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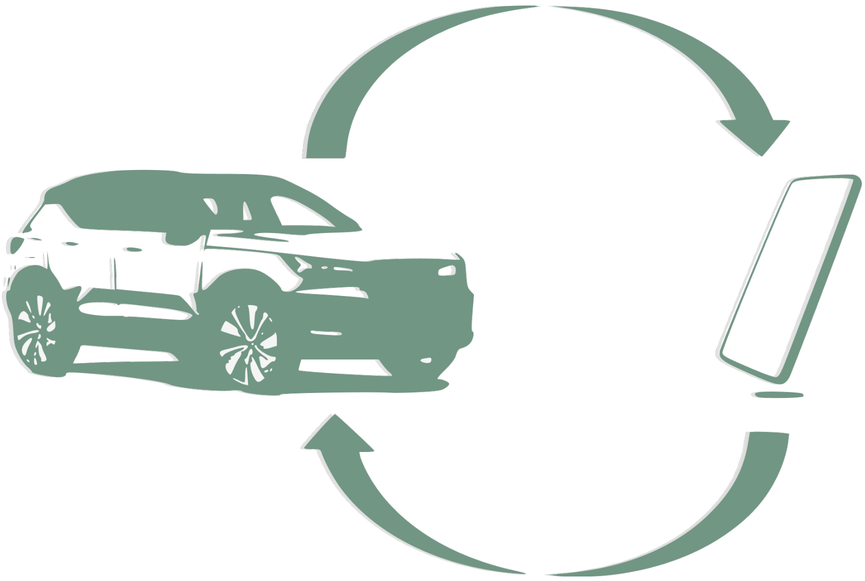

Recommendations for Designing a Cross-Device Coaching Experience

To Enable Energy-Efficient Driving for Electric Vehicle Users

Master's Thesis in Interaction Design and Technologies

EBBA LINDBERG
LINDA SILBERBERG

Department of Computer Science and Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
UNIVERSITY OF GOTHENBURG
Gothenburg, Sweden 2023

MASTER'S THESIS 2023

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EBBA LINDBERG & LINDA SILBERBERG

Supervisor: Mohammad Obaid, Department of Computer Science and Engineering
Advisor: Micaela Nilsson, Volvo Cars
Examiner: Palle Dahlstedt, Department of Computer Science and Engineering

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Department of Computer Science and Engineering
Chalmers University of Technology and University of Gothenburg
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Illustration of an electric vehicle and a smartphone being interconnected. The image of the vehicle was adapted from Volvo Cars

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Abstract

A paradigm shift is taking place in the automotive industry, where combustion engines are replaced with batteries. Electric vehicles powered by clean energy reduce greenhouse gas emissions, for a more sustainable way of living. However, electric cars have a shorter range and are to a greater extent affected by the driver's behaviour and other external factors, such as weather conditions. The need to teach electric car owners about their car's performance has thus emerged. This thesis investigates how to coach users of electric vehicles to drive more energy efficiently while simultaneously enhancing the driving experience by utilising two interconnected devices, a smartphone and an in-car application. By applying a cross-device approach when coaching drivers, the feedback can be tailored to the context.

The research has been conducted with the user at the centre. By executing several user research methodologies and including literature studies on related work, understanding the user group, their context, and the problem space has been strengthened. From the insights gathered, prototypes were developed and evaluated iteratively with users which enabled further investigation into their needs. Based on all findings collected throughout the research, 10 design recommendations were established on the topic. These recommendations address three domains when it comes to developing a cross-device coaching experience: feedback, usability, and device. For example, the research result indicates that coaching via a smartphone should take place before a trip, in the planning phase, and after a trip, for evaluative purposes. Further, a combination of momentary and historic feedback is recommended together with transparent feedback that discloses the impact of external factors on the range.

Keywords: eco-coaching, interface, cross-device, electric vehicle, energy efficiency, range, interaction design, user experience, user-centric design.

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Ebba Lindberg & Linda Silberberg, Gothenburg, May 2023

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Introduction

The increased demand for sustainable products using clean energy has caused the mobility industry to adjust by phasing out cars using combustion engines and instead producing battery electric vehicles (BEVs) to a greater extent. In 2021, sales of electric light-duty vehicles (LDVs), e.g., cars, were approximately 7 million and are predicted to increase to over 30 million by 2030, according to the Stated Policies Scenario [1]. This corresponds to more than 20% of the total share of LDVs. The Net Zero Scenario predicts a much larger expansion where the share of electric LDVs in 2030 is estimated to be 60% [1]. Consequently, there will be a significant growth of electric car drivers in the coming years resulting in the increase of users having to adapt to an electrified vehicle.

1.1 Research Problem

In comparison to cars with combustion engines, electric cars' driving range are shorter and to a greater extent affected by the users driving behaviour. The range is further influenced by additional factors such as battery health and environmental conditions, as described in section 2.1.1. As one might guess, it has thus become difficult for electric car drivers to estimate their range since it is shorter and more unpredictable. Charging electric cars at home covers most of the energy demand for propulsion, but to compete with conventional vehicles, the deployment of more public chargers is essential [2]. Furthermore, cars powered by electricity are more troublesome to charge in an infrastructure still made for gas fuelling. Charging the cars is more time-consuming and at times it can be hard to predict the time required to fully recharge the battery. Therefore, owners of electric vehicles have to carefully plan their trips to ensure that they have enough range to get to their final destination, especially for longer trips. All these factors have contributed to the phenomenon of range anxiety to emerge.

Since most people are unfamiliar with BEVs and possess limited knowledge concerning the cars' performance and technology [3], it has become of interest to Volvo Cars to teach drivers about how their driving behaviour affects the range and to provide them with tools to drive more energy efficient so that the range is optimised. Especially when the number of the user group *electric car drivers* is increasing. In 2021, Volvo Cars launched "Range Assistant" for their electric vehicles, to serve this purpose and to minimise range anxiety amongst drivers [4]. It is an in-car application that gives instant feedback to the user while driving. Metrics such as estimated range, energy consumption and parameters of energy-draining behaviours are visualised on the display, further explained in section 2.2. Today, the information from Range Assistant is only available in the in-car application, and despite it being useful to get feedback while driving, solely providing feedback in the context of driving the car might miss other opportunities to coach users. Thus, other supplementary feedback in other contexts could be valuable and provide additional insights and knowledge to the driver, such as via a smartphone when the users have more time to analyse the data without distractions. Researching how to design a system utilising multiple interconnected devices across different contexts that complements one another, to reach the goal of coaching energy-efficient driving, is therefore of relevance. How this can be done from a user-centred perspective to ensure the coaching enhances the user experience is also important to study.

1.1.1 Research Question

Based on the problem space described, the following research question has been composed:

What are the design recommendations when developing a cross-device coaching experience for electric car drivers?

Cross-device refers to the use of multiple devices, a smartphone and an in-car application in this project, to be utilised in different contexts to provide coaching for every occasion. *Coaching* entails teaching the drivers about their car's energy consumption and helping the BEV drivers to adjust their driving behaviour to be more energy-efficient. This ought to be pursued whilst maintaining a good user experience for the key user group, electric car drivers.

1.1.2 Purpose

The purpose of the thesis is to identify how and where coaching of electric car drivers should be performed to improve their knowledge of how energy-efficient driving can be achieved and increase their understanding of energy consumption and range. This requires exploration into how the mapping of an in-car application, in this case, Volvo Cars' Range Assistant application and a second device, a smartphone, can be designed from an interaction design perspective to ensure a user-centred coaching experience for BEV drivers. Therefore, information about contexts and usage of the respective devices in regard to the key users need to be identified. In addition, an exploration into what type of information, feedback and interactions users need to be coached and where they are best suited in the system, is of relevance.

The goal is to find design recommendations for developing a coaching experience across devices, utilising the in-car application and a smartphone. The recommendations will cover both what content and where the content may be placed in the system to provide valuable coaching for BEV drivers to achieve energy-efficient driving. Further, the goal is also to ensure the design recommendations on coaching provide a better user experience for the drivers. The hopes are to encourage users to minimise their energy consumption, optimise the range of BEVs, and ensure the experience of driving electric is improved thanks to the coaching.

1.2 Delimitations

This study focuses on creating an ecosystem of digital devices based on already existing ones, meaning new artefacts will not be developed. Although this type of ecosystem might be helpful for users of hybrid electric vehicles as well, this study focuses on the coaching experience connected to fully electric cars that are powered exclusively by electricity. Further, the developed design recommendations will only focus on adding to the coaching experience of teaching electric vehicle owners about what affects range and how to lower their energy consumption to drive energy efficiently. This means that other areas that are also important to the drivers across devices, such as charging or having additional smart functions, will not be included.

As important as it is to save energy, the drivers should simultaneously have a pleasant experience. Therefore, it is important to understand how much one can design for a change in the users' behaviour without consequently creating a worse user experience. The trade-off will have to be discussed with all stakeholders involved. If the new eco-coaching system disregards the user experience, there is a risk of the applications not being used. Lastly, this thesis will not have its main focus on road safety. Taking safety measures when interacting with the car on the road is important and part of the user experience. However, to narrow the scope of this thesis, road safety will not be explicitly addressed in the design recommendations.

1.3 Expected Contributions

By conducting this master's thesis and answering the research question, contributions to the research field are expected within several areas. First and foremost, a set of design recommendations for when creating a digital ecosystem, with the purpose of coaching electric car drivers to drive energy efficiently and enhance their understanding of what affects energy consumption, will be provided. Previous research has not explored this field with the user at the centre nor taken a wider perspective by exploring several contexts of the coaching experience. Secondly, conducting user research through a questionnaire, observations, a field study and interviews have created new insights into the user group of BEV drivers. Therefore, this research will contribute to creating a deeper understanding of this new and growing user group along with their wants and needs in different contexts when interacting with their electric car. The design recommendations will also contribute to insights about what type of coaching is important to the user group when it comes to having a pleasant experience of driving electric vehicles.

The research area is a new and emerging field and highly relevant due to the rapid development of electric vehicles, the global strive for sustainability, and the challenge with electricity supply. By sharing these findings, the research can benefit related studies and further research within the field.

2

Background

This chapter presents the relevant background to the thesis, including electric vehicles and their range-influencing factors as well as Volvo Cars and its Range Assistant application.

2.1 Battery Electric Vehicles

Battery electric vehicles are vehicles which use an electric engine powered by a battery pack for propulsion. The globally agreed-upon goals to lower carbon emissions have inevitably affected the car industry, creating a higher demand for electrified cars, and the last few years have been signified by an effort to transition from fossil fuel vehicles to BEVs. They contain a different set of characteristic traits compared to vehicles with combustion engines, leading to new opportunities as well as challenges in the mobility industry. Examples of the advantages of electric vehicles are their high efficiency, zero emission when driving and high comfort level due to the absence of vibration and engine noise. However, there are challenges for the electric car where the most significant ones are the limited driving range and the long charging time [5, 6].

2.1.1 Range-Influencing Factors

Studies have been conducted to determine the main influencing factors limiting the range of battery electric vehicles. Pichler and Reiner [7] provide three main domains of range limiting factors which are *environmental*, *vehicle dependent*, and *personal*. Environmental factors include outdoor temperature, wind, topology, traffic conditions etc., while vehicle-dependent factors cover for instance inside temperature, electric vehicle body (air resistance), weight, and battery capacity. The third category, personal factors, contains elements such as individual driving style, state of electric consumers (heating, AC, lights, entertainment systems), distance to the front vehicle, and plugged electric devices.

The types of driving behaviour that influence the range the most has been listed in a study by Alvarez et al. [8]. They point out four main behaviours, which belong in the personal category, that affect the electric driving range:

- Speed during highway driving
- Frequency and the intensity of braking and acceleration
- Frequency of stop
- Time to collision, which is defined as the following distance from one car to another divided by the speed difference, in the case when the second car is overtaking the first.

2.2 Volvo Cars' Transition Towards Electrification

Volvo Cars is an automotive company founded in Gothenburg, Sweden and the first car was launched in 1927 [9]. In 2020, Volvo Cars delivered its first fully electric car and has demonstrated a determination to lead the development of electrification by putting forward ambitious goals such as producing only fully electric cars by 2030 [10]. Substituting fossil fuel cars with ones that are powered by electricity is not only a big change for the company, but also for the drivers. As mentioned in the introduction, the range of electric cars is shorter and more unpredictable. This has led to some drivers suffering from *range anxiety*, a rather new phenomenon which is defined as "a concern, experienced by the driver of an electric vehicle, that the battery may be fully discharged before a suitable charging point is reached" [11]. Range anxiety is further discussed in section 3.5. To help the user acclimatise and adapt to a BEV and minimise range anxiety, Volvo Cars released an in-car application to teach users what affects their range and how much range they have left depending on their driving behaviour.

2.2.1 Range Assistant Application

The Range Assistant application [12], depicted in figure 2.1, is Volvo Cars' newly launched in-car application that provides the user with real-time feedback on the main parameters affecting the range of the vehicle during driving. The parameters are speed, driving style, which translates to a frequency of heavy acceleration and braking, and climate control. In addition, the application visualises the estimated range based on current driving behaviour together with predicted ranges based on the most optimal and sub-optimal driving behaviour. The battery's momentary consumption (kWh/100km) is also displayed. Further, the application contains a Range optimiser-button which on press optimises the range by restricting performance and functionalities in the car to save energy. The Range Assistant application is meant to coach users to drive more energy efficiently by giving information on what behaviours affect electric range, what actions can be taken to optimise range, and how much range is left to avoid range anxiety.

Figure 2.1: Volvo Car's Range Assistant application. From [4]. Reproduced with permission

Polestar is a car company founded by Volvo Cars and is now a stand-alone brand that in 2017 decided to only pursue premium electrical vehicles [13]. The two companies have a close relationship and frequently collaborate due to their history. Therefore, a version of Range Assistant [14], which can be seen in figure 2.2, is present in Polestar 2 as well [15]. Similar data is visualised, but the user interface of the application differs. This thesis will also consider Polestar's Range Assistant since the companies have worked so closely in developing the products. However, this thesis is written together with Volvo Cars only and Polestar has not been involved.

Figure 2.2: Polestar's version of the Range Assistant application. From [16]. Reproduced with permission

3

Related Work

Literature studies were executed to gather knowledge and insights from previous research conducted in related areas which have contributed to findings relevant to this thesis. These studies and their results are described in this chapter and include research findings within eco-coaching interfaces, multi-device systems, and feedback and coaching. Further, studies on range anxiety and environmental psychology are also presented. Lastly, two studies about visualising electric vehicle data to coach drivers are described which are considered to be of high relevance. Their work tackles a similar research problem and provides results motivating further research within the area.

3.1 Eco-Coaching Interfaces

How technology can be used to promote behaviours that lower the environmental impact and monetary costs can be found in several research studies. Usually, they are referred to as eco-coaching interfaces or eco-feedback systems and are used to provide information to stimulate or sometimes persuade users into sustainable behaviours. Petkov et al. [17] describe eco-feedback as a type of feedback that aims at promoting behaviours:

> "Feedback is a mechanism, through which people can monitor their performance in various activities and evaluate their progress over time [30]". Eco-feedback is a type of feedback that relates to behaviours aimed at reducing the negative human impact on the environment [17]. Research has shown that it is one of the most effective motivational techniques for promoting energy conservation at home. For example, in a comprehensive analysis of past studies, it was found that feedback on energy consumption at home potentially results in up to 15% in energy savings [10]."

