the dedicated storage and how would it look like?

Table 31: If you could wish, where would you like the dedicated storage and how would it look like?

Solution	**Quantity**	**%**
Core winder	45	34
Dedicated storage over load floor in trunk	45	34
• Bag or pocket	• 16	• 36
• Compartment or net pocket in side panel	• 11	• 24
• Box	• 11	• 24
• Other dedicated storage	• 7	• 16
No comment	25	19
Under load floor in the trunk	11	9
Loose in the trunk	2	1,5
Compartment near the EVI	2	1,5
Always fixed to the charging station	1	1

21. How many charging cables do you have?

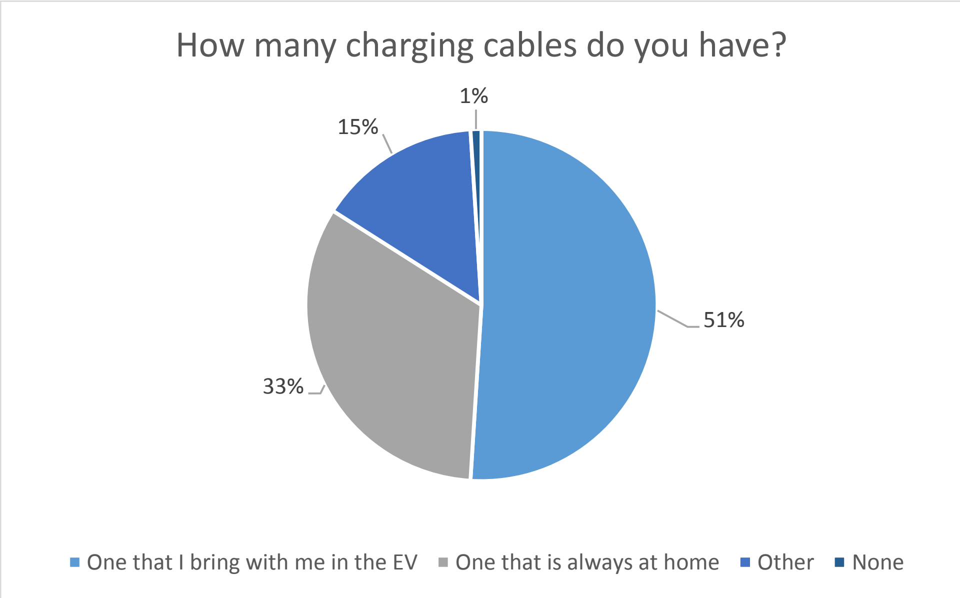


Figure 55: How many charging cables do you have?

22. If other, how many charging cables do you have?

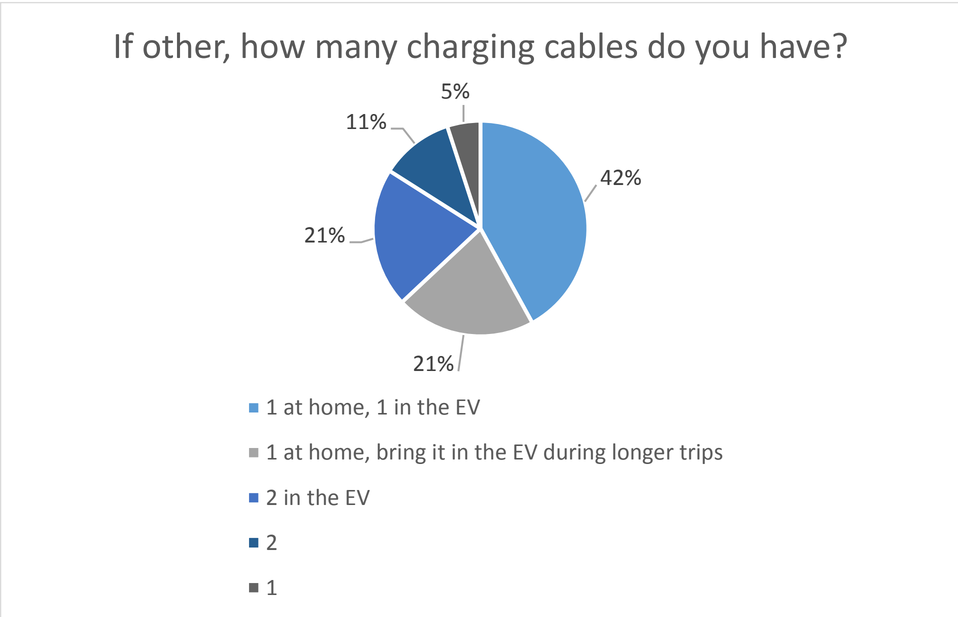


Figure 56: If other, how many charging cables do you have?

23. How satisfied are you with the charging cable storage in your EV?

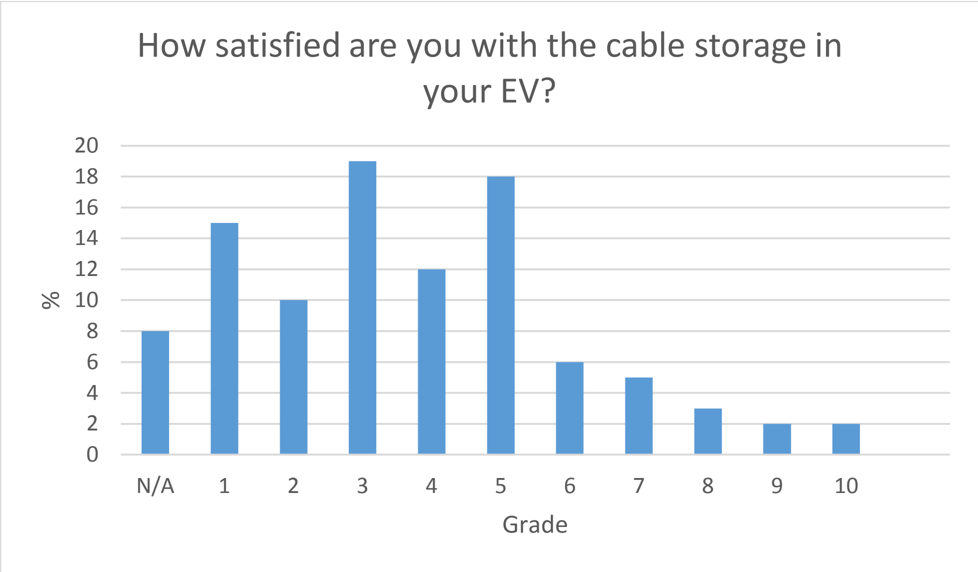


Figure 57: How satisfied are you with the charging cable storage in your EV?