With today's technology, any type of feedback is possible, whether it be abstract visualisations or pure numeric data. Concrete, instant feedback could teach the drivers how their actions affect their range, while abstract feedback with symbolic representations could be used to motivate the user to drive more energy efficiently [18]. According to Dahlinger et al. [18], most existing studies neglect the visual design of the feedback and they stress that the design approach will differ depending on the level of abstraction of the feedback. Further, [18] conducted a study where they compared the effect of abstract and concrete feedback on fuel consumption in cars and found that the abstract feedback was more effective. Moreover, what type of feedback users prefer was linked to their motivations. Petkov et al. [17] concluded that between egoistic, altruistic, social, and biosphere motivations. The egoistic feedback, which included monetary savings, was ranked as the most relevant and useful. However, the authors still proposed having a mixture of all types of feedback. It is important that the feedback have a positive or neutral connotation for it to effectively evoke behaviour change [19].

The realm of eco-feedback can be seen as an extension of persuasive technologies, which in turn stems from environmental psychology [20]. Brian Jeffrey Fogg is one of the leading researchers in the field of persuasive technologies and according to him, an aesthetically pleasing interface has a greater chance of persuading the user [21]. In terms of concrete feedback such as graphs, the familiarity and ability to read them are key factors to perceived attractiveness, which is especially true for laymen [22]. In addition, the designer can implement social cues to further persuade the users by equipping the interface with a personality or assigning the device a social role, like "teammate" or similar. Social cues should however not be used when a device is facilitated to improve efficiency as that can negatively affect the efficiency and thus irk the user [21].

3.2 Cross-Device Ecosystems

The number of connected devices keeps increasing and nowadays it is common to perform tasks using multiple artefacts. Levin [23] describes how the devices interconnected in a multi-device system create an ecosystem of their own, resembling ecosystems that can be found in nature. A multi-device system is what the report refers to as a cross-device system. Paterno and Santaro [24] point out in their research the importance of understanding how tools and applications utilising multiple devices can be designed and present a framework containing 10 relevant design dimensions and their possibilities in a cross-device system. For a specific design solution, one (or multiple) dimension can be presumed. According to the authors, a problem with cross-device systems is the various usability issues users face when interacting with them, such as "poor adaptation to the context of use", "lack of coordination among tasks performed through different devices", and "inadequate support for seamless cross-device task performance". Further, [24] describe users' inability to continue performing a specific task after a change of device as a possible source of frustration in these systems. The research also provides results from a related study on how people use multiple devices which found that when interacting and accessing information from such multi-device systems, users already apply various techniques in order to succeed. However, from these findings, it was concluded that there are areas for improvement within cross-device systems, in particular when it comes to the user experience.

To get insights into how smartphone users re-access information in a cross-device system, Bales et al. [25] conducted a study researching the combination of a computer and smartphone by logging users' data, have screenshot-dairy studies and interviews. They discovered that cross-device re-access happens in both directions and that convenience and accessibility of the device were contributing factors when deciding on which device to use. Computer-to-phone re-access took place mostly due to the contextual factor of location. If users realised the information was needed when mobile and/or in another location, the shift to smartphone occurred since location and mobility put several constraints on what devices users can interact with. Time was also a contextual factor that motivated a shift to smartphone use from computers. Users relied on their phone to be available at other times and would re-access tasks at a later stage via phone that initially took too long (postponing), were hindered to be finished by external factors, or where users did not have all information from the start. Social factors were also mentioned as an aspect influencing phone re-access and were motivated by social interactions and the desire to share information with other people. Here, the re-access was usually spontaneous. On the other hand, phone-to-computer re-access happened when there was a technical barrier making the phone not convenient to perform the task. Also, when in-depth research about a specific subject was needed, users usually divided the task and used the phone to initially get brief information, and later shifted to a computer to fulfil the research task, preferably in the "locational context of home " [25].

An important factor that creates digital ecosystems is the sharing of information between the devices [26]. The authors discuss that a perceived hierarchy occurs within the system and a computer is often ranked as the highest. Other aspects such as functional compatibility, commonality, and general attitudes and values towards the devices were identified as contributors to constructing an ecosystem. For a long period of time, interfaces have relied on *consistency* as one of its cornerstones, being one of the 10 heuristics, for user interface design, divided into internal and external consistency [27]. With the rise of multi-device systems, it might be good to revisit what consistency means. Pazmino and Lyons [28] did an experiment where they tried to improve learnability in a multi-context environment at an exhibition at a museum. The authors present a new way of viewing consistency in a multi-device context:

1. **Across-device consistency**
   The interface follows the conventions of other similar devices.
2. **Within-device**
   This type of consistency is achieved when the interface is similar to other applications on the specific device.
3. **Context consistency**
   The interface is based on the context.

Pazmino and Lyons [28] designed three interfaces to evaluate the consistencies and how they interplay with other aspects, such as ease of use. The experiment concluded that learnability and usability do not always correlate, that usability seemed to be the most important, and using within-device consistency performed the best.

Moreover, Levin [23] has also observed the need to broaden the perspective on consistency where consistency refers to the ability to have access to the same information and features on multiple different devices. He presents a framework including the three Cs: *consistent*, *continuous*, and *complementary*. Not only consistency but also continuity and complementary aspects have to be considered for a good user experience when multiple devices are working together. Continuity accounts for achieving the same goal between the devices and the latter includes adapting the functions based on the context. Sørensen et al. [29] present a similar framework to that of Levin but focus on the interactions which they divide into different categories. For example, the authors differentiate between sequential interactions, when people use one device at a time and simultaneous interactions when the user uses multiple devices at the same time. The framework is divided into four categories, each targeting two principles of interaction:

1. **Communality**
   Personalisation: The interaction is tailored to suit the individual based on e.g., data from the user.
   Generalisation: The opposite of personalisation, the device does not know who the user is.

2. **Collaboration**
   Division: The interface is divided to accommodate multiple users at once. One example is the split screen view on the TV in multiplayer games.
   Merging: The users have a shared view, such as in board games where the users see the same thing.

3. **Continuity**
   Synchronisation: The data and its structure are the same across all devices and if changed in one place, it is changed in all the synchronised units.
   Migration: The activity can be transferred across the devices. For example, if you are watching a movie on the tablet, you can continue watching where you left off on your TV.

4. **Complementary**
   Extension: The devices are a direct extension of another device, such as adding complementary functions to a sister device.
   Remote Control: This occurs when one artefact is controlling another device, such as a remote controlling the TV.

Lastly, it is important not to design each application in isolation when creating a digital ecosystem, but to view them holistically and think about how each device can contribute to the different principles of interaction. The multi-user and multi-device interactions should be the determinants, not the applications themselves [29].

3.3 Feedback and Coaching

There are multiple definitions of coaching. Many relate it to training, sometimes synonymously. What distinguish it from other similar forms of training is the relationship between people. Atkinson et al. [19] highlight the importance of the interaction and relationship between the person who gives feedback, the coach, and the person receiving it, the trainee. The feedback is more likely to be effective if they have a strong bond built on trust. Moreover, effective feedback should not be passed from the coach to the trainee only but be a conversation between the two [19].

Immediate and Delayed Feedback

The timing of the feedback is an important factor to consider. Delayed feedback can be used if it is not appropriate to use immediate feedback. Delayed feedback could either mean that the feedback is scheduled a few seconds later to the event to not overload the user cognitively [30], or the feedback can be aggregated and delivered post-task.

Orsini et al. [31] did an experiment where they studied the effect of real-time feedback in cars to promote safe and smooth driving, providing the test objects with either visual or auditory feedback. The metrics used were acceleration and speed, which are some of the same variables that are of interest in energy-efficient driving. The study showed that real-time feedback was helpful for the users. Another study was made by Dijksterhuis et al. [32] where they compared immediate in-car feedback to delayed feedback on a web interface connected to monetary savings. The results showed that both types of feedback were effective, with the people receiving the in-car feedback performing slightly better. They concluded that the most important factor was to make sure that users received the feedback, not whether it is immediate or delayed.

Feedback and Modality

Previous research points towards multi-modal feedback being effective. Vitense et al. [33] studied different combinations of feedback types. Visual feedback is the most common method of feedback, however feedback types such as auditory and haptic are frequently seen as well [33]. Although the combinations are largely dependent on the task and context, their research found that haptic and visual feedback performed the best. Either alone or used together compared to other combinations.

3.4 Environmental Psychology

Froehlich et al. [20] did a comparative study in which they examined environmental psychology and eco-feedback within the field of human-computer interaction (HCI) and how the two correlate. They found that there is a gap to fill between the disciplines in terms of actual behaviour change. The research in HCI often focuses on the visual design, and not the behaviour change. In order to change behaviour, it is important to understand the underlying determinants and motivations for human behaviour and decision-making.

Steg and Nordlund [34] present different models that explain environmental behaviour, one of which is the theory of planned behaviour. The model suggests that humans are rational and links that to our attitude, subjective norms, and perceived behaviour control, which together form our intentions. If our intentions to perform a task are strong, we will put more effort into realising them. Moreover, the norm activation model highlights the importance of personal norms, meaning that our morality impacts our behaviour if we engage in an activity or not. The activation of our personal norms is made up of problem awareness, the ascription of responsibility, outcome efficiency, and self-efficiency. A further extension of this model is the value-belief-norm theory, which put a larger emphasis on altruistic motivations such as values and pro-environmental beliefs. Altruistic and biosphere values reinforce pro-environmental behaviour, contrary to egoistic values. However, according to the experiment that [17] did with motivations linked to user interfaces, the egoistic motivation seemed to be the most common, regardless of how egoistic they had rated themselves.

Above are only three frameworks described and although similarities can be seen between them, there are a plethora of others to be discussed. Kollmuss and Agyeman [35] conducted a meta-analysis on different frameworks that researchers have developed to gain more insight into the disconnect between environmental awareness and acting accordingly, i.e., pro-environmental. In their study, they concluded that the factors that influence pro-environmental behaviour are so complex that putting them into one single model would be useless. Something important they establish early on in their paper is that environmental knowledge has no strong correlation to living a sustainable life. Other factors are more important, highlighting some of the same attributes as in the models above.

Even though some people want to act sustainably, old habits can act as barriers [35]. Habits are a part of the autonomous nervous system, which can be hard to break [36]. Not only can they be hard to break, but they also are a part of forming our values. To interrupt the automatic processes, nudging can be facilitated. Nudging aims to influence decision-making based on presenting information in different ways according to the context [37].

3.5 Range Anxiety

Range anxiety among electric car drivers is directly linked to the current limiting driving range in BEVs according to [38]. However, it has been discovered in several studies that experienced drivers of electric cars face less range anxiety than those unfamiliar with driving BEVs. Alvarez et al. [8] reported that after 3 months of driving, range anxiety decreased by more than a third among UK BEV drivers due to a positive attitude change after being accustomed to the electric car. Furthermore, [8] put forward in their paper the importance of communicating information to drivers to influence driving behaviour and range. A study conducted by Rauh et al. [39] also found that inexperienced BEV drivers had substantially higher range stress than experienced ones. How well the driver understands the electric vehicle's abilities and functioning is therefore closely linked to the level of range anxiety perceived and the driving experience. Rauh et al. [39] draw the same conclusion as [8] by saying how teaching users about range influencing factors and strategies for saving energy can be a beneficial approach to reduce range anxiety. However, further empirical studies need to be done in this field. In their study, [39] also advocate for the facilitation of the learning process by motivating exploration of the BEV range in the form of assisting systems through a gamification concept.

3.6 Data Visualisation for Electric Vehicles

Pichler and Reiner [7] conducted a study to gain further insight into the most influential factors affecting the battery drainage and driving range in electric vehicles. In their research, they recorded trips from an Austrian car-sharing provider to gather data from BEV drivers. Based on the trip data, a web-based interactive exploration tool was implemented to enable analysis and a more accurate range prediction by taking several influencing parameters affecting range into account. In addition, gamification concepts and recommendations were provided in the tool to motivate economic driving. Even though [7] seem to exclude the end-user in the design of the exploration tool, their study highlights the potential of energy-efficient driving by providing an interactive device visualising cause and effect in terms of range from historic trip data to motivate more sustainable driving.

Lundström [40] investigated through several design experiments on battery management how electric car interaction is perceived by users and furthermore, how one can design usable interfaces to provide energy control, empowerment and a better understanding of BEVs. The study was conducted by using the approach of Constructive Design Research, which stems from Research Through Design, and uses design as an active element in the research process. Different interactive interfaces providing electric vehicle data were explored by users and their insights and reflections were collected. From the design-driven research, [40] concluded that instead of solely providing accurate vehicle data as "distance-to-empty", the attention should rather be on how one can empower electric car drivers through the information. In order to do this, it is necessary to provide information regarding energy management which drivers can act upon [40]. They need information about how their driving behaviour influences the range or battery level to feel in control and to be able to plan ahead. However, how these systems ought to be designed to reveal this information is an important design challenge for future studies according to [40].

This conclusion makes the case for the need of interactive systems such as the Volvo Cars' Range Assistant and put forward the need to investigate further how these systems can be properly designed to ensure users are in an informed position and can act upon the information in beneficial ways. All with the intent to empower and coach BEV drivers and make them feel in control of their vehicles. Lundström [40] also explains the need to design energy-sensitive interactions in his research. This means that energy use needs to be balanced between being the responsibility of the designer and the responsibility of the end user.

4

Theory

This section explains relevant theoretical frameworks used in the research. Firstly, Research through Design is introduced which is of relevance since it combines research and design practice. Thereafter, the realm of interaction design is presented where certain areas of importance are highlighted.

4.1 Research Through Design

Research through design (RtD) has emerged in the last decades and was coined by Frayling in 1993. It combines traditional scientific research with design practice and is frequently discussed in relation to interaction design and HCI [41]. There is not yet a shared view on a theoretical framework for how research through design should be performed amongst researchers [42, 43]. However, in RtD, the creation of an artefact is a cornerstone in the conducted research. It enables novel discoveries that otherwise had not been possible. Moreover, the research practice brings constraints to the design practice, making the prototype suitable to meet the theoretical goals [41]. On the other hand, commercial concerns can be overlooked resulting in the attention being put on exploring the potential of technology [43].

Design many times concerns problems that are difficult to solve, in other words, wicked problems. Thus, RtD can be vague and hard to evaluate since the problems are complex [42]. This means that the solution proposed will not guarantee success in regard to the research question and the focus is instead on generative solutions. When using RtD, researchers design for the future and thus, enabling for the creation of artefacts that contributes to the society that we wish to have [43].

4.2 Interaction Design

Interaction design is a broad umbrella term describing the design of interactive products with the purpose of assisting people's way of communicating and interacting in their everyday life [44, p. 9]. It acts as a foundation for many disciplines within research and computer-based system design and includes the methods, theories, and approaches used within the field. According to Sharp et al. [44, pp. 9-10], it can be difficult to distinguish between interaction design and other related design practices such as experience design and user-centred design since many of them overlap. However, the main difference between them is the perspective and methods they use.

The Interaction Design Foundation [45] defines interaction design as the design of interactive products and services to meet precise demands. Further, the focus of interaction design goes beyond the product itself and includes how users interact with it, making analysis and understanding of users' needs, context and limitations of great importance.

4.2.1 User Experience Design

In ISO 9241-210:2010, User Experience (UX) has been defined as "A persons perceptions and responses resulting from the use and/or anticipated use of a product, system or service". It is a holistic perspective and includes all experiences derived from a product both before, during and after use [46]. Law et al. [47] explain how UX goes beyond usability, which primarily focuses on users' cognition and performance when interacting with technology, by incorporating aspects such as user affect and sensation. According to [48], the seven factors that influence UX and describe its meaning are:

- **Useful:** fulfils a purpose
- **Usable:** allows users to complete their goal
- **Findable:** the product itself, and the content it holds should be structured so that it is easy to find
- **Credible:** conveys the correct information and assistance, as well as being of high quality
- **Desirable:** is created through less tangible metrics, such as emotional design and brand image

- **Accessible:** allows users with different disabilities to use it
- **Valuable:** provides value to users and the company that developed it

Moreover, UX design is the process of designing products, services or systems that provide experiences to the user that are meaningful and relevant. The founder of the term User Experience, Donald Norman, explained that a product is a united, integrated set of experiences, making a product more than the product itself [49]. The UX design approach contains methods which are used during the process of designing interactive experiences and ensures that the user's experience becomes the primary focus [50, p. 14]. According to [51], we no longer solely design physical things but we primarily design to engage users in an experience. However, [44, p. 13] point out in their book that one cannot design the user experience. Instead, one designs for a user experience by designing the features that can evoke it.