24. How satisfied are you with the placement of the EVI?

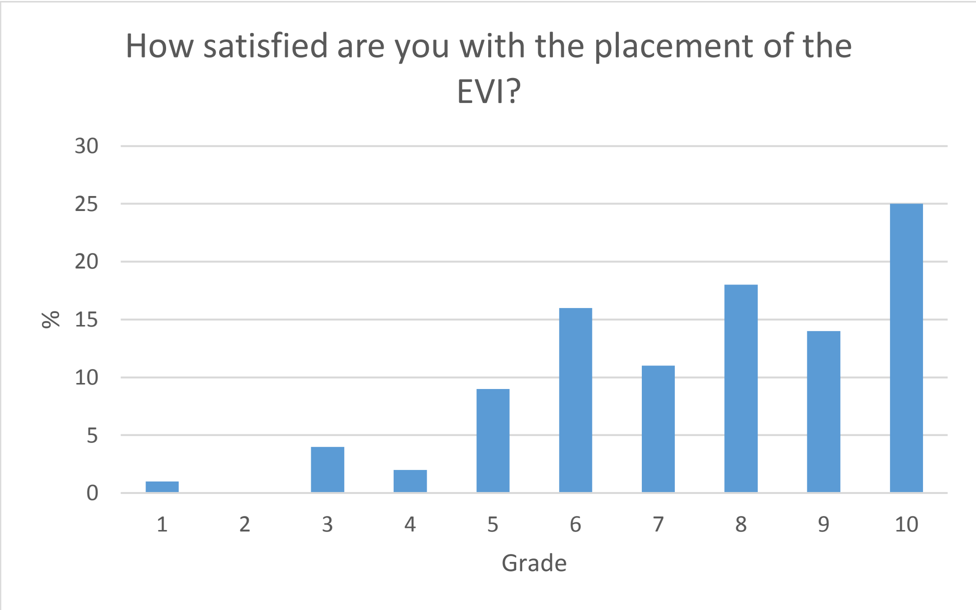


Figure 58: How satisfied are you with the placement of the EVI?

25. What would be required for a higher grade regarding the placement of the EVI?

Table 32: What would be required for a higher grade regarding the placement of the EVI?

Solution	Quantity
EVI placed in the front, protected from snow and dirt	27
Front or back placement of EVI	7
Several EVIs	5
Core winder	4
Hidden EVI	3
EVI placed front right hand side	2
EVI closer to charging cable storage	2
Easier to connect the connector	2
Wireless charging	2
Premium	1
EVI placed back left hand side	1
Standardised EVI	1
Adjustable placement of EVI	1
Minimize the risk of getting dirty	1
Optimized placement, so that the cable is always long enough to reach the charging station	1
The EVI door should not stand out when opened	1

26. Do you check the feedback light when you have connected the connector to the EVI?

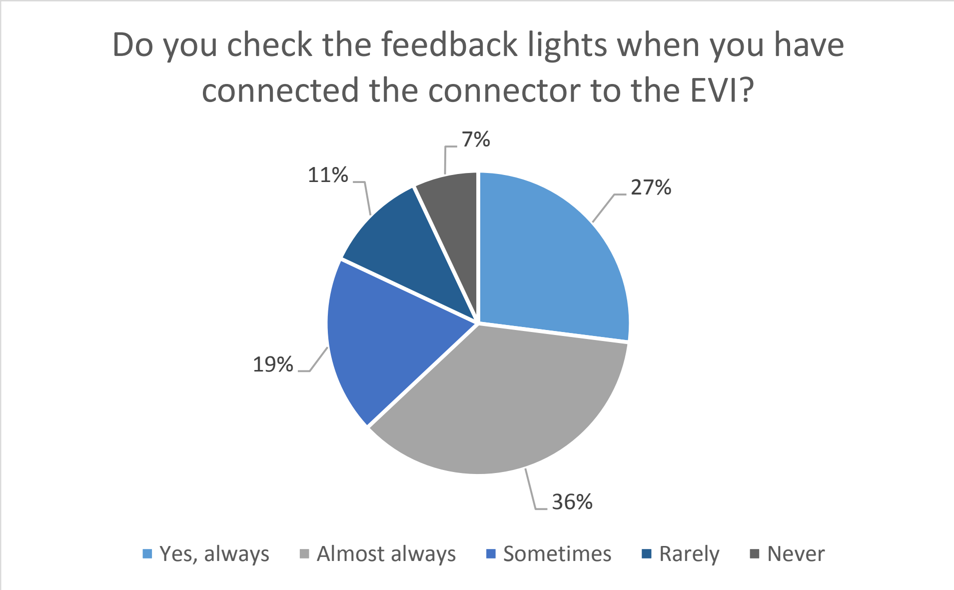


Figure 59: Do you check the feedback light when you have connected the connector to the EVI?

27. Why don't you check the feedback lights?

Table 33: Why don't you check the feedback lights?

Comment	Quantity
Gets the information in the app	11
Trusts that it is working	9
Checks the feedback on the charging station	2
Gets audial feedback from the connector	2
Checks the feedback on the control unit	2
Does not care if the car is charged	1
Does not know	1

28. How satisfied are you with the feedback light in the EVI?

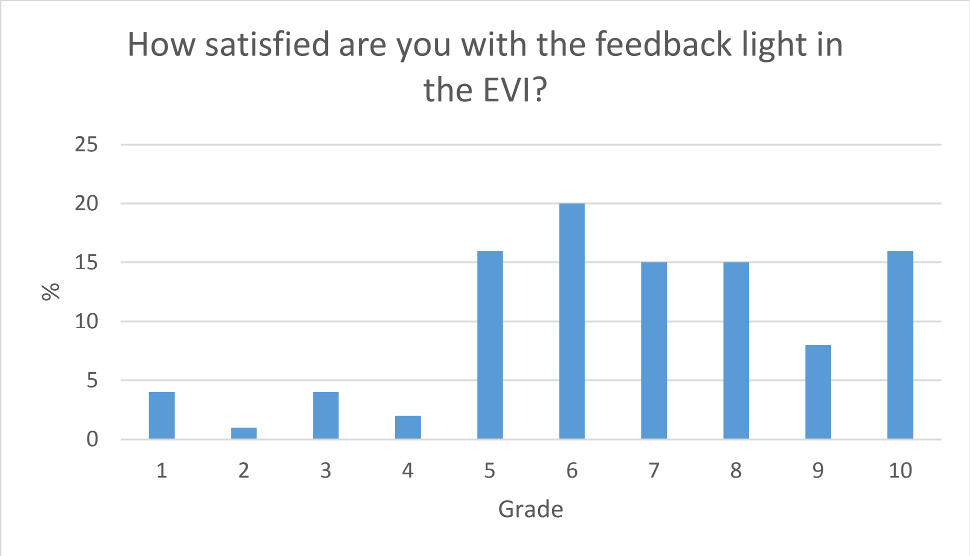


Figure 60: How satisfied are you with the feedback light in the EVI?

29. What would be required for a higher grade regarding the feedback light?

Table 34: What would be required for a higher grade regarding the feedback light?

Comment	Quantity
Better explanation of the different feedback colours	8
Faster feedback	5
Better feedback with clearer and brighter colours	4
LED light in windshield	3
Feedback in app	2
Interest in the function overall	2
LEDs with relevant numbers lit to see charging status	2
Better placement of light, visible from every angle	2
More distinct feedback	2
Likes the feedback on the control unit better	1
More different colours	1
Show percent of charging in display	1
Brighter light	1

Less bright	1
Indicator in the turn signal	1
Red light when not charging	1
Did not know that the feedback light existed, should be more obvious	1

30. How satisfied are you with the depth of the EVI?

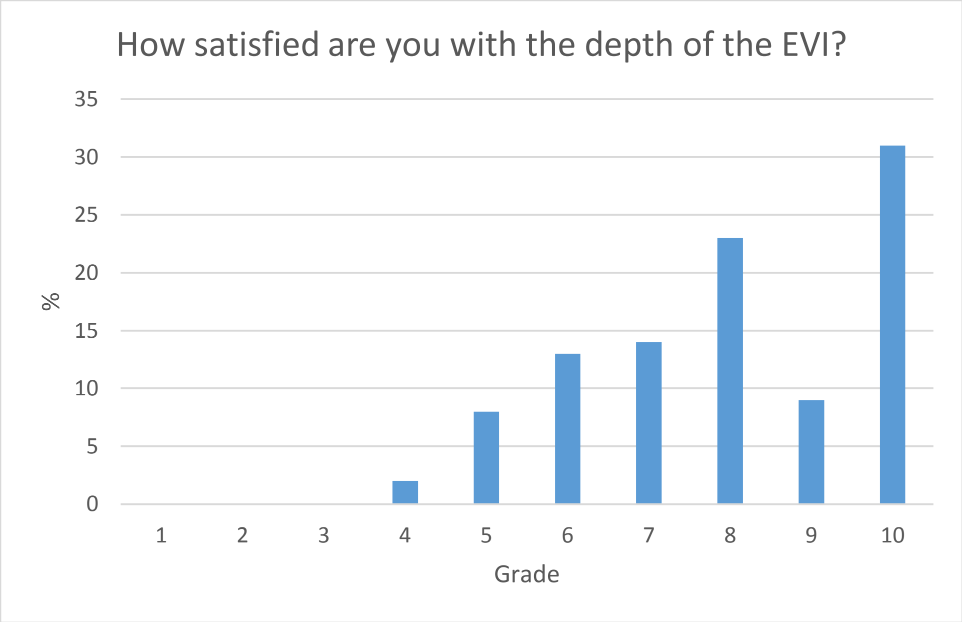


Figure 61: How satisfied are you with the depth of the EVI?

31. What would be required for a higher grade regarding the depth of the EVI?

Table 35: What would be required for a higher grade regarding the depth of the EVI?

Comment	**Quantity**
More shallow	5
Deeper for better protection	2
Better angle to improve the access to the EVI	1

32. How satisfied are you with the opening mechanism of the EVI door?

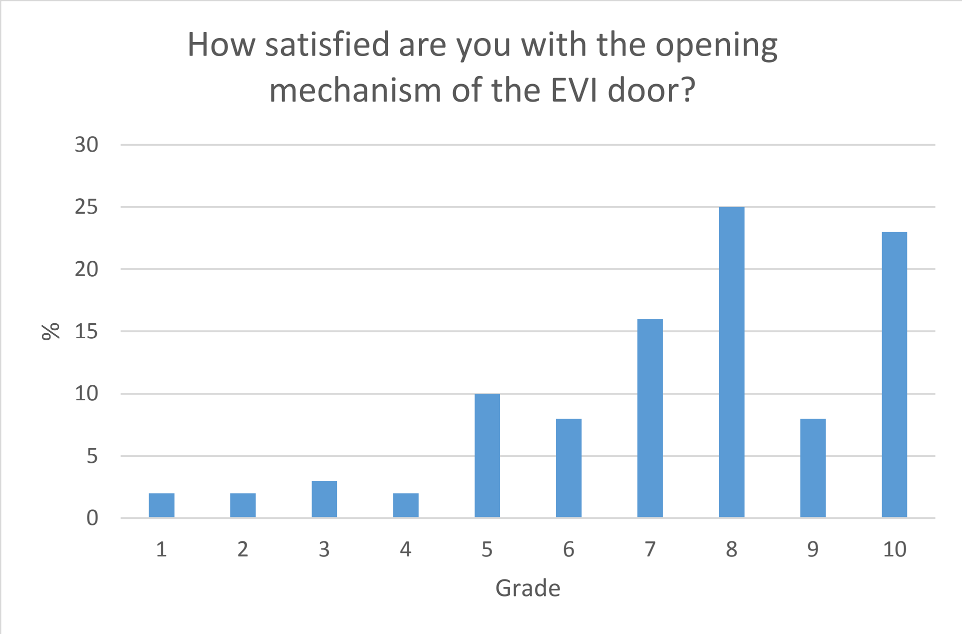


Figure 62: How satisfied are you with the opening mechanism of the EVI door?