4.2.2 User-Centred Design

User-Centred Design (UCD) is a design approach which actively involves users in the design process to gain insight into the users and their requirements through a variety of techniques [52]. Sharp et al. [44, p. 39] describe UCD similarly as an approach which bases the direction of development upon users' concerns instead of solely technical concerns. The goal of UCD is to produce usable and user-friendly products by considering different user perspectives and applying repeated iteration and evaluation. To clarify the User-Centred Design approach and what it contains, [44, p. 48] put forward five principles for UCD:

1. Users' tasks and goals are the driving force behind the development
2. Users' behaviour and context of use are studied, and the system is designed to support them
3. Users' characteristics are captured and designed for
4. Users are consulted throughout development from the earliest phases to the latest
5. All design decisions are taken within the context of the users, their activities, and their environment

5

Methods

In this chapter, the design process which will be used in the thesis is introduced and the phases it includes. Further, each method used in the phases is presented and described here.

5.1 Interaction Design Process

In interaction design, different processes can be used, one of which is the Double Diamond by the Design Council [53]. It is a framework visualising the design process and contains four key phases: *Discover, Define, Develop*, and *Deliver*. These phases are the main steps taken in the Double Diamond process, where any method or tool can be applied. The design process is illustrated in figure 5.1.

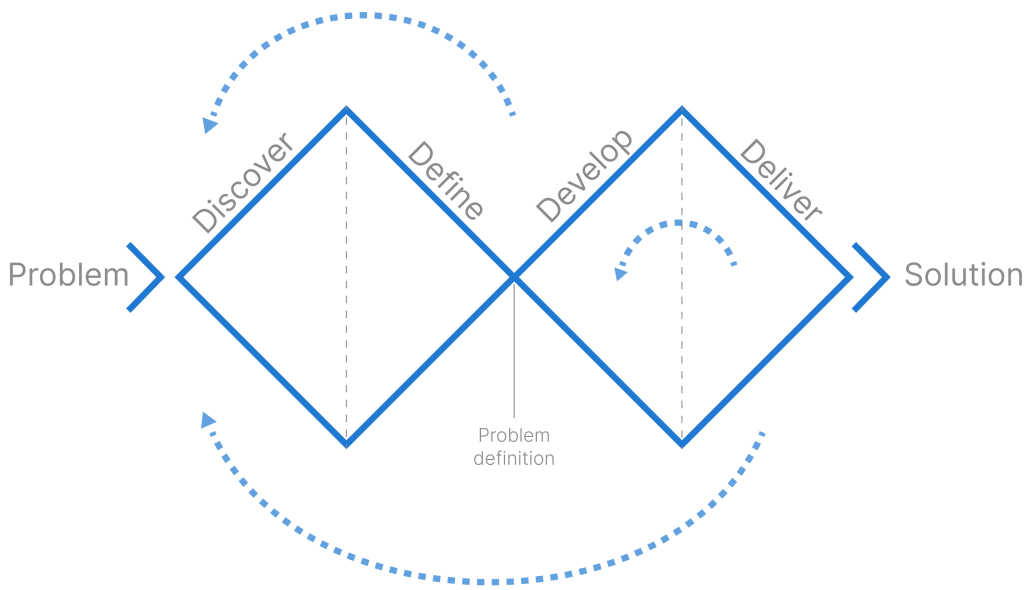


Figure 5.1: Illustration of the Double Diamond design process

The first phase, Discover, focuses on research and identification of user needs. Sharp et al. [44, p. 38] describe this phase as where insights about the problem are gathered. The following phase, Define, is for understanding the findings from the research and aligning the user needs with the problem. This phase results in a clear definition of the challenge based on the insights. Thereafter, the Develop phase starts where multiple solutions are developed, tested, and iterated to meet the requirements. According to [44, p. 50], the main elements of this phase are the design of alternatives, prototyping and evaluation of them. Lastly, the fourth phase, Deliver, is where a final solution is selected and prepared for delivery [44, p. 38].

5.2 Methods for Discover

The methods used during the discovery phase largely focus on collecting data about the users and the environment in which they operate. In this section, observations, questionnaires, and interviews are presented, describing their aim, how they are executed, and when they are suitable to facilitate.

5.2.1 Observations

An observational study is a research method with the purpose of collecting insights into user behaviour. These can be structured in different ways, such as casual or systematic observations. A casual observation is a suitable method to use during the exploratory phase of the design process. As the name suggests, the researchers have not meticulously planned the observation, but instead, have a few areas that they would like to observe. The observation should still be documented through notes, photos etc., even though it is casual. Systematic observations are done with more intent and the researchers could have checklists to take notes and observe in a structured way. Things to look at could be how long time is spent on a certain task or how many times a task is performed. The observations show the researchers what users are doing, but not why. Thus, it is suitable to follow up with an interview to understand the underlying motivations [54, p. 158].

5.2.2 Survey Research Methods

Questionnaires

Questionnaires consist of a collection of questions that are distributed and answered by participants from the user group, often in written form. The questions can be close-ended where the respondent selects from pre-existing answers or open-ended which gives room for more personalised answers. An advantage of questionnaires is that they are easy to distribute which makes it possible to collect a large amount of data that can be analysed statistically [54, p. 214]. To gather high-quality data, it is important that the questions asked are easy to understand and follow a logical structure. To examine the validity of the questionnaire, demographic data can be used to ensure that the group of respondents are diverse or otherwise representative of the user group. Examples of demographic data are age, gender, education, and job [55, p. 114].

Interviews

Interviews are a method for collecting qualitative data based on the first-hand experience of the interviewee. The person being interviewed could either be a user or a stakeholder of interest. As with observations, there are semi-structured and structured interviews. The semi-structured interviews have a guiding set of topics to be discussed, while structured interviews follow a script [54, p. 138]. According to [56], semi-structured interviews are usually seen as the format used when collecting qualitative data. Structured interviews, on the other hand, commonly produce quantitative data. The sample of interviewees should be carefully selected and share similarities related to the research question. The purpose of the purposeful sampling of interviewees is to maximise the richness and depth of the qualitative data in order to address the research question [56]. In qualitative data collection, researchers often talk about *Theoretical saturation*. It occurs when no new insights are gathered from the data samples and is a widely accepted condition to discontinue the data collection phase. For a relatively homogeneous target group, 9-17 interviews are necessary to reach theoretical saturation [57].

5.3 Methods for Define

In this phase, the users' needs and requirements are established. Affinity diagrams were used to analyse and contextualise the data collected in the previous phase. Methods used in this project to further understand the users and the contexts were persona and scenario, before finally summarising the findings in a user requirement list.

5.3.1 Affinity Diagram

Affinity diagram is a technique used to bring meaning and structure to the gathered data by identifying common themes and narratives. The process results in an affinity diagram where data is well organised into clusters based on their resemblance [44, p. 323]. Initially, data points collected from user studies are written on one sticky note each, preferably with source referenced, and placed on a board. Thereafter, sticky notes which are similar in their underlying message are grouped together, creating the diagram [54, p. 12]. When exercising this method, it is important to not define the related themes beforehand, but instead, let the process reveal the cluster in an organic way. Thereafter, each cluster should be given a name relevant to the theme it represents [54, p. 12].

5.3.2 Persona and Scenario

Personas are archetypes of typical users, created based on the data gathered in the previous phase and the analysis of it. The purpose of a persona is to give the design team a shared understanding of who they are creating the product for [54, p. 170]. Common information to include in a persona is name, photo, demographics, and ethnographic information such as beliefs and goals.

A scenario is a fictional narrative that describes activities a typical user would partake in, with the aim of providing insights into how a design concept is used to explore requirements and user needs in the right context [44, p. 408]. Scenarios support the design of meaningful products or services that are convenient in users' daily activities by focusing on telling a story of what the technology enables rather than technical details [54, p. 190]. By phrasing a scenario, user goals, behaviours and artifacts included in a certain activity and context can be described. This provides a deeper understanding of the users and their constraints, irritations, and facilitators when performing a task in different situations [44, p. 408].

5.3.3 Requirement List

According to [44, p. 387], a requirement is "a statement about an intended product that specifies what it is expected to do or how it will perform". Through the activity of requirement analysis, these statements are discovered, defined, and captured based on previous user research and data collection. One way of capturing requirements is through user stories which represent the functionality of value for the user, presented in the following format: *As a <role>, I want <behavior>, so that <benefit>*. Further, user stories can capture the user experience and usability goals of the product as well [44, p. 388].

Vijayan and Raju [58] explain how the goal of eliciting requirements is to define what problem needs to be solved. When choosing which techniques or methods to use in order to gather data to find the requirements, the available resources and time need to be considered. Examples of methods to use are, according to [58], interviewing, questionnaire, workshops, role playing, prototyping etc.

5.4 Methods for Develop and Deliver

The last two phases of the double diamond were combined into one in this thesis. Methods used here aimed at understanding the user journey and developing proof of concepts. Also, the methods used to evaluate the concepts and analyse the feedback gathered is presented.

5.4.1 User Journey

A user journey map is a form of research deliverable visualising users' experiences when interacting with a multi-channelled product or service. [54, p. 244]. The map is a flow chart displaying the major phases a user goes through when interacting within a system on the horizontal axis. On the vertical axis, important metrics to uncover within each phase are pinpointed. For instance, the user tasks, goals, needs and thoughts, etc. [59]. These interactions are commonly categorised into positive, negative or neutral experiences from the user's perspective. By doing this, the user's experiences in a larger context in which a product or service is used can be overviewed and understood. Further, it helps to identify areas of improvement by identifying where in the journey of interactions a negative experience occurs [54, p. 244].

5.4.2 Benchmarking

Benchmarking is a method applied in order to measure, compare and identify best practices across an industry [60]. The definition of benchmarking varies and has evolved over time. Anand and Kodali [60] have reviewed several of these definitions and conclude that benchmarking can be described as:

> "a continuous analysis of strategies, functions, processes, products or services, performances, etc. compared within or between best-in-class organisations by obtaining information through appropriate data collection method, with the intention of assessing an organisations current standards and thereby carry out self-improvement by implementing changes to scale or exceed those standards."

A commonly used and cited model for benchmarking according to [60] is the Xerox benchmarking model. The model encapsulates the process of benchmarking into four phases, starting with a planning phase where the subject of what is to be benchmarked and which benchmarking partners to analyse are defined. Also, which data collection methods to use to gather data is settled here. The next phase is to analyse the data by defining where there is a current gap in competition followed by an estimation of future performance. The third phase in the Xerox benchmarking model is the integration phase where findings are communicated, and functional goals are established. Lastly, the action phase begins where an action plan is developed, containing necessary recommendations, and thereafter implemented to reach the goals [60].

5.4.3 Brainstorming

Brainstorming is an ideation technique used to generate a large number of ideas in a group setting. It utilises collective thinking by ensuring members of the brainstorming session engage with one another, build on each other's ideas and inspire new ones. Each session has a pre-decided time set beforehand and during the session, the focus is solely on generating ideas by excluding the evaluation of them to make sure a large set of ideas, including experimental and wild ones, are produced. To stay focused on the topic, a Point of View is determined that addresses the specific problem statement or question that is to be explored [61].

5.4.4 Prototyping

Prototyping is the realisation of ideas with the purpose to test and evaluate them. The level of fidelity of the prototype will depend on when in the design process they are being created. In the early stages, it is common to create simple low-fidelity prototypes which enable the designers to try out multiple different concepts. In later stages, refined high-fidelity prototypes, which more closely resemble the final product, are made. [54, p. 176].

Prototypes are experimental artefacts and act as a "physical hypothesis that can be tested" [62]. When conducting design research, prototypes can purposefully be used to support the research by, through its design, generating data from new perspectives. In addition, the activity of prototyping can in itself also serve as a tool aiding the examination of the design space where a research question can be answered [62].

5.4.5 Evaluative Research

Evaluative research aims to gather feedback on the proof of concepts by involving end users, also known as user testing. This type of research benefits from being iterative and collecting input from users and refining the product tested multiple times throughout the whole design process. The evaluation can either take place in a controlled setting where external factors can be monitored. They can also take place in a natural, or close to natural, environment, which more closely resembles a realistic interaction [54, p. 100].

Evaluative research can be done in various ways and conducting a focus group is one of them. A focus group is a qualitative method used to gather opinions, attitudes, and feelings about a product or service from a group of carefully selected participants. A successful focus group creates a group dynamic where the participants view each other as peers without fear of judgment, which helps them in sharing experiences, perceptions, wants and needs with each other. A moderator is also present to guide the conversation to obtain useful insights about what is of value and importance to the group. The result from the focus group should be complemented with other methods of data collection for further investigation and not be seen as the attitudes or opinions of an entire population [54, p. 118].

Evaluative research can also be conducted in an interview format. Through interviewing, subjective perspectives can be gathered from users such as users' perceptions, insights, attitudes, experiences, or beliefs [63]. By applying evaluative interviews, follow-up questions can be asked on a subject that needs further assessment. The interview session should be carefully planned beforehand in order to be successful by determining the focus of the evaluation and the questions that ought to be asked, either in an unstructured, semi-structured or structure composition. The user group and number of participants should also be selected beforehand [63].

5.4.6 Thematic Analysis

Thematic analysis is a method used for systematically identifying meaningful themes from qualitative data. The procedure of thematic analysis begins by identifying interesting features from the collected data, relevant to the research aim. These features, also referred to as codes, act as small units of analysis and are used when building meaningful themes from the data. These themes organise the data analysis and create an overview of identified patterns. The advantage of thematic analysis is its flexibility of being a useful method for both large and small data sets [64].

6

Execution and Process

The execution of each step in the interaction design process is described in this chapter. It follows the framework of the Double Diamond with the phases *Discover, Define, Develop*, and *Deliver*, further explained in section 5.1. The methods applied in each phase of the process and how they were conducted and implemented are described, where the two last phases *Develop* and *Deliver* are combined.

6.1 Discover

The discovery phase aimed at gathering a wide range of data, both qualitative and quantitative information, to understand the problem space as well as the behaviours, wants, and needs of the users. The methods applied here to collect data and the execution of each method are explained in the following section.

6.1.1 Data Collection

A questionnaire, observational study, and field study together with interviews were methods used to collect data. The first three activities aimed at creating a high-level understanding of users' behaviours, motivations towards energy-efficient driving, and needs in terms of coaching. Further in-depth interviews were conducted to gather detailed qualitative information towards the topic.

6.1.1.1 Questionnaire

To collect quantitative data from BEV drivers, a questionnaire was created and sent to 100 electric vehicle drivers. The questionnaire addressed the topics of energy-efficient driving, the Range Assistant application, and the usage of smartphone applications for their cars. To be able to gather data about Range Assistant, drivers of either Volvo or Polestar cars (which both contain the Range Assistant application) were selected to participate in the survey. The questionnaire was distributed through

Volvo Cars' internal collaborative development fleet, which consists of employees at Volvo Cars who lease a Volvo or Polestar car from the company. The questionnaire was only given to drivers of BEVs. The vast majority of questions were mandatory and close-ended with predefined alternatives to select from. However, a few questions were open-ended and voluntary where qualitative data could be entered, see appendix A for the questions asked. This ensured that valuable qualitative insights could be collected from users who wanted to share further thoughts. To distribute the questionnaire, Microsoft Forms was utilised.

The purpose of the questionnaire was to gather a large amount of data from BEV drivers as a basis for the research. In addition, the questionnaire enabled the selection of interviewees by giving the BEV drivers a final question about whether or not they would like to participate in a future interview. Based on their answers and their input in the questionnaire overall, suitable interviewees could be selected. See section 7.1.1.1 for the questionnaire results.