33. What would be required for a higher grade regarding the opening mechanism of the EVI?

Table 36: What would be required for a higher grade regarding the opening mechanism of the EVI?

Comment	**Quantity**
Easier to open/close overall and when icy/snowy	13
Automatic	11
More robust	9
That it always closes properly	8
Integrated lid	5
Better protection of EVI against snow/ice	4
Electrical opening mechanism	4
Avoid getting dirty	4

Open the EVI from inside the vehicle	4
Same mechanism as for the fuel tank door	3
Premium	3
Minimize the risk of scratching the paint	3
Tighter door to the vehicle	2
Less force when pushing on the door	2
Open on the key/connector	2
That the cable does not get stuck in the EVI	1
Avoid trouble with the locking mechanism	1
Inductive charging	1

34. How would you like the EVI door to be opened?

Table 37: How would you like the EVI door to be opened?

Comment	**Quantity**
Electrically	7
Opened automatically when the connector is close	7
From inside the vehicle	6
Better closing mechanism, that it really closes properly	5
EVI door with integrated lid	2
Keyless	2
Same as the fuel tank door	2
Hidden	2
Open upwards	1
Close without having to clean off the dirt	1
Turn/slide the door	1
No EVI door at all, wants inductive charging	1

Spring system on EVI door	1
Button on connector	1
Button on key	1
More robust	1
Not having to unlock with the key	1

35. How easy is it to connect the connector to the EVI when it is light outside?

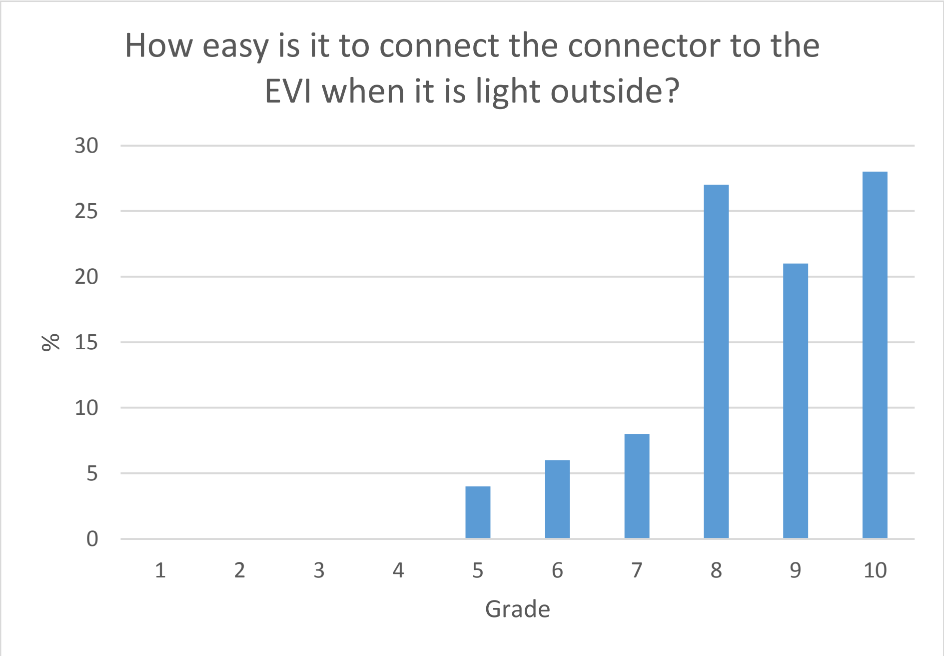


Figure 63: How easy is it to connect the connector to the EVI when it's light outside?

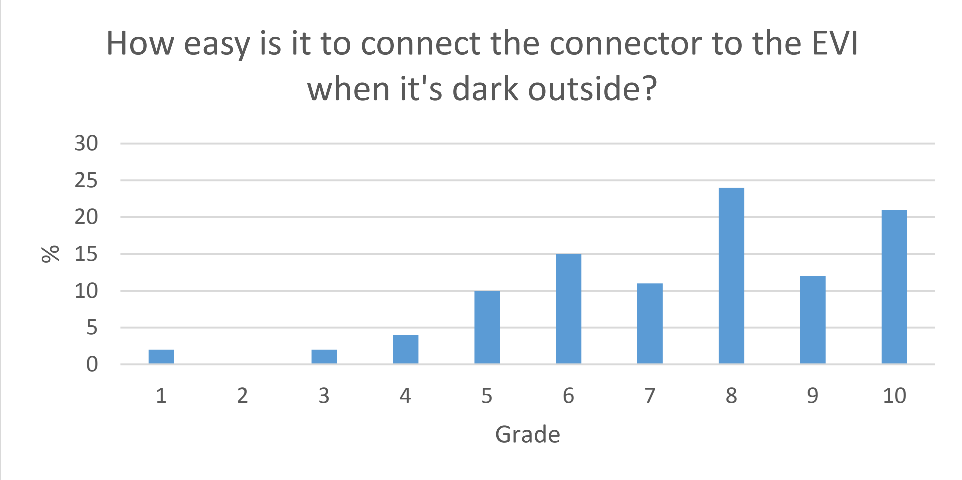
36. Do you have any idea what would make it easier for you to plug in the connector to the EVI when it is light outside?

Table 38: Do you have any idea what would make it easier for you to plug in the connector to the EVI when it is light outside?

Solution	**Quantity**
Core winder	7
Easier to fit the connector	2
Remove extra lid	2
The connector should not end up obliquely	2

Better feedback that the connector is plugged in correctly	3
Green feedback light instead of blue	1
Less force to plug in the connector	1
Better angle of EVI	1
Less heavy connector	1
Shallow EVI	1
Inductive charging	1
Magnetic locking mechanism	1
There should not be any up or down on the connector	1

37. How easy is it to connect the connector to the EVI when it is dark outside?



38. Do you have any idea what would make it easier for you to plug in the connector to the EVI when it is dark outside?

Table 39: Do you have any idea what would make it easier for you to plug in the connector to the EVI when it is dark outside?