6.1.1.2 Observational Study

An observational study was executed to gain more insights into people's actual driving behaviours when using a BEV. Seven observations were conducted, see table 6.1 for participants in the study. Prior to the observation, a pilot study was run, and some minor changes were made to the structure of the observational study according to the feedback from the pilot study. To recruit participants, an email was sent out to Volvo Cars' employees with a declaration of interest form to fill out if they were willing to participate. They were asked about their age and previous experience with BEVs and the Range Assistant application. In total, 42 people signed up on the form and a subset of eight people to be observed was chosen from this. Purposive sampling was made, which aimed to get a diverse test group regarding the parameters mentioned above. In the study, four out of seven drivers were women, with the age group 20-29 years represented the most. Further, the experience with BEVs varied from familiar, which meant that they had driven BEVs before, and very familiar, which meant that they were frequent users. In the study, an electric car, (either Volvo XC40 or Polestar 2) was utilised. What car they were assigned was based on what car they were most familiar with and the availability of the cars, while also trying to attain an even distribution between the two. Most people stated they had no experience with the in-car application, but some people had used it occasionally. The study took place in Gothenburg, Torslanda during the daytime, avoiding rush hours with long queues. Approximately 45 minutes were spent on each occasion and the observations were done with the participants individually.

Observational study					
Test person	Age	Gender	Vehicle	Experience with BEV	Experience with RA
Pilot	20-29	Female	XC40	Familiar	None
T1	20-29	Female	XC40	Familiar	None
T2	20-29	Female	XC40	Familiar	None
T3	50-59	Male	XC40	Very familiar	Some experience
T4	30-39	Female	XC40	Familiar	None
T5	40-49	Male	PS2	Very familiar	Some experience
T6	40-49	Male	PS2	Very familiar	None

Table 6.1: Participants in observational study

During the observation, the test person drove a shorter route while being observed by a test leader positioned in the backseat to minimise interaction with the participant. See figure 6.1a for the test leader's view. A GoPro camera was mounted on the front passenger seat window and recorded the whole session, as seen in figure 6.1b. Before the test, each participant signed a consent form, ensuring the handling of their data was aligned with GDPR. The general data protection regulation is a privacy and security law that has to be complied with when collecting and processing data from EU citizens [65]. The test began with a short introduction to the thesis followed by a short scenario, where the users had to imagine making a 6-hour drive to northern Sweden, more specifically "Sälen". This location was chosen so that the participant had to reflect on managing their energy. The participants were encouraged to think out loud throughout the observation. Behaviours observed at the initial stage were how and what applications they used to plan their trips. When they started driving, their general driving style was observed and whether they used the existing Range Assistant. Once they had made a drive of about 10 km, they were asked to pull over and park at a gas station. The test leader asked the test person to drive back to the starting point, however, this time making use of the Range Assistant application if it had not been used on the way there. This gave the test leader the opportunity to see how they would interact with the application and if they changed their driving behaviour according to the feedback. Upon return, the participants were asked general questions about Range Assistant and energy-efficient driving and their overall experience during the observation. See appendix B for the full template used and section 7.1.1.2 for the observational study results.

(a) Test leader view

(b) GoPro setup

Figure 6.1: Set-up for observational study

6.1.1.3 Field Study

To gain insights into electric car drivers' thoughts about range, coaching, and energy management, who are not using a car by Volvo or Polestar, a field study was conducted at a charging station north of Gothenburg. The study lasted for approximately 2 hours and seven BEV owners participated, only one of which was a woman. Convenience sampling was used for this study as this was a quick screening to see if the drivers' attitudes aligned with those that had previously participated in the user research for the thesis. The charging station was hosted by another electric vehicle company, meaning that only electric car drivers of this specific brand were present and available for the study. While the drivers were charging their cars, they were asked a set of questions in a structured interview. See appendix C for the template of the questions asked. The interviewer took notes throughout the study, which were later used to aggregate and analyse the participants' answers. When conducting the field study, the data collected varied amongst the participants, where some provided more in-depth answers and others where more brief. In addition, the time to complete each field study interview was restricted, which resulted in answers and emerging topics being difficult to elaborate further on. Therefore, a large set of takeaways couldn't be extracted from the study. However, some important conclusions could be drawn. For the field study results, see section 7.1.1.3.

6.1.1.4 Interviews

From the questionnaire, 10 people were chosen to be interviewed, see table 6.2 for a detailed description of the participants. Similar to selecting participants in the observational study, a diverse sample of interviewees was preferred. Half of the participants interviewed were men aged 50-59 years old. Only two women were interviewed. All interviewees received a consent form to sign before their interview to make sure they were consenting to their data being processed in the thesis. Before the interviews, a semi-structured interview guide was created. See appendix D for the final interview guide. The questions were open-ended, and a set of warm-up questions were written for the initial stage of the interview. The questions were designed to extract the data needed to answer the research question.

Interview participants			
Test person	Age	Gender	Vehicle
Pilot	30-39	Male	N/A
P1	40-49	Male	C40
P2	30-39	Male	PS2
P3	>60	Male	C40
P4	<29	Female	PS2
P5	50-59	Male	PS2
P6	50-59	Male	C40
P7	30-39	Female	C40
P8	50-59	Male	C40
P9	50-59	Male	PS2
P10	50-59	Male	PS2

Table 6.2: Participants in interviews

Further, the findings from the questionnaire and observations were furthermore a basis for the questions asked. The interview guide was tested beforehand through a pilot interview with an expert user who was an employee at Volvo Cars. The pilot interview provided insights into how much time would be spent on each interview, if the questions were understandable, and whether any further questions of interest could be added. A small set of data was also collected here. After the pilot interview, minor changes were made to the interview guide in terms of wording and structure of questions. At the interviews, only the interviewer and interviewee were present. The interview template was used as a guide, following up with probing questions whenever the interviewer wanted the participant to elaborate on the answer. Five of the interviews took place online and the remaining ones were held in person, on-site, including the pilot interview. Each interview was recorded with an audio recorder to support the data collection. See section 7.1.1.4 for the results extracted from the interviews.

6.2 Define

The purpose of the *Define* phase was to establish an understanding of the electric car drivers and their attitudes and wants and needs, connected to energy-efficient driving. This was done by analysing the collected data with affinity diagrams. The insights from those were used to create a persona, a fictional scenario, and a requirement list.

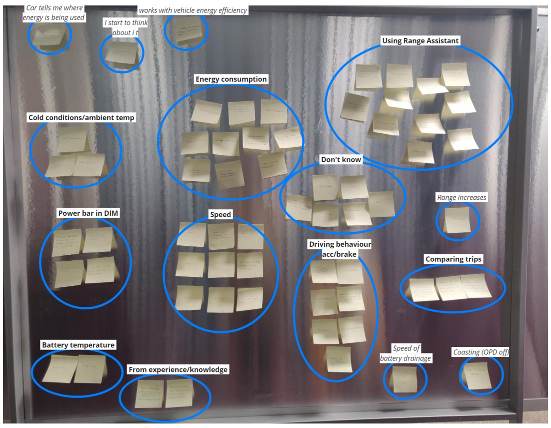
6.2.1 Data Analysis

Multiple affinity diagrams were created with the aim to analyse the qualitative data from the user research. More specifically, they helped to analyse parts of the results from the questionnaire which provided qualitative answers, the observational and field study, and the interviews. The quantitative answers from the questionnaire were instead analysed through statistical tools. All data analysed was conducted by the two authors. When creating the affinity diagrams, relevant data points from the respondents were written down on sticky notes, where some answers resulted in several notes if they covered multiple topics. Thereafter, one note at a time was read out loud and placed on a board. Whenever a note resembled another data point, the two notes were placed side by side. Eventually, larger clusters of data emerged, creating different themes of answers. After all of the notes had been placed on the board, they were further analysed and, if needed, merged with another theme. Each group of sticky notes was named with a general, suiting title based on its content. If necessary, a cluster was divided into multiple sub-categories.

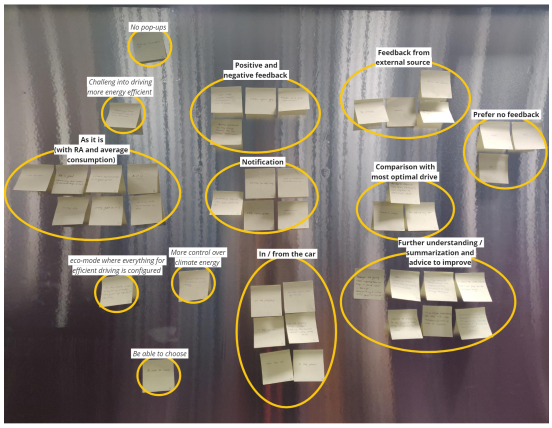
6.2.1.1 Analysis of Responses in Questionnaire

The analysis of the questionnaire responses was divided into two parts, divided into qualitative and quantitative information. To examine the quantitative data, the visualised diagrams and charts generated by Microsoft Forms were thoroughly investigated and if needed, data was inserted into Microsoft Power BI. The reason for visualising the data in Power BI was to be able to apply filters to the graphs in order to isolate the information from what a particular person or group of persons had answered, for a more in-depth analysis. Whereas the graphs from Microsoft Forms were non-interactive. Metrics that were examined were mean and mode values of the Likert scales, and the distribution between the different answer alternatives for the remaining questions. By extracting the data from the survey and putting results from multiple questions in relation to each other, conclusions could be drawn. From the insights, the most important conclusions were summarised.

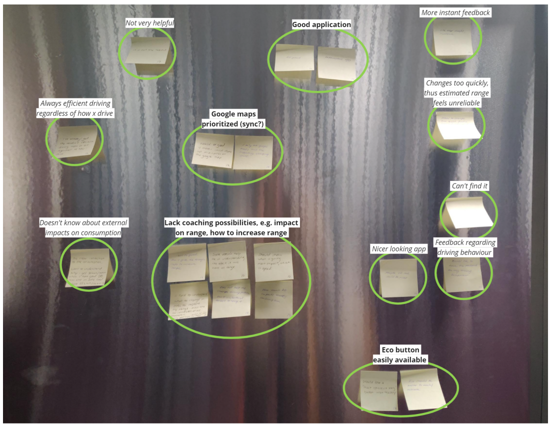
Affinity diagrams were created to analyse the qualitative, open-ended questions from the questionnaire survey, following the procedure of affinity diagrams described above. See figure 6.2 for affinity diagrams. A separate affinity diagram was created for each of the questions, which resulted in four diagrams. Each of the participants had an identification number assigned to them, which also was noted on the post it. This ensured that the answers could be backtracked to each person if more context was needed and to verify that not one participant's answers would skew the analysis. The results from the qualitative and quantitative questions created a better understanding of BEV drivers' habits and attitudes which was necessary in order to create the interview template.



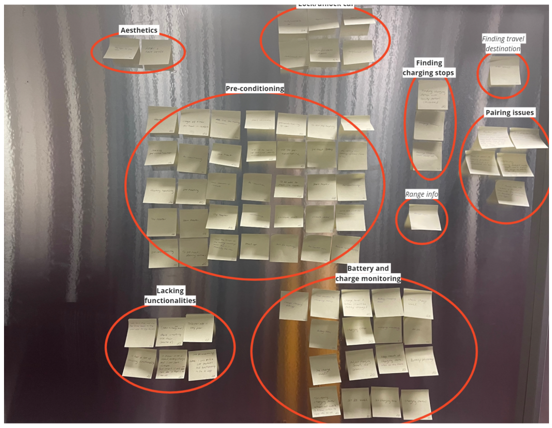
(a) Data from question 10:
How do you know when you are being more or less energy efficient?



(b) Data from question 11:
How would you prefer to receive feedback on how to drive more energy efficiently?



(c) Data from question 17:
Other comments regarding Range Assistant

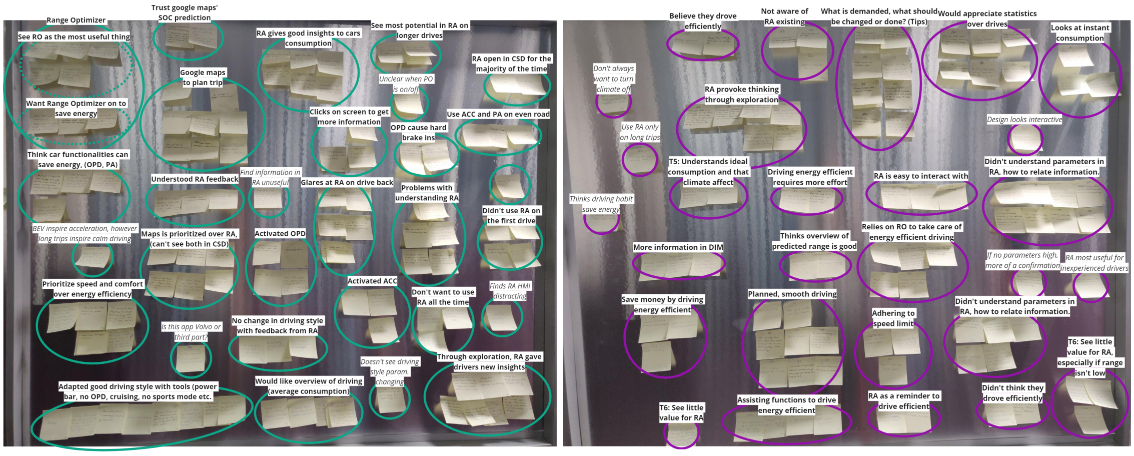


(d) Data from question 20:
What are you most satisfied with when it comes to the car app?

Figure 6.2: Affinity diagrams from qualitative responses in questionnaire

6.2.1.2 Affinity Diagram From Observational Study

The video material recorded during the observational studies was carefully reviewed and all observed elements of interest were noted in an Excel spreadsheet. From the notes, relevant data were extracted and used to create affinity diagrams. Two diagrams were generated, where the diagram seen in figure 6.3a contained observed data and figure 6.3b contained data from the answers to the questions asked at the end of the study. The two diagrams were used to enable the structuring and analysis of the qualitative data. After all the results from the affinity diagrams were listed, important takeaways could be formulated.



(a) Data from observations (b) Data from observation questions

Figure 6.3: Affinity diagrams from observational study

6.2.1.3 Analysis of Field Study

The notes from the structured interviews were compiled to get an overview of the material. All data from the interviewees were noted in an Excel spreadsheet and the answers to the corresponding questions were written in the same column to get an easy overview of the material. Thereafter, one question at the time was analysed and common themes for each question could be established. Since the interviews were very brief, not much time was spent on each question and therefore, the answers were not as elaborate as those in the deep interviews. Thus, only a few, high-level takeaways, could be drawn from the field study. The conclusions were directly related to the questions asked and concerned their attitude toward their range, energy-efficient driving, and what metrics they used.

6.2.1.4 Affinity Diagram From Interviews

The interviews were transcribed using Microsoft Word's built-in transcription service as a tool. From these, qualitative data was collected and analysed with an affinity diagram created digitally in Miro, a digital collaboration tool, due to the sheer size of the diagram that would otherwise be hard to manage if it was physical notes. The diagram is illustrated in figure 6.4. All data from an interviewee were colour coded by assigning a unique colour to their sticky notes, which secured that all data points could be tied to a user. The content and structure of the finalised affinity diagram were thereafter analysed to gain further insights, followed by the major insights being written down.

Figure 6.4: Affinity diagram from interviews

6.2.2 Creating Personas

Two personas were created which portray typical electric car users. The purpose of the personas was to create a common understanding of who the users are and refer to them while developing the design concepts. All the prior data collection was a basis for the personas. However, the affinity diagram from the interviews acted as the main source. Two main types of users could be identified by reviewing the material, either people who were passionate about a sustainable lifestyle or because they were interested in the technology behind it. The personas were given different experience levels with driving a BEV to exemplify the diversity in terms of experience of ordinary electric car drivers. See the result chapter, section 7.1.3 for the personas created.

6.2.3 Formulating Scenarios

From the user research, three distinct scenarios, in which the user group can find themselves, were identified: short trips, long trips, and long trips where external factors vastly affected the range. Drivers' behaviours, motivators, and the coaching needed differed between these scenarios leading to the need for addressing all three and taking them into consideration in the development of design recommendations and design concepts. A text-based scenario was written for each of the three scenarios from a persona's point of view, describing the context and the distinct goals, activities, and thoughts for each scenario. Here, cold temperatures were chosen as an example of an external factor. The purpose of the scenarios was to, in a concise way, communicate different contexts the user group finds themselves in to understand their overall experience in different settings. This will enable a deeper, holistic understanding, useful in the development of design concepts and design recommendations. The three scenarios were also a basis for the development of user journeys later in the process. See the result chapter, section 7.1.4 for the written scenarios.

6.2.4 Establishing Requirement List

To summarise the insights gathered from the *Define* phase, a requirement list was established which presents a set of user requirements. These requirements concern how to design a coaching experience for electric car drivers when utilsing both a smartphone and an in-car display. By finding commonalities in the results from the user research conducted, as well as from the literature study material, requirements could be derived from these sources. The requirements were formulated as user stories in the following format: As a <role>, I want < behaviour>, so that <benefit>. A requirement was created if several takeaways from multiple sources could support it. The purpose of the requirement list was to guide the development of prototypes and to be the first iteration towards the design recommendation list. See the result chapter, section 7.1.5 for the requirement list created.

6.3 Develop and Deliver

In this section, the process for developing the design recommendations is presented. These include creating user journeys, benchmarking e-mobility applications, and developing and evaluating prototypes for the smartphone and in-car application.

6.3.1 User Journey Mapping

User journey maps were created to visualise the actions BEV drivers take when going on a trip and what interactions they engaged in with the car and smartphone. Three different journey maps of today's system were created to demonstrate the user flow of the identified user scenarios: short trip, long trip, and long trip where external factors (in this case cold temperature) affect range. The creation of the user journey maps began with defining what phases to include. Material from the transcribed interviews pinpointed actions BEV drivers commonly took before, during, and after their trip which formed each phase. To get a holistic view of the user's journey, several tasks related to interacting with the car and smartphone, energy-efficient driving and charging were included. The phases were accompanied by a goal to clearly define the objective which made it easier to categorise the tasks and touchpoints into appropriate phases. In addition, pain points within each phase were included that could either be related to tasks that were cumbersome to perform or activities that they wanted to do, but for some reason could not. From those, design opportunities regarding how to solve the pain points arose. See the result chapter, section 7.2.1 for the user journey maps.

6.3.2 Benchmarking e-Mobility Applications

Multiple automotive companies have electric vehicles in their product repertoire and offer different types of energy management and eco-coaching applications, both in the car, but also as smartphone applications. Thus, competitive benchmarking was conducted with the aim of establishing what types of functionalities are already available in other applications and collecting insights from those solutions. The Xerox model was used as a framework during benchmarking with emphasis on the three first phases: planning data collection, analysis of the data gathered, and communication of findings. By doing this, common practices in the electric vehicle industry when it comes to energy management and eco-coaching could be found and used in the development of prototypes.

Six brands that produce electric vehicles and their e-mobility applications were studied. Since most e-mobility applications require the application to be connected to a car to have access to all the functionalities, the benchmarking had to rely on information found in articles, Google Play, App Store, and video demonstrations of the applications, made by either the company or private persons, to learn more about them. An exception to this is the benchmarking of Ford Mustang Mach-e which was performed with an actual car and a connected smartphone. This benchmarking was conducted by exploring and observing features, functionalities, and interactions related to energy management and energy coaching for both the car's Human-Machine Interface and its smartphone application. In the car, there are multiple places where information can be displayed, such as in the instrument cluster or centre stack display. Benchmarking was mainly done for the information shown in the centre stack display of the cars, however, if relevant, features in the instrument cluster were included.

When conducting the benchmarking, commonly found attributes in the smartphone applications were remote controlling of certain functions in the car. This included controlling the climate, lock or unlock the car, and start or stop charging. Monitoring the state of charge (SoC) and seeing the corresponding range was also available for multiple apps. However, as mentioned earlier, the focus of the benchmarking was to explore what features considering energy management and eco-coaching existed both in the car and in smartphone applications connected to the car. Therefore, these remote-controlling features or other functions not relevant to the research question were not highly considered. See table 7.1 in the result chapter for the benchmarking findings.

6.3.3 Development of Low Fidelity Prototypes

The development process of the prototypes began with a brainstorming session with the purpose of ideating multiple design concepts. The personas, scenarios, and user requirements constructed from the user research were used as material during the brainstorming. Insights from the user journeys and benchmarking were also used during the brainstorming as a tool to inspire ideas and solutions. Initially, systematic ideation was performed for both in-car concepts and smartphone concepts by discussing, writing, and sketching ideas. Each idea was reviewed with the intention to estimate how well the ideas fulfilled the requirements and solved the pain points found in the different user journeys. A second brainstorming session followed, to iterate the developed ideas and come up with new ones, where the previous ideas had been proved unfulfilling.

Later in the process, the brainstormed ideas were transformed into wireframes to test different ideas for the devices and iterate upon those. Thereafter, lo-fi prototypes were created. Existing design components were already available in Figma, both for the current Range Assistant and the mobile application. These components and their design language for each device were used as a basis when developing the new prototypes. Today, the applications for the car and the smartphone do not share the same design language, leading to the lo-fi prototypes following the conventions of the respective application. The lo-fi prototypes were only static frames and could not be interacted with. The prototyped frames can be seen in the result chapter, section 7.2.3.

6.3.4 Focus Group to Evaluate Low Fidelity Prototypes

To gather feedback about the lo-fi design concepts, a focus group session was facilitated with end users, consisting of two male BEV drivers in the age group 50-59 years. See table 6.3 for information on the participants. One of the BEV drivers had been a participant previously in the thesis for the questionnaire and interview. As it was hard to recruit people for the focus group, being available at the same time slots, a convenience sample was made, with the criterion that they had to be electric vehicle drivers.

Participants for Focus Group			
Person	Age	Gender	Vehicle
F1	50-59	Male	PS2
F2	50-59	Male	Ford

Table 6.3: Participants in focus group

During the focus group, the participants discussed paper-printed lo-fi concepts for both the smartphone- and in-car application. See figure 6.5 for the focus group set-up. The purpose of the focus group was to gather high-level feedback about the concepts and the context they are used for later iterations.

Figure 6.5: Set-up of focus group

Before the session took place, a pilot focus group was conducted to test the set-up and execution in advance. Three participants engaged in the pilot focus group, all employees from Volvo Cars. The pilot session confirmed that the planned arrangement and set-up were appropriate when it came to evaluating and gathering feedback about the design concepts from a variety of perspectives.

When it was time for the actual focus group with the two BEV drivers, a consent form was handed out at the beginning to ensure the participants agreed upon the handling of their data. Thereafter, an audio recorder recorded the whole session. In the initial stage of the session, the participants were asked to present themselves. The personas created were displayed to the participants to paint them a picture of the user group. Then, they were asked if they saw any resemblance of themselves in the personas. Thereafter, the focus group was performed in three sections with the following execution:

Part 1 - short trip:

1. Present short trip scenario
2. Display A3 paper visualising a simplified user journey for a short trip with the phases *before*, *during* and *after*
3. Introduce different design concepts and place them in the user journey
4. Open and monitor discussion about design concepts and their placement in the user journey

Part 2 - long trip:

1. Present long trip scenario
2. Display A3 paper visualising a simplified user journey for a long trip with the phases *before*, *during* and *after*
3. Introduce additional design concepts and place them in the user journey
4. Open and monitor discussion about design concepts and their placement in the user journey

Part 3 - long trip with external factors:

1. Present long trip scenario in cold conditions
2. Display A3 paper visualising a simplified user journey for a long trip in cold conditions with the phases *before*, *during* and *after*

3. Introduce additional design concepts and place them in the user journey
4. Open and monitor discussion about design concepts and their placement in the user journey

After the focus group, the recorded material was carefully reviewed, where important feedback from end users on the design concepts was written down. Through thematic analysis, the information was grouped into several categories based on the content it referred to. The themes that surfaced were partly the different prototypes shown to the group and what was important for those, such as the planning view and the historic view. Beyond feedback on the design concepts, the focus group session also provided further insights into the problem space, contexts, user needs and what the design recommendations should include. The feedback also confirmed that the created personas were accurate and relatable to a BEV driver and that several of the new components implemented in the concepts were relevant and valuable. The feedback gathered from the focus group can be found in the result chapter, section 7.2.4.

6.3.5 Development of Mid Fidelity Prototypes

After the development of low fidelity prototypes and the evaluation of them with end users in a focus group, it was necessary to iterate the design concepts and apply changes and alternative design concepts based on the feedback. From the feedback, the following changes were made to the design concepts:

- An additional concept having consumption as the Y-axis of the graph in the Range Assistant's historic view was designed
- Additional alerts and driving tips were designed based on user research and feedback
- Feedback communicating a range update when external factors are affecting was implemented
- Inclusion of state of charge on arrival in the planning view in smartphone, with transparency on its changeability
- Option two of the momentary view in Range Assistant was removed

There were also changes implemented in the design concepts based on further reviewing of the user requirements and benchmarking. These changes were the following:

- Implementation of external temperature as a factor in the energy distribution chart in both smartphone and car
- Statistics for a single trip in the smartphone

In this stage, colours were added as well to the prototypes to provide a realistic feel to them and increase their fidelity. A few interactions were also added to the prototypes so that the user could navigate and explore features. The mid-fi prototypes can be seen in the result chapter, section 7.2.5.

6.3.6 Evaluation of Mid Fidelity Prototypes with End Users

A pilot study was conducted to evaluate the mid fidelity concepts. The aim of the study was to assess whether the content of the concepts derived from the user requirements and focus group was valuable and provided usable coaching regarding energy efficiency. Further, the feedback gathered during the evaluations aimed at supporting the establishment of design recommendations. There were six participants in the pilot evaluation study, see table 6.4 for participants. Two of them were women and all participants were employees at Volvo Cars and frequently drove electric vehicles. Five of the participants had previously been participants in the thesis during data collection, either for the questionnaire and interview or observational study. The evaluations were individually conducted in an interview format, held on-site, where each evaluation session lasted for 30 minutes.

Pilot evaluation participants			
Test person	Age	Gender	Vehicle
E1	50-59	Male	C40
E2	50-59	Male	PS2
E3	<29	Female	PS2
E4	30-39	Female	C40
E5	40-49	Male	Opel Mokka-e
E6	40-49	Male	PS2

Table 6.4: Participants in end-user evaluation

The session began with a consent form being signed by the participants to allow for the session to be audio recorded and the data handled appropriately. After that, a briefing was held about the thesis and the purpose of the pilot study. The design concepts were then displayed in the stages according to a trip: before, during or after the trip. The map view on the smartphone where the users can plan their trip was displayed first, followed by the momentary and then the historic view for the in-car Range Assistant. Lastly, the statistics view on the phone was shown. The interface for the smartphone was displayed on such a device and the in-car interface was presented on a tablet. See figure 6.6 for the evaluation session set-up. When the users were presented with the interfaces, they familiarised themselves with the information visualised. Thereafter, they were asked to verbally walk through the interface and vocalize what they were seeing and what their attitude was towards the information shown. In parallel, semi-structured questions were asked to gather feedback about the concepts and whether or not the concepts and their information provided value and usable coaching. See appendix E for the questions.

Figure 6.6: Set-up of evaluation study

The recorded material from each evaluation session was thereafter analysed to collect feedback in order to understand how well the design concepts provided value and usable coaching to the end user. A thematic analysis was conducted by extracting relevant data points from the recorded material, which were noted on sticky notes in Miro. The data were first grouped into large clusters based on what view of the prototypes they concerned: planning view, Range Assistant, statistics view, and general feedback. Within each category, the notes that covered similar topics could be grouped together. The feedback gathered from the evaluation study can be found in the result chapter, section 7.2.6.

6.3.7 Establishing Design Recommendations

After the pilot evaluation study, all insights and knowledge gathered throughout the design phases were compiled by establishing a list of design recommendations. The recommendations act as a final output of the research conducted. They are based on the user requirements from the primary user research and literature studies as well as the feedback gathered from the focus group and evaluation study with end users. The design recommendations were formulated and given a description, together with sources for reference. One source could be used as a reference for multiple design recommendations. The recommendations were divided and labelled with categories based on what type of area they were directed at. For example, if they targeted what type of feedback to display it was included in the *Feedback* category. See the final design recommendation list in the result chapter, section 7.3.

6.3.8 Future User Journey Mapping

To communicate and visualise the foreseen proceedings of BEV drivers in a future system containing the design solutions developed, additional user journeys were created. Similar to the previous ones, three user journeys were made to demonstrate the future user flow of the three user scenarios identified: short trip, long trip and long trip with external factors affecting range (in this case cold conditions). These future user journeys are anticipations of expected user flows in a new system with design concepts that are based on the design recommendation list created. They serve as a deliverable to encapsulate the tasks and user goals of the future system, the touch points included and the user experience in each phase and context. They also describe new design opportunities for a future iteration of the design solutions. See the future user journeys in the result chapter, section 7.3.1.

7

Results

In this chapter, the results from the carried-out activities are presented. The results are displayed in chronological order, starting with the insight from the data collection, continuing with the development of the user requirements and finally presenting the design recommendations. Results from literature studies can be found in chapter 3.

7.1 Development of Requirement List

To develop a requirement list, user research was conducted with the goal of understanding electric car drivers' wants and needs in terms of coaching. The conclusions from the user research are presented below, followed by persona and scenario which were created based on the findings to exemplify typical drivers and contexts. Lastly, the user requirement list is presented, which consists of 10 requirements.

7.1.1 Results from Data Collection

The data collection aimed at both collecting qualitative and quantitative data from end users. Four different methods were used to collect data and the most important results are presented below.

7.1.1.1 Questionnaire Takeaways

The response rate of the questionnaire was 59%, resulting in 59 responses. The majority of respondents were men (83%) and the age group 50-59 (39%) represented the most. See appendix A for the questions asked. Below are 10 takeaways from the questionnaire presented, labelled Q1-Q10. Each takeaway contains references to the questions that produced the answers supporting it, labelled q1-q20. For the affinity diagrams from the qualitative answers, see figure 6.2.

Q1. BEV drivers are interested in improving their range

When users were asked if they were satisfied with their electric range [q5], 45.8% stated that they were neither satisfied nor dissatisfied. Overall, the results were skewed towards satisfied, although only 1.7% answered that they were very satisfied. Therefore, there is a decent number of people who potentially would be interested in improving their range. When asked what motivated them to drive more energy efficiently [q7], the most common answer was improving range/charge less often. The second largest motivator was economic reasons (30%) followed by environmental reasons and sustainability. From this result, the conclusion is that extending the range to minimise the amount of charging stops is a major reason people drive energy efficiently. In line with the answers to the seventh question, all participants thought about driving energy efficiently in some situations. People generally considered driving energy efficiently when they need to charge along the way, drove long distance or had low battery. A third even stated they always thought about driving energy efficiently.

Q2. Experience could play a role in BEV owners' knowledge about driving energy-efficiently

Most people, 68%, answered yes when asked whether they knew how energy efficient their current driving behaviour is [q9]. This means that participants of the questionnaire believe they possess some level of knowledge on if their driving behaviour is efficient or not. When analysing the results further, of all the people who answered yes regarding the question mentioned, about two thirds, (67,5%), had had their car for more than a year. Of the people answering no, the majority (54.6%) had had their car only between 6-12 months. This could indicate that experience plays a role when it comes to understanding the effect one's driving behaviour has on a BEV. How BEV owners' knowledge has evolved throughout their ownership is something that has to be investigated further.