Solution	**Quantity**
Better illumination	18
Better feedback light	3
Core winder	3
LED lights around the EVI	2
Illumination in the EVI	2
LED light on the connector to use as a flash light	2
Better feedback that the connector is plugged in properly	2
Green feedback light instead of blue	1
Light that marks where the EVI is placed	1
Illumination further into the EVI	1
Shallow EVI	1
Inductive charging	1
There should not be any up or down on the connector	1

39. How satisfied are you with the overall charging procedure in your EV?

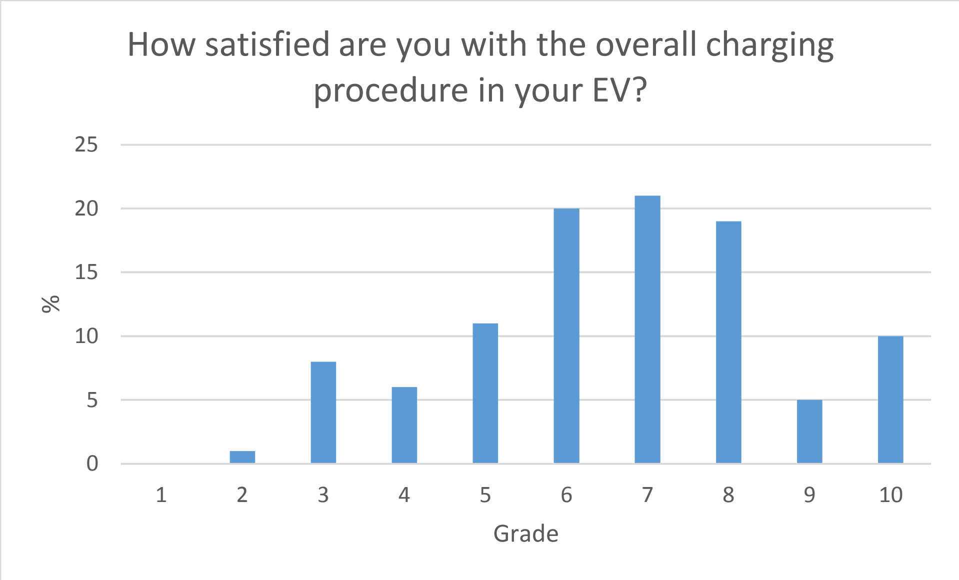


Figure 64: How satisfied are you with the overall charging procedure in your EV?

40. What would be required for a higher grade regarding the overall charging procedure?

Table 40: What would be required for a higher grade regarding the overall charging procedure?

Charging cable	
More flexible cable	4
No control unit	2
Easier handling	2
Have a suspension loop on the control unit	1
Longer cable	1
Shorter cable	1
Less force to adjust the ampere setting	1
Charging cable storage	
Core winder	7
Avoid having to handle a dirty cable	4
Avoid having to open the trunk to store the cable	1

EVI	
Longer time before the connector locks into the EVI after one unlock the vehicle	2
Better opening/closing mechanisms of the EVI door	2
Front placement	2
Better illumination	1
EVI placed front right hand side	1
Easier to find EVI when dark	1
Automatic opening of EVI door	1
Better locking mechanism for the connector and EVI	1
Avoid struggle when connecting the connector to the EVI	1
Better placement of EVI	1
Faster feedback	1
Less force when connecting the connector to the EVI	1
Button on connector to unlock it from EVI when using keyless	1
Other	
Faster charging	37
Wireless charging	12
Improved battery range	7
Having to charge less often	4
Be able to fast charge the PHEV	4
Cheaper electricity	1
More charging stations at work	1
Less steps included in the charging procedure	1
More reliable charging stations	1
Better keyless solution	1
SMS from the app if the charging is interrupted	1

41. What do you think about the charging procedure compared to refuelling a fossil fuelled vehicle?

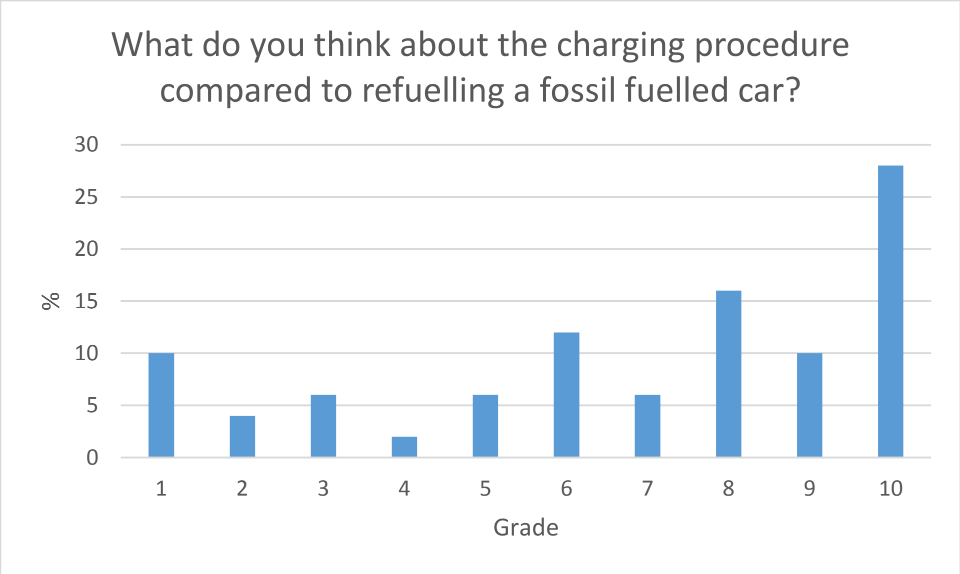


Figure 65: What do you think about the charging procedure compared to refuelling a fossil fuelled vehicle?