Q3. A decent number of people are unsure about how energy efficient their current driving behaviour is

Even though the majority of people answering the questionnaire could determine whether they drove energy efficiently or not, there were still 33% who found it hard or simply didn't know whether or not they drove energy efficiently [q9]. This is a topic to be explored further to understand why that is.

Q4. People use different metrics to evaluate energy-efficient driving

When participants were asked how they evaluated their driving behaviour regarding energy efficiency, there were two types of answers [q10]. The first group of answers concerned the factors they knew impacted the energy drainage, such as driving style (acceleration/braking), speed and weather conditions. The other group of answers were more related to tangible metrics, such as using Range Assistant and checking the energy consumption or gauge bar. Some people also stated that they had learned from experience and compared their own trips to each other. The answers are not mutually exclusive, which makes it hard to draw any conclusion from these answers, other than that the variety of the answers shows that there is not a single way for the participants to determine how energy efficiently they drove, which could be confusing to BEV owners.

Q5. BEV owners are open to feedback on how to drive energy efficiently
The respondents stated that they wanted further understanding, trip summaries and advice on how to improve their driving style [q11]. Another theme that emerged when asked how they would like to receive feedback on their driving, was the satisfaction with how it is now, pointing to the existing consumption number (kWh/100km) and the in-car Range Assistant application. The positive attitude towards receiving feedback in or from the car was seen as a well-established theme in the affinity diagram. In contrast, one smaller theme communicated the preference for no feedback at all.

Q6. People generally used Range Assistant sparingly
A predominant majority (81%) of the survey respondents had used the Range Assistant application at least once [q12], but despite this, it had a low rating in the frequency of use during trips, where the mode value was two on a five-point scale [q14]. The mean value was 3.0, thus the numbers point to the Range Assistant being used occasionally, but not every time. How often it is used should be put in relation to the context of use, as well as how easy it is to understand the feedback to get a holistic understanding of the usage. Out of the people who hadn't used it, some stated that they did not know about it, and the rest said that it was because they prioritised other applications, and did not like being distracted while driving amongst other things [q13]. This must be investigated further to understand why and when it is not being used.

Q7. The longer the trip, the more useful the Range Assistant became

Regarding when participants found Range Assistant to be most useful, 36% answered "very long trips, above 3h", and 26% answered "longer trips, above 30 min" [q15]. Only 10% thought short trips were a scenario where Range Assistant was useful. Some people gave other answers than the ones predefined. For instance, when wanting to see the exact range in kilometres (since this information is not seen elsewhere in Volvo cars), and to see momentary energy consumption. An interesting aspect of the result was the 15% who thought that there wasn't a situation where the in-car application was useful for them. The reason for this is of interest to understand further.

Q8. There is room for improvement for the feedback to be more effective Out of the respondents who had used Range Assistant, 35% deemed the feedback from it to be neither easy nor difficult to understand, which corresponds to a 3 in the Likert scale [q16]. Further, 50% ranked the perception of the feedback a 4 or 5, where 5 was "very easy", and the remaining 25% deemed the feedback to be difficult or very difficult. These numbers show that there is room for improvement to make the feedback more effective. An interesting aspect to investigate in the interviews is what makes the feedback easy or hard to understand. Moreover, an open-ended question giving the opportunity for respondents to provide any further comments regarding Range Assistant provided a variety of answers where one theme that emerged consisted of answers pointing out a lack of coaching possibilities, e.g., by not showing behaviour's impact on range or how to increase range [q17].

Q9. The smartphone is a tool that is generally used by BEV owners to interact with their car
The answers from the 18th question [q18] showed that 95% of the drivers had used their mobile application connected to their car at least once in the last three months which indicates it is a tool commonly used by BEV owners. When participants were asked when the mobile application provided by Volvo (or Polestar) was most useful, most people answered before a trip [q19]. However, what to consider here is the fact that the functionalities in the apps today are ones that are used primarily before trips, such as pre-conditioning and checking charge status, which also were the most used functions [q20]. If other functionalities were available, that could be used after trips, the distribution would likely be different.

Q10. The smartphone application lacks functions
Despite being asked in an open-ended question what features in the mobile application they were most satisfied with, some respondents mentioned that the smartphone car app was lacking functionalities and sometimes compared it to other apps func-

tions [q20]. This shows that BEV drivers do want useful functionalities in their smartphone car app and see little value in a minimalistic app.

7.1.1.2 Observational Study Takeaways

The 10 main takeaways from the observational studies are listed below, labelled O1-O10. They are the result of two affinity diagrams from data gathered during the observational studies, both observed behaviours and from the answers extracted at the end of each study. See figure 6.2 for the affinity diagrams.

O1. Most drivers didn't use the Range Assistant on the way there and the main cause for it was that they didn't know about its existence.
Drivers who didn't use the Range Assistant didn't know about it. One person stumbled across it on accident.

O2. Exploration with the Range Assistant app made several drivers understand more about the cause and effect of their behaviours.
By changing climate settings and seeing Range Assistant's climate bar become orange provided insights to people about the source of their energy consumption. Seeing the instant consumption bar turn negative made people realise there was regenerative braking. Further, seeing the instant consumption become orange on standstill made observees understand their consumption was high.

O3. The range optimiser (or eco-climate) button was what most drivers thought was most useful.
Driving style was not noticeably changed in any participant when interacting with the Range Assistant, however adjusting to a better climate, from an energy point of view, through the range optimiser/eco-climate button as well as turning down heating was done by many participants. For participant driving Volvo, a confusion was observed regarding understanding whether the button was turned on or off.

O4. The level of understanding or coaching that the Range Assistant provided was overall low.
Drivers who saw the app for the first time had difficulties understanding the feedback. Some tried to interact further by tapping the screen to find more information. Also, many expressed they were not very coached by it. From the answers, people would like some more tips on how to improve their driving and more information about what was displayed.

O5. Many drivers had theories about whether the cars assistive functions helped them save energy or not
Some drivers thought that the one pedal drive setting was energy efficient since it made use of regenerative braking, while others thought that cruising was better from an energy-saving point of view. The same dissension was found for the Pilot Assist function. Overall, drivers had much faith in the car saving energy through its functions.

O6. Some drivers thought that there was a question of prioritisation when it comes to driving energy efficiently.
During some scenarios, drivers prioritised speed to feel like they were getting somewhere or a comfortable climate over energy efficiency.

O7. Drivers thought the app gave good insights into the cars consumption, however, many expressed a want for having an overview of their driving with an indication on average consumption for trips.
Several drivers expressed a want for having a better overview of their driving. One participant took action and turned on trip information (average consumption) which was currently off in the display. Another driver expressed how a historic view of consumption and average number would be insightful.

O8. Drivers didn't think the Range Assistant application was necessary to have open all the time.
Some observees closed the in-car app or stopped interacting with it after a while of driving.

O9. Drivers saw the most potential for Range Assistant on longer trips.
When being asked when the Range Assistant application would be of most use, most drivers answered on longer trips.

O10. Google Maps is frequently used for planning trips in the car.
In the car, Google Maps were used to plan the trip. Drivers also prioritise Google Maps and if they have Range Assistant open, they still want navigation somewhere.

7.1.1.3 Field Study Takeaways

From the study, it was concluded that most drivers were quite satisfied with their range. They stressed that the range could be improved, but they had gotten used to driving a BEV and had accustomed themselves to plan their trips more carefully. Most drivers stated that driving energy efficiently is important to them for economic, and sometimes environmental reasons. When the interviewees were asked if they knew how energy efficiently they drove, almost every driver pointed to the energy consumption of their car (kWh/100km), which suggests that this is an important and easily understood metric to measure energy-efficient driving for BEV drivers. Participants frequently made use of this consumption metric and one driver also mentioned that the car gave useful insights into battery level and range left, which could be used to understand how energy efficiently the driving is. Another driver mentioned there where a button which could be activated to maximise range by shutting down functionalities in the car. However, no participant believed that their cars actively taught them to manage their efficiency when driving, even though there were some features in the cars that gave them driving tips on how to reduce energy consumption. One of the participants discovered that these features existed during the interview, despite having owned a BEV for multiple years. Maybe it could be a result of the users themselves having to actively look for this information. Even though the cars gave drivers access to statistics regarding energy usage, many did not seem to make use of them. This could be due to different reasons such as them not knowing it existed, did not understand, or find it useful, or did not have time to look at it in the car.

7.1.1.4 Interview Takeaways

From the interviews, 18 takeaways were identified from the analysis which were divided into four categories: Driving habits, Energy-efficient driving, Coaching, and Mobile car application. These takeaways are listed below, labelled I1-I18, together with quotes from interviewee participants. See table 6.2 for the participants and figure 6.4 for the affinity diagram created from the data.

Driving Habits:

I1. Shorter trips to work is the most frequent trip
All interviewees mentioned that their most frequent trip was commuting to work. In line with those answers, people did not really think about their range for short everyday trips and did not use Range Assistant during these short trips. This indicates that short trips are a very common trip BEV drivers do and a scenario where the range is not a critical aspect.

"If I only travel to and from work I don't use whatever it [Range Assistant] is called /.../ but for long trips, I check it sometimes" - P5

I2. Energy-efficient driving and using Range Assistant is mostly used for long trips

For longer trips where charging stops were needed, the range became more important. Seven of the drivers were more conscious about driving energy efficiently for those trips. Five BEV users said that they would like to keep the number of charging stops to a minimum and that it was a big motivator for them to drive energy efficiently. Four interviewees said that they used Range Assistant for longer trips to optimise their range.

"So when I make long trips, I let that [energy-efficient driving] affect me more than in my everyday trips" - P1

I3. Drivers plan where to charge for longer trips

In the interviews, a commonly occurring topic was charging the BEV, especially on trips. For long trips, the interviewees used different tools to help them plan their routes and where to charge. The drivers expressed that they wanted functions such as seeing the location and occupancy of the charges, if any of them are broken and what type of charger they are.

"Then I try researching about and plan where I will charge /.../ I spend quite some time on that" - P8

Seven of the interviewees mentioned that they thought the charging stops were an inconvenience to them for various reasons. P9 mentioned that they thought that it was annoying to download new apps on their smartphone in order to charge their car since there is no standardised payment solution. Three drivers said that they were worried about not being able to make it to a functioning charging station and having to find another one with a low battery percentage.

"That's what's annoying if you arrive somewhere and the charger doesn't work and you're at the limit" - P1

I4. Drivers have learned a lot through experience with BEV

While the interviewees naturally had some previous knowledge about BEVs due to their work, their knowledge about electric cars had still increased notably after driving and interacting with them. Eight drivers stated that they knew beforehand what factors influenced battery consumption, but they did not know how significant of an impact the factors had on range and consumption. For example, most interviewees understood that speed and outdoor climate affected battery consumption, but through experience, they had learned how much it really affected the battery drainage.

"You knew that cold weather is rough for electric cars, but how rough is it? I have a much better understanding about that." - P9

In addition, completely new insights arose with time, P6 and P8 noticed that the extra weight of towing a trailer with the car drastically increased the energy consumption.

"The biggest thing that I noticed was when we rented a trailer, a pretty big one. It wasn't possible to get far. I wasn't really prepared that it would make such a difference" - P6

Moreover, two people stated that their range anxiety had decreased by getting a better understanding of their car as they learned more about it. Some drivers also explained that they had become more conscious about energy consumption now than they were before when driving a combustion engine car.

Energy-Efficient Driving:

I5. Drivers look at several consumption metrics in the car
Four interviewees stated that they made use of the battery percentage to determine their remaining range and to gain a better understanding of their energy consumption.

"I can compare the battery level with the kilometres /.../ Often times I use my work trip as a reference. I know the distance in kilometres and how many percentages it consumes" - P4

Five interviewees were interested in the average consumption metric in the car when determining how efficiently they were driving and three of them also stated they made use of the power and charge gauge bar. These metrics can all be viewed in the driver display. Five people mentioned they used Range Assistant where instant consumption and estimated range values were most frequently used to determine efficiency. No interviewee mentioned they made use of the energy usage bars in Range

Assistant.

I6. Several actions are taken by BEV drivers to be more efficient

Precautions taken by the drivers to save energy were predominately to lower their speed. Four interviewees always implemented this specific behaviour when driving, especially on highways or sometimes by choosing roads with a lower speed limit.

"But I have lowered my average speed with about 25 kph since I got my electric car and it's not just an economical matter" - P9

Other participants limited their speed to save energy only in critical moments where they had to extend their range. Additional things mentioned were to drive smoothly with a more consistent speed, and strain away from using settings to increase comfort, such as heating of steering wheel and climate control.

"I've become more and more thrifty with time, I don't need to activate the steering wheel heater. I can wear gloves if I'm gonna wear them when leaving the house." - P4

In addition, three users mentioned that they use the range optimiser button to extend their range. Two of them mentioned that this predominantly happens for longer trips.

I7. Comfort can sometimes be prioritised over energy efficiency

Many interviewees mentioned that there were occasions when they did not drive as energy efficiently as they could have. In some cases, the drivers prioritise their comfort or lifestyle in general. Multiple people explicitly stated that they were aware of further measures to take in order to drive energy efficient but chose not to do so. P1 mentioned that cars are a hobby for him and that he wanted to have fun while driving. P9 mentioned that he thought that he already had adapted his driving behaviour to save energy and that more actions such as driving less frequently, would impact his life too much. Further, P4 mentioned that she rarely used the eco-climate setting because it felt like having no climate on at all.

Another reason for deliberately disregarding energy efficiency was the price aspect since it is cheaper to drive an electric car compared to a combustion engine car. Two interviewees stated that they had clean energy at home, where they usually charged their cars. This further decreased the incentive to save energy.

"Regardless of how I drive my electric car, it's still much cheaper than driving a diesel or petrol car" - P1

"We charge with cheap and green electricity at home every day. So the energy efficiency for an electric car doesn't matter that much to me" - P2

Coaching:

I8. There are flaws with the current Range Assistant application

From the interviews, there were a significant number of data that indicated flaws with the current Range Assistant application. The lack of coaching was considered a major reason for the Range Assistant to be perceived as flawed. Eight interviewees expressed that the coaching was not fully satisfactory or useful, for instance, that it provides too little help, is missing positive feedback, and only shows momentary feedback. Further, three interviewees mentioned how the energy usage bars are constantly low even when they consume a lot of energy. By having too gentle coaching, the level of coaching became insignificant for these drivers.

"You want to use it in order to improve, but if I already drive as efficiently as I can there is no reason for me to use it" - P4

"You never get an indication that you drive inefficient." - P2

Further, five interviewees expressed how Range Assistant did not provide any valuable insights to them, resulting in them rarely using it or not using it at all. P8 explained how data on the remaining range was appreciated. However, the rest of the application was useless to him:

"I use the application pretty rarely. I think it is meaningless." - P8

I9. Drivers want more feedback and data about their trips

Out of the eleven interviewees, eight of them expressed they wanted further feedback. Six of these interviewees mentioned they would like to see historical data from their trips.

"If you get some kind of data on how it has looked over time, then I believe as

a BEV driver you become more aware of like, this trip doesn't look very great vs what the car can do optimally" - P7

Five interviewees expressed they would be interested in seeing statistics on how they have been driving, for instance through detailed information, e.g., how long steering wheel heating had been on, or information about trip consumption. Two interviewees expressed that the goal of the new information would be to get insight into whether you have been driving efficiently. Six interviewees also brought up a driving journal as a feature they would like to have access to.

"If you have a driving journal, then you absolutely would like to see if this was an energy-efficient trip because you had this average speed and this temperature in the car maybe. It would have been interesting to see because then you can compare your trips each day." -P4

I10. Gaining more knowledge and information when needed

Seven interviewees indicated how gaining further information as a BEV driver could be beneficial, especially for those who are interested and want to become aware and understand more. Therefore, valuable information that can support and inform about energy-efficient driving should not be seen as redundant.