Appendix E Complete results from workshop

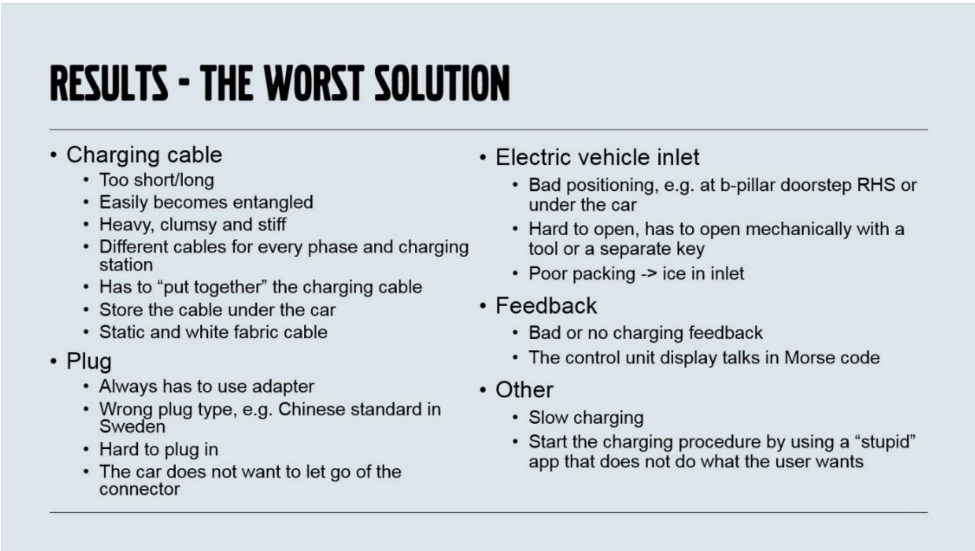


Figure 66: The results from "The worst solution" exercise

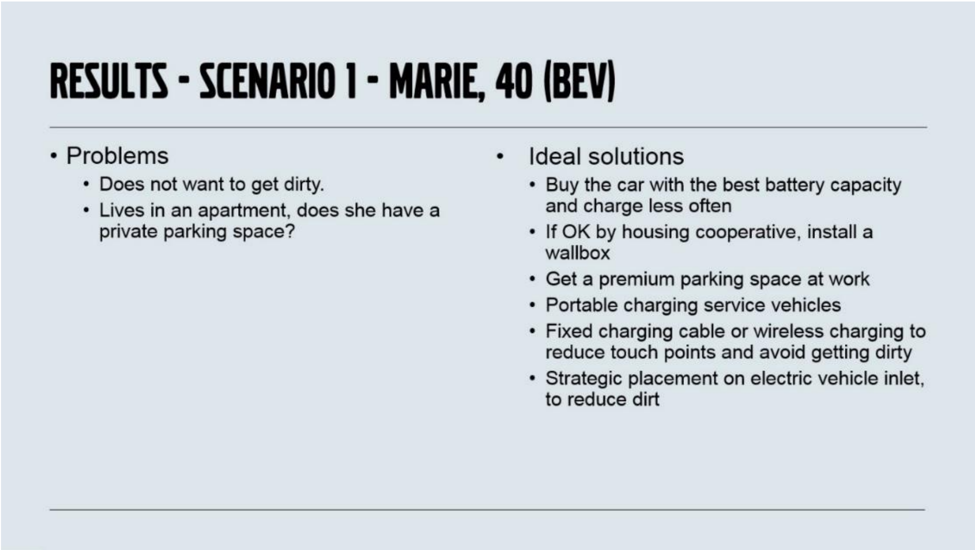


Figure 67: The ideal solutions for Scenario 1

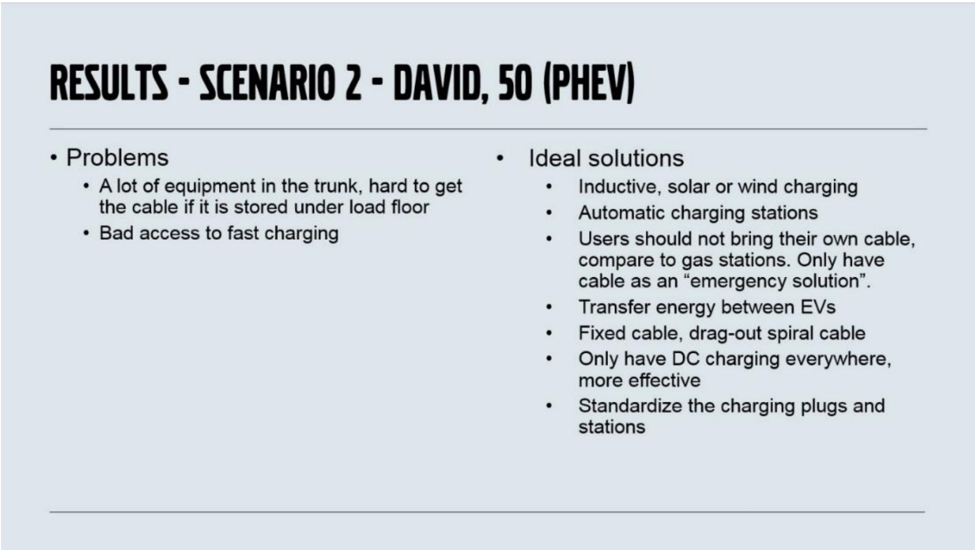


Figure 68: The ideal solutions for Scenario 2

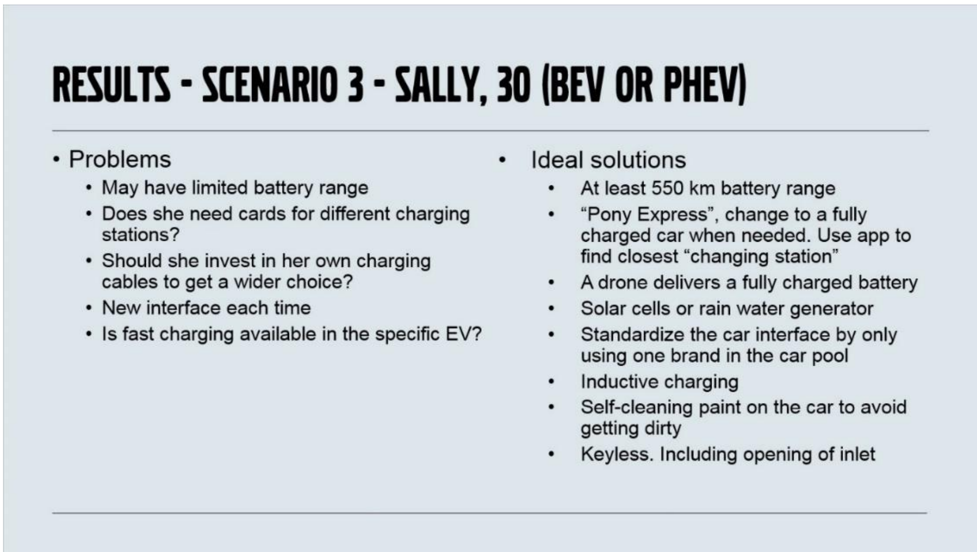


Figure 69: The ideal solutions for Scenario 3

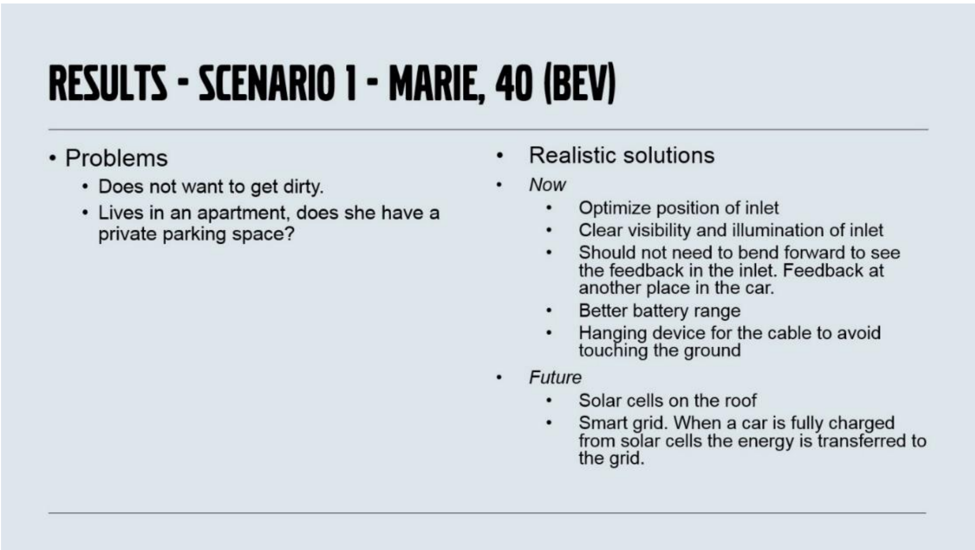


Figure 70: The realistic solutions for Scenario 1

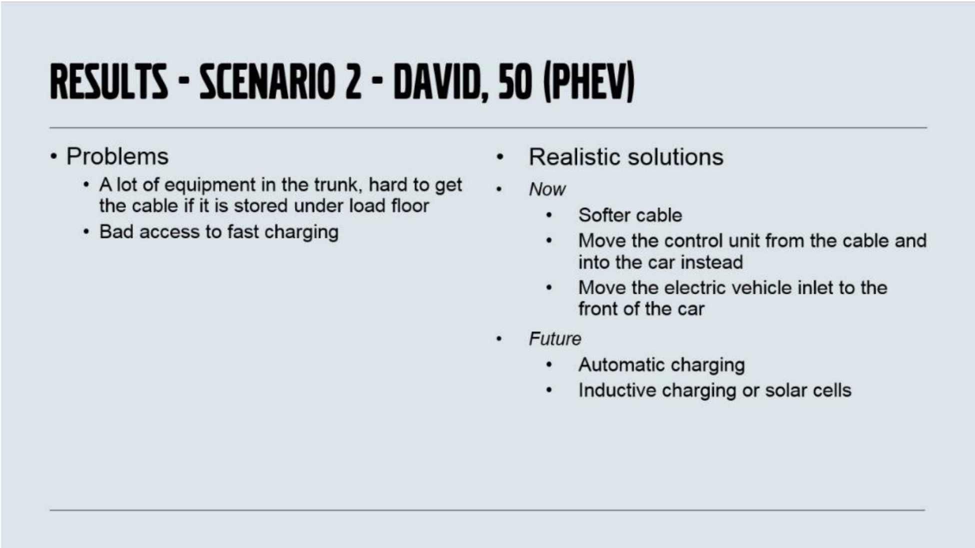


Figure 71: The realistic solutions for Scenario 2

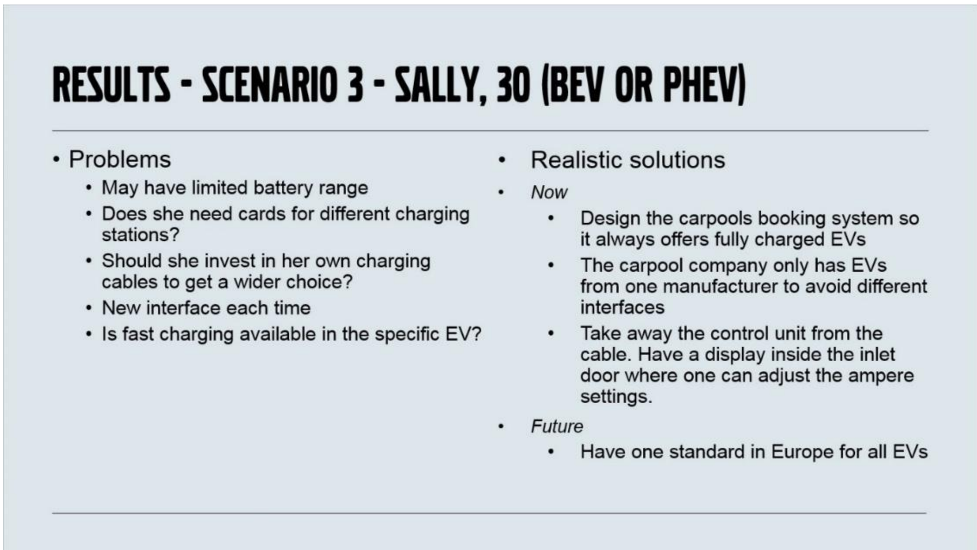


Figure 72: The realistic solutions for Scenario 3

Appendix F Complete results from user tests

Table 41: Complete result user test – charging cable handling

Cable stiffness	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Average**
Concept 1: Yellow Mode 3	8	6	5	8	5	6	7	7	6	7	7	7	7	6,6
Concept 2: Red Mode 3	6	3	4	6	5	7	5	5	6	4	4	5	6	5,1
Wrap the cable together	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Average**
Touch fasteners mode 2	3	5	5	7	3	7	5	1	6	6	8	7	6	5,3
Portable "Wallbox"	6	2	2	5	3	7	3	6	8	4	2	3	4	4,2
Control Unit	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Average**
Control unit middle of cable	6	5	3	6	5	7	5	3	6	6	3	5	6	5,1
Control unit on schuko	7	7	6	3	5	5	4	4	4	5	5	7	4	5,1
No control unit	4	3	8	5	7	8	8	5	4	4	7	9	8	6,2
Connector release	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Average**
Type 1 connector with a latch	2	5	7	6	8	7	6	5	5	6	4	6	7	5,7
Type 2 connector without a latch	6	3	6	6	7	9	5	7	6	6	6	7	7	6,2
Type 2 connector with a touch button	8	8	7	8	9	6	7	7	9	7	8	9	9	7,8
Cable handling	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Average**
Yellow mode 2/3	5	7	4	6	6	5	6	5	6	6	7	7	7	5,9
Coiled cable	8	4	5	6	8	8	8	7	7	3	4	10	6	6,5

Cable storage	1	2	3	4	5	6	7	8	9	10	11	12	13	Average
Yellow mode 2/3	5	7	4	6	6	5	6	4	6	6	5	7	6	5,6
Coiled cable	8	4	6	7	8	8	8	6	7	3	6	10	7	6,8

Table 42: Complete result user test - cable storage

Storage unloaded trunk	1	2	3	4	5	6	7	8	9	10	11	12	13	Average
Lose	4	7	5	5	5	3	3	4	4	6	4	6	1	4,4
Container with a hook	7	4	2	7	6	5	5	1	7	7	6	6	7	5,4
Soft weekend bag	5	6	2	6	2	2	4	5	6	4	9	6	9	5,1
Small hard bag	6	6	2	6	2	2	4	1	6	7	7	8	8	5,0
Net on side	6	7	2	6	6	4	7	4	7	7	8	8	5	**5,9**
Plastic box	4	7	2	6	6	5	3	1	5	5	4	5	4	4,4
Under load floor with net	4	5	2	7	3	6	3	2	5	8	6	8	3	4,8
Under load floor without net	3	1	2	7	2	4	3	2	6	9	6	8	4	4,4
Storage loaded trunk	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Average**
Lose	4	6	3	4	3	3	3	4	2	5	4	4	1	3,5
Container with a hook	7	3	7	8	6	7	4	3	7	2	6	7	5	5,5
Soft weekend bag	5	6	4	6	2	2	5	5	7	3	9	6	8	5,2
Small hard bag	6	6	5	6	2	6	6	1	7	5	7	8	8	5,6
Net on side	7	5	5	6	6	4	7	1	8	4	8	8	7	**5,8**
Plastic box	4	3	4	6	3	5	3	1	5	3	4	4	4	3,8
Under load floor with net	5	5	6	5	3	6	2	1	5	3	4	4	3	4,0
Under load floor without net	4	1	5	5	2	6	2	1	5	4	4	4	4	3,6

Table 43: Complete result user test - EVI placement and feedback

Opening EVI door	1	2	3	4	5	6	7	8	9	10	11	12	13	Average
Concept 1: With a	8	7	2	3	5	5	9	1	2	3	5	2	3	4,2

button inside the vehicle														