"I usually wonder why. And theres a lot to reflect on regarding BEV and why it behaves like it does, especially when it comes to range." - P9

"I believe that if you become aware of something it will impact how you drive." - P7

"You should really investigate settings and learn about your car. You do not always have to learn everything through experience, you can also read about it." - P4

"You could always learn more. It's hard to know what you don't know" - P10

Further, to gain more insights and knowledge, six of the interviewees mentioned they do some experimenting. For instance, by changing climate settings to see the effect or by resetting average consumption to see the efficiency of a new trip.

"You do some analysis to see how different external conditions affect, for instance, it is much less effective to warm up the car than to cool it down." - P1

I11. Placement of feedback: in mobile application versus in car
When discussing receiving feedback about a trip, the majority saw the benefit of having this information in their mobile car application. Six interviewees expressed that the mobile phone application was where they wanted to get information and feedback about trips. Also, all interviewees who mentioned the driving journal explained it as a feature they missed or had missed in their smartphone app.

"Would they have more information there [mobile app], then it should be more long-term information, driving journal" -P9

"Such detailed information about your trip, that you do not want to sit and read in the car perhaps" -P4

However, in terms of the feedback to coach the driving behaviour, interviewees preferred having this type of coaching in the car. Six interviewees explained that coaching better driving behaviours was something they would like to access in the car. Further, a common type of feedback drivers would like to have more of was advice. Five interviewees mentioned how advice from the car could be beneficial, e.g., advice on how one can drive a route the best way, advice on what actions one can take and advice based on the circumstances. Again, this was preferred to be accessed in the car.

"I would like other information in the Range Assistant. And that is more advice actually that take into account, I mean, the car should know if it is winter and cold? Give me advice then that is based on this that I can affect" -I8

"Direct advice about what you can do right now, that you want in the car" -P4

I12. Drivers think that it is unclear what drains battery
The drivers sometimes felt that they could not explain why the consumption was higher at times and they saw no obvious reason for it. Some participants expressed their frustration and felt that they would need some more information to understand why. Moreover, uncertainties arose regarding a few behaviours and the BEV drivers did not know if they indeed were energy efficient. Examples of this were one-pedal

driving and preheating the battery since it consumed energy when being heated. The conclusion that can be drawn from this is that drivers generally want to understand what drains or saves energy to lessen frustration and confusion.

"I can not always explain it, regarding temperature, wind and speed. It feels like it [range] fluctuates a lot." - P9

"You understand the connections, but you do not always understand 100%, it isn't very transparent" - P3

I13. Users would like assistance and transparency with how external factors are affecting the range

How external factors affect the car's range and efficiency was something eight interviewees expressed they wanted feedback on when driving and should be considered in the coaching. Three of the interviewees were especially dissatisfied with the Range Assistant not providing accurate data or explanations when external factors increased the consumption, such as an attached trailer or cold weather.

"When the driving conditions change you don't get any feedback from the car. When you have a trailer attached, everything was wrong, the calculated range and how far you could make it was visible, however everything was just wrong." - P8

"Yesterday it said low consumption on driving style and climate, yet I had very high momentary consumption since it was freezing cold outside, that info wasn't explained to me anywhere." - P1

Two out of the eight interviewees did not specifically mention the weather or trailers as external factors they wanted to be considered but explained how they in general wanted transparency by having information about how important factors are affecting the range calculations.

"You're interested in the things that matter. So the factors that are affecting I want to understand and see, like what it is that is happening." -P9

Further, the pilot-interviewee, who also mentioned they would like transparency on what the values displayed are based upon, explained how one should be careful giving too precise data when the reality is uncertain. Exact values will easily be interpreted as factual truth, however, the reality is more indeterminant since many factors are affecting it. Therefore, being transparent about the uncertainty and providing an interval for e.g., range could be a good approach.

"Instead of saying, we will arrive with this much range, it could provide an interval, to indicate that it is uncertain/.../it can be dangerous to give too detailed information because you might not be able to display correct information the day before which makes you unable to accurately plan the day before" - Pilot

I14. Drivers are interested in the state of charge level upon arrival

The drivers were not only interested in their energy consumption during a trip, but also their battery level at the final destination to determine if they had to charge along the way. All the interviewees that mentioned they were interested in this specific metric used the integrated Google Maps in-car application for the matter. Two participants stated that they thought that it was very accurate in its predictions which they appreciated.

"I have used the map [Google Maps] sometimes when I have been unsure if I will make it all the way. Then you can input the destination and it makes a calculation and say yes or no, you're missing 5%" - P10

I15. Find the most energy-efficient route

Six of the interviewed participants mentioned how they wanted to be able to find the most effective route when planning their trip. According to their responses, some interviewees found this information to be best suited in the mobile phone app and some thought it could be provided in the car. The common theme for their data was that they wanted to understand which route is either the most energy efficient and leads to an extended range or has the most charging possibilities etc. and then be able to compare and evaluate the routes according to their needs.

"There should be a function for when you use navigation, if you drive from Gothenburg to Stockholm, alright, which route consumes the most energy?" -P10

"I want to find the route which makes the most out of my range" -P7

Mobile Car Application:

I16. BEV drivers want more functions in their mobile car app

As of now, both Volvo and Polestar have a limited number of functionalities in their mobile car applications. From the interviews, it became clear that a limited number of functionalities were not preferred. Eight of the interviewees mentioned functionalities they missed in their mobile car application. Some of them were functionalities that had existed before in their old car but were not available for a BEV car.

"It is useless, there are no functionalities, and the ones that I want don't exist and the ones I had for my old car are missing." -P8

"There's a lot I'm missing in it" -P7

I17. Trip planning in mobile phone

From the interviews, several data points regarding trip planning in the mobile phone were found. Six interviewees expressed they wanted to be able to plan a trip in their phone and some of them also mentioned how one should be able to send the planned trip to the car before departure.

"Prepare a trip, like destination and choose a route and plan everything, that's a typical thing you want to prepare offline, or off car. In the car, you want to just start driving." -P8

I18. Frequently used functions in Volvo and Polestar mobile app: pre-climatisation and check charging

The most frequently used function in the car's mobile application today, out of the few ones existing, is starting pre-climatisation of the car. Nine out of the eleven interviewees mentioned this function to be regularly used during the winter to pre-heat the car remotely through their mobile phones. I1 mentioned that one element they are missing with this function is to have outdoor temperature visible in the app as guidance when deciding on whether to start the pre-climatisation.

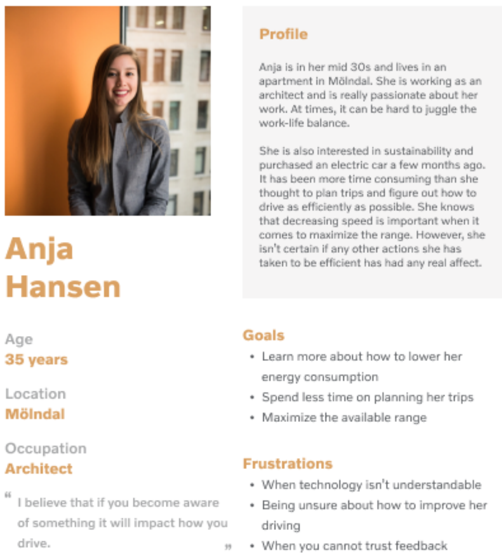
Another frequently used function used in the mobile car application, are tasks related to charging. Six interviewees mentioned checking the battery level and charging status as tasks they frequently used their mobile car application for. A missing feature in this function, according to I8, is being able to change the charging level remotely through the mobile phone. This feature is only available to be done in the car at the moment.

7.1.2 Summary of Data Collection Results

When all user research had been conducted and analysed, the takeaways and insights gathered were summarised to establish an understanding of the big picture conclusions from the research. What could be concluded was how including a smartphone as a complimentary device in the eco-coaching experience for BEV drivers was a promising opportunity that could satisfy user needs which the car would have trouble doing. It was also concluded that the context for the smartphone as a device in the eco-coaching system was before and after a trip. Further, the scenario where coaching and information about energy-efficient driving were most useful were on long trips when the interest in applying energy-efficient driving to optimise range was considered high. Lastly, it was concluded that the current Range Assistant had flaws when it came to its coaching and had room for improvement to become more in line with user needs. These conclusions motivated the continuation of answering the research questions and entering the *Develop* phase.

7.1.3 Personas Portraying Typical Electric Car Drivers

(a) Persona one. Picture from [66]. Unsplash license



(b) Persona two. Picture from [67]. Unsplash license

Figure 7.1: Personas representing typical electric car drivers

Two personas were created to exemplify typical BEV users and facilitate them as a tool to develop the design concepts. Each persona includes a stock photo, name, and demographic information to provide some background information. The goals and frustrations of the personas give context to their attitude towards energy-efficient driving and how they would like to interact with their car. Lastly, a short biography describes the personas' lifestyle and relation to BEVs.

One of the personas, see figure 7.1a, is an engineer with a general interest in technology and how things operated. Sustainability was not his main incentive to buy an electric vehicle. He has had his car for around two years and has learned a lot through experience when driving his car. The other persona, see figure 7.1b, is a busy woman who works as an architect. She is passionate about sustainability and recently bought an electric car. Due to her hectic lifestyle, she does not have the time to learn how her BEV works in detail. However, she rather wants tips and guidance on how to lower her energy consumption.

7.1.4 Scenarios for Electric Car Drivers

The identified scenarios for BEV drivers are described below in a text-based format. They are based on the results of the user research conducted and include goals, activities, and thoughts of a persona, when interacting with a BEV, for each of the scenarios.

Scenario 1 - short trip
Anders is an engineer from Kungälv who each day commutes to his work, in Gothenburg. It is a trip of 22 kilometres which usually takes approximately 25 minutes, depending on traffic. When commuting, Anders uses his electric car which he purchased almost 2 years ago. He is very fond of his car because it is quiet, smooth, and the fact that he never needs to visit a gas station is a huge plus. After having experienced a BEV, he would never switch back to a petrol car.

Each morning, Anders takes his car to work. This specific morning, the weather is quite warm, 10 degrees Celsius which made Anders deactivate the timer for preclimatisation in the car the night before. Since it is not winter anymore, it would be a waste of energy according to him. When he goes out to the car, he unplugs his charger and takes a seat in the driver's seat. The battery level shows 80%, which is the charging level he always sets for his daily commute. He turns on Google Maps in his car and sets his destination to "work". The roads seem quiet and the displayed battery level at arrival is just as expected. Anders turns on his car and quietly exits his driveway.

When Anders arrives at work he takes a quick look at the average consumption for his trip which displays 25 kWh/100km. From experience, he knows this is quite a high number for this specific trip during these weather conditions. He wonders what made the consumption this high today and tries to recall if he drove differently than usual this morning. Maybe he did? Anders tells himself that on the way home, he will make a little effort to lower the consumption number.

Scenario 2 - long trip
It is a Saturday morning in March, and Anja is planning a trip to Västerås to visit her family for the weekend. She has gone to Västerås many times before. However, today is the first time she will be doing the trip using the new electric car she got a couple of months ago. She prepares her trip by planning it on the Google Maps app on her phone and searches "Mölndal" to "Västerås". The result shows that it is a trip of 383 kilometres. According to her car, the electric range is 400 kilometres, which makes Anja relieved that she probably will not need to make a charging stop on the way there. However, she isn't sure if she could trust the numbers since her range happened to be much shorter than 400 last month. An alternative route suggested on Google Maps is 404 kilometres and takes 25 minutes longer to drive. "This road must drain more range right?", Anja speculates. She decides to take the fastest route and also looks at where she could charge for safety measures if she would be having a range crisis at the end of her trip. She knows that there are several actions she could take to maximise the range in her car, for instance by driving slower and turning off the climate. However, she wonders how much range these precautions actually save her. Despite her unknowing, she makes it her mission to get to Västerås without charging to save time by driving as efficiently as she can.

Anja goes out to her car and unplugs the charger. She made sure the day before to put her charging level to 100%, for today's trip. When in the car, Anja opens the integrated Google Maps app and writes once again in her destination and chooses her route. 10% at arrival is the prediction made by Google. Anja trusts the estimation, however, she has a look at possible charging stations on the road just in case the battery will not be enough for the whole trip.

When on the highway, Anja opens the Range Assistant application to ensure she is maximising her range and has enough for the whole trip. She also activates the Range optimiser button to get some extra margins. Hopefully, it makes a difference in avoiding a charging stop, Anja thinks. She checks her consumption now and then and sees it is rather high, however, no parameters are indicating she is driving energy inefficiently. Anja feels as if there isn't much more she can do to improve her efficiency, and she closes the Range Assistant application and looks at Google Maps instead. She sees the predicted level on Google Maps has dropped to 6%. Anja wonders if there was anything she did to cause the battery to drop 4 extra units of percentage and gets a bit anxious. She decides to stop at a charging station midway to avoid being nervous the rest of the drive. She quickly chooses a charging stop in Google Maps as Anja doesn't want to spend time figuring out the best spot for charging. The one she chooses seems good enough.

When Anja arrives at her destination in Västerås, she is content but annoyed she had to stop charging. She feels as if she was driving as efficiently as she could but maybe there were more things she could have done to improve the range further. Anja thinks it's difficult to estimate how energy efficient the driving was. Range optimiser felt like an easy way of applying efficient driving, however, the rest of the feedback from the Range Assistant didn't coach her that much.

Scenario 3 - long trip with external factor affecting range: cold conditions

It is a cold winter morning and Anders is planning a trip to Malmö with his electric car. It is a trip he's been doing many times with his car before, and from experience, there is no need to charge along the way since the range in his car is more than enough. However, Anders knows that wintertime is negatively affecting the battery resulting in a drop in range, but how much of the range will be lost during today's winter conditions is something he is clueless about. He trusts his feeling that there will not be a need for charging today and heads to the car. The car's charging level says 100%, which is the battery level Anders always sets when he is planning on doing longer trips. He also scheduled pre-climatisation of the car yesterday, to avoid having to enter a freezing cold car when departing. He sets his destination in the Google Maps application in the car and drives off.

Google Maps predict his battery level to be 25% at arrival which Anders is satisfied with. He opens the Range Assistant application for additional information about his range and consumption. He sees that his consumption is very high, and he tries to find out why this is the case. Nothing about his driving behaviour indicates he is being inefficient, yet the meter shows high instant consumption. "Perhaps the cold weather is affecting it?", Anders wonders.

After a couple of hours of driving, Anders is closing in on his final destination. He has been checking the Range Assistant from time to time and has seen his estimated range drop significantly for each mile he's been driving. It worries him that he doesn't feel like he can control the energy consumption and starts considering if he should lower the climate settings in the car, perhaps even turn on the Range Optimiser. He knows it will make the temperature in the car much colder and is therefore reluctant to do so, yet he is now not sure whether or not he will reach his final destination if the range continues to drop at the current rate. He decides to turn on the Range optimiser in hopes that it will make the range prediction slightly longer.

After exiting the highway, Anders is ensured he will reach the destination without any charging stop. Google Maps predicts 15% at arrival, and the estimated range is enough for the remaining distance. With relief, he arrives at his final address and looks at the average consumption for the trip which displays 30 kWh/100km. It is the highest consumption Anders has had in a while. He wonders what he usually lands on when he drives this trip in other conditions. Perhaps that would help him figure out how much these winter conditions actually affect his range and his energy efficiency.

7.1.5 The Resulting Requirement List

In this section, the user requirements extracted from the user research and literature studies are presented. The requirements derive from takeaways established from the questionnaire, observations, field study, and interviews as well as from literature sources. In total, 10 user requirements were formulated which will act as a foundation for the *Develop and Deliver* phase.

User Requirements
As an electric car driver, I want...