Concept 2: With push	8	6	6	9	10	9	9	7	9	8	8	9	8	8,2
Concept 3: With key	5	6	5	3	7	2	10	7	6	2	5	3	3	4,9
Concept 4: With connector	6	7	8	10	4	9	9	6	9	8	10	9	4	7,6
Concept 5: With touch button	8	4	2	3	1	5	9	1	1	3	5	2	3	3,6
Concept 6: Turn and slide	3	6	4	3	4	4	4	3	9	5	3	3	6	4,4

Feedback in form of lights	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Average**
Concept 1: One big light beside the EVI	5	8	7	6	7	9	8	5	8	6	6	7	8	6,9
Concept 2: Three lights on the side of the EVI	6	7	6	9	7	9	3	6	8	6	7	7	6	6,7
Concept 3: Light inside the EVI	5	5	6	3	2	2	4	8	9	6	3	7	6	5,1
Concept 4: LED windshield	8	7	4	8	8	8	9	5	10	4	9	5	5	6,9

Feedback in form of sounds	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Average**
Concept 1: A "buzz" after 5 sec	3	7	4	6	2	7	5	6	7	5	2	4	7	5,0
Concept 2: Click sound after 2 sec	3	6	4	9	6	6	5	4	7	5	3	4	6	5,2
Concept 3: A direct low "buzz"	3	4	4	8	1	7	4	8	9	5	2	4	8	5,2

Unlocking the connector	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Average**

Concept 1: With the key	5	9	6	9	8	7	8	7	8	2	6	3	7	6,5
Concept 2: Keyless, touch door handle	7	8	5	8	8	7	8	7	9	8	7	5	7	7,2
Concept 3: Button on connector	10	10	7	9	10	9	7	8	10	10	8	5	4	8,2
Concept 4: With an app	3	1	2	5	1	1	7	3	2	2	2	2	9	3,1
Closing EVI door	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Average**
Concept 1: Push	7	3	6	9	8	9	8	7	6	8	8	9	7	7,3
Concept 2: Electromagnetic	9	9	7	9	9	10	9	9	9	8	8	9	6	8,5
Concept 3: Slide and turn	2	1	3	5	1	3	2	2	2	3	1	4	3	2,5
Concept 4: Connector	6	9	8	9	6	10	5	3	9	6	9	9	4	7,2
Concept 5: Automatic, 3s after pulling out	7	10	8	10	6	10	10	9	10	9	9	9	8	8,8