U1. to have supportive feedback guiding me in different circumstances so that I can avoid or know how to handle critical/difficult situations
Derived from: [I2], [I10], [I13]

"You could always learn more. It's hard to know what you don't know" - P10, from interview.

U2. to receive coaching based on the context I'm in so that the feedback I get is relevant to the situation
Derived from: [I1], [I2], [I11]

"When the driving conditions change you don't get any feedback from the car. When you have a trailer attached, everything was wrong, the calculated range and how far you could make it was visible, however everything was just wrong." - P8, from interview.

U3. to have a combination of momentary and historic feedback so that I also receive an overview of my driving data besides being coached real time
Derived from: [Q3], [O7], [I8], [I9], [I10]

"If you get some kind of data on how it has looked over time, then I believe as a BEV driver you become more aware of like, this trip doesn't look very great vs what the car can do optimally" - P7, from interview.

U4. the car to have transparent coaching and feedback so that I understand the underlying reason for the displayed data
Derived from: [I8], [I12], [I13]

"Yesterday it said low consumption on driving style and climate, yet I had very high momentary consumption since it was freezing cold outside, that info wasn't explained to me anywhere." - P1, from interview.

U5. to be able to analyse my driving data outside the car so that I'm not bound to be in the car for time-consuming tasks beyond driving
Derived from: [25], [32], [Q9], [I11], [I17]

"Such detailed information about your trip, that you do not want to sit and read in the car perhaps" -P4, from interview.

U6. to be able to know which route is the most energy efficient one so that I can plan trips that maximise my range
Derived from: [I7], [I15]

"I want to find the route which makes the most out of my range" - P7, from interview.

U7. a seamless transition between the smartphone and the car so that I

can avoid unnecessary frustrations
Derived from: [24], [29], [Q9], [I17]

U8. certain feedback to be present both in the smartphone and the car so that the feedback is not fully exclusive for each device
Derived from: [23], [29]

U9. the feedback to be relatable and fit my mental model so that I can understand it
Derived from: [22], [Q4], [O7], [FiSt], [I5], [I9], [I14]

U10. the coaching to accommodate drivers of various experiences so that I can learn something both as a new driver and an experienced driver
Derived from: [24], [39], [O4], [I4], [I7], [I8], [I9], [I10]

"I saw that it [range assistant] was orange at times. That might've been an indication that you should adjust your driving. But it didn't say what you were supposed to do" - T2, from observation.

"You want to use it in order to improve, but if I already drive as efficiently as I can there is no reason for me to use it" - P4, from interview.

These quotes indicate how some drivers would like more help understanding the feedback, whilst others thought that it was trivial.

7.2 Development of Prototypes

This section contains several results, starting with the results of the user journey mapping and benchmarking of e-mobility applications, which were used as tools for developing the low fidelity prototypes. Then, the lo-fi prototypes are presented together with the design choices made for them, motivated by the user requirements written above. Thereafter, the resulting conclusions from the focus group evaluating the lo-fi prototypes are communicated. These conclusions fed into the development of the mid fidelity prototypes, and their interfaces are presented at the end of this section.

7.2.1 User Journey Maps

Three user journey maps were created to describe and visualise the users' interactions and user flow with the car and smartphone throughout different types of scenarios: short trip, long trip, and long trips where external factors vastly affected range. Cold conditions were used as an example of an external factor for the third user journey.

Short Trip

The user journey map created is depicted in figure 7.2. For everyday trips, few interactions were identified, and the drivers do not have to plan their trips in advance. The overall experience of a short trip is trouble-free, with one inconvenience of trying to evaluate a trip after driving. The only metrics provided aiding this task is nowadays average energy consumption and, if calculated by the driver, the reduced battery percentage.

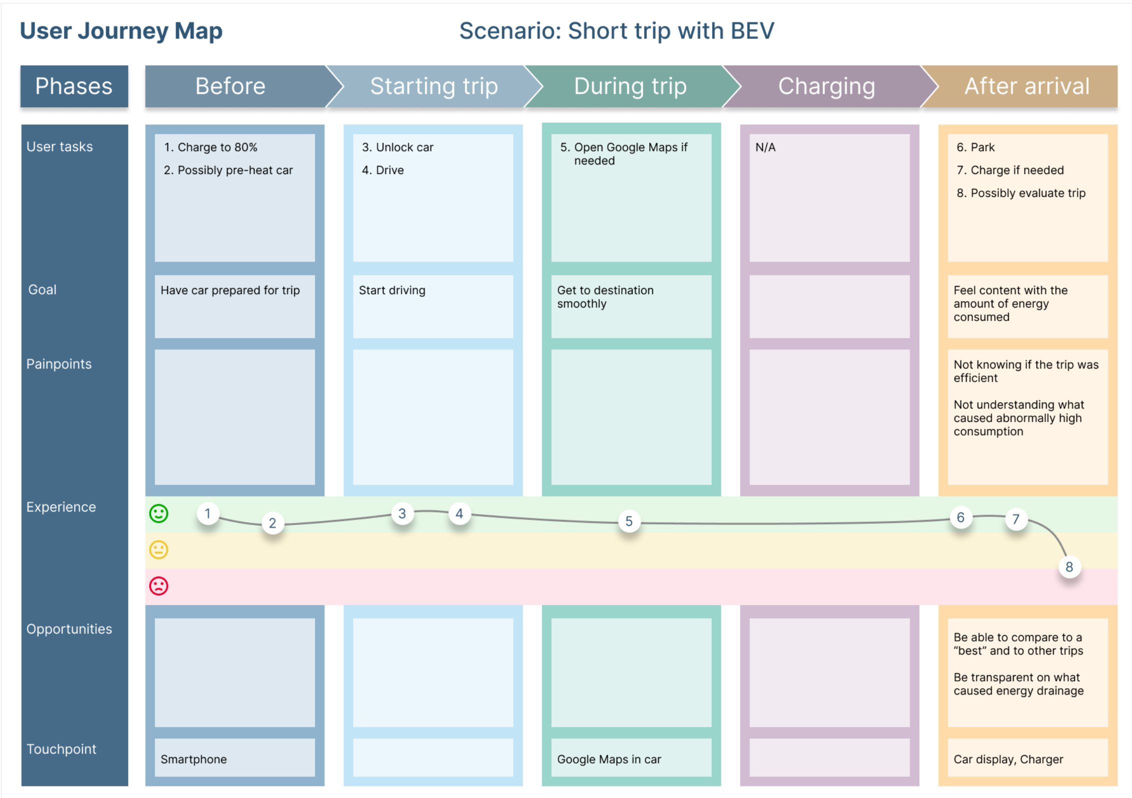


Figure 7.2: User journey map for a short trip

Long Trip

More planning is required for longer trips, which occur both before and during a trip. In addition, saving range and driving more energy efficiently become more important for longer trips. Pain points for users include not knowing what consumes range or how to improve their driving. Here, evaluating a trip afterwards is also an inconvenience. See figure 7.3 for user journey map.

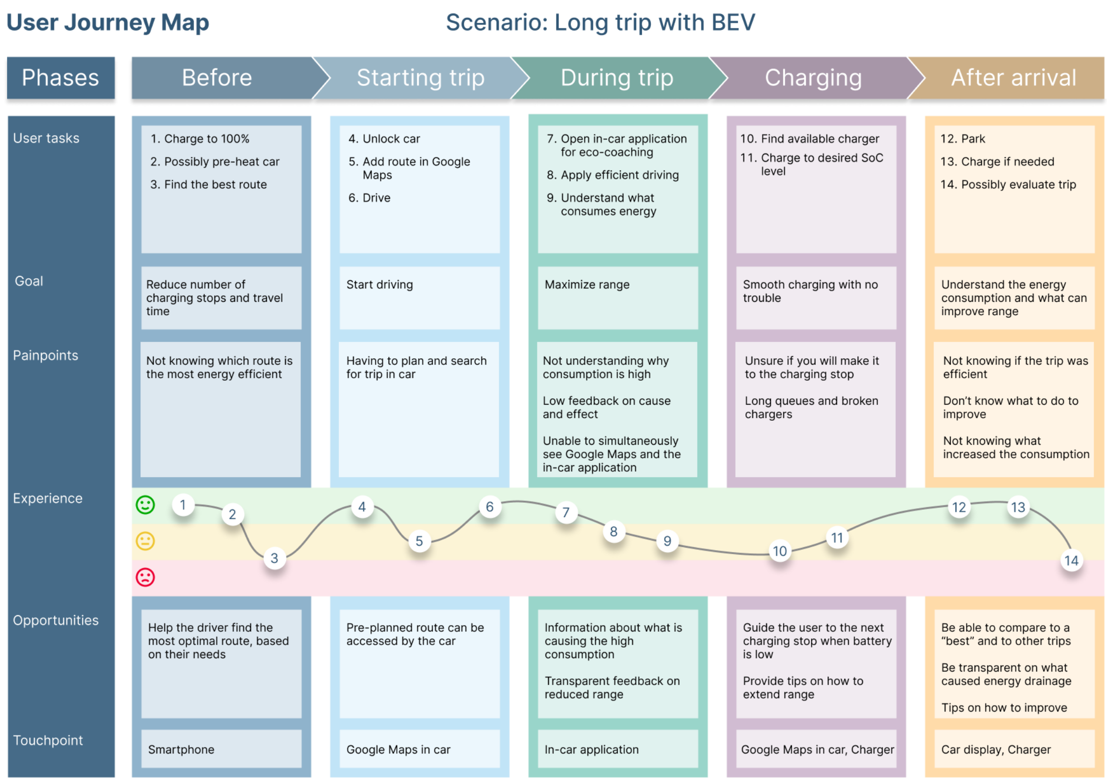


Figure 7.3: User journey map for a long trip

Long Trip - Cold Conditions

Estimating the range whenever external factors are contributing to a larger reduction of energy can be challenging. This user journey map, illustrated in figure 7.4, shows the difficulties drivers experience when external factors such as cold temperatures are affecting the range. For instance, in these conditions, drivers are not sure how much the range will be affected. When they experience high consumption numbers without the estimated range being updated to an accurate metric, they consequently stop trusting the range prediction number. Thus, a big pain point for the drivers is the lack of transparent feedback regarding what causes the high consumption and how far they can drive in the current conditions. Further pain points are the inconvenience of evaluating the trip since the effects of external factors are not accounted for.

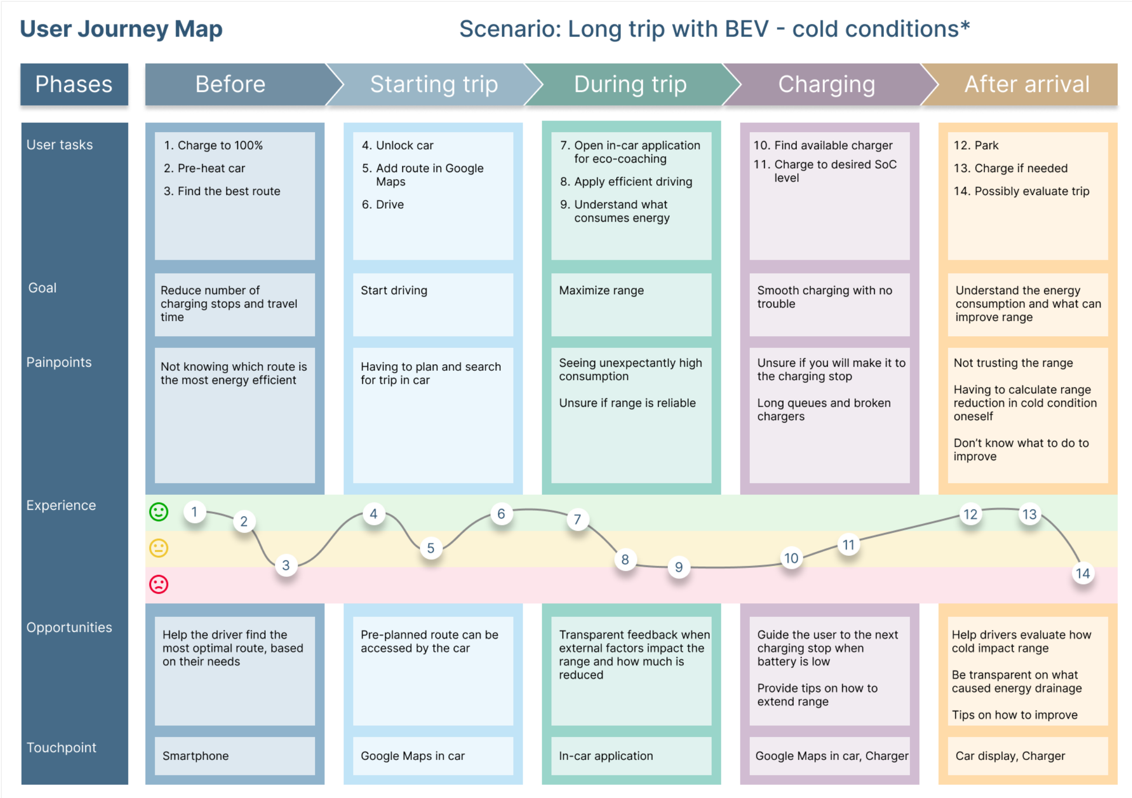


Figure 7.4: User journey map for a long trip in cold conditions
**can be replace with other external factors*

7.2.2 Benchmarking Outcomes

Below, in table 7.1, is a summary of the existing features in Volvo Car BEVs together with the six benchmarked BEV models. Benchmarked features mostly consider energy management and eco-coaching. However, a few other relevant features are also present. For a more detailed description of the findings, see appendix F.

Table 7.1: Benchmarking of energy management and eco-coaching features in BEV models and their e-mobility applications

Model(s)	In-car features	Smartphone features
Volvo	• Estimated range including min & max interval for range • Momentary energy usage • Instant and average consumption • Range-optimiser button • Power and charge gauge • Navigation: State of charge (SoC) at destination	• Vehicle data: SoC • Navigation: Find route • Driving Journal
Tesla Model 3/S/X/Y	• Range tips • Broken down range consumption • History of energy consumption • Actual range consumption compared to trip projection • Navigation: SoC at destination	• Vehicle data: SoC • Charging data: Solar vs Powerwall vs Grid • From Google Maps, possible to send route to vehicle
Porche Taycan	• Integrated range optimiser that regulates climate and optimises route when route guidance is activated	• Vehicle data: SoC, range • Navigator: Send route to vehicle
Nissan Ariya/Leaf	• Intelligent route planner • ECO-mode button to maximise range by reducing climate and acceleration response	• Vehicle data: SoC, range • Driving statistics: – Average consumption – Total energy consumed – etc. • Navigation: Send route to vehicle
KIA e-Niro/EV6	• Broken down consumption • Energy consumption history • Power and charge gauge • Range warning	• Vehicle data, SoC, range • Navigation: Send route to vehicle

Mercedes Benz EQS/EQC	• History of energy consumption • Average consumption • ECO-mode: shows optimal speed, haptic feedback through the pedal	• ECO-score • Range tips • Gamification: Electric vehicle challenges, *"Mercedes me Eco Coach"* • Navigation: Send route to vehicle
Ford Mustang Mach-e	• Momentary energy usage feedback • Broken down energy consumption • Average consumption • Navigation: SoC at destination	• Vehicle data, SoC, range • Driving Journal including energy efficiency and scores. • Explanations for displayed metrics • Navigation: Send route to vehicle

Takeaways for in-car features

Below are the main takeaways from the in-car benchmarking.

- Three out of six benchmarked BEV brands had statistics on broken-down consumption distribution. However, different categories were used
- Three out of six brands had energy consumption history
- Two out of six brands provide eco-modes, either through reducing functionalities or by coaching the driver's speed and driving style
- Ford Mustang mach-e includes external temperature as energy consumption factor
- Tesla provides range tips in the car and potential range consumption from trip projection

Overall, the features in the benchmarked vehicle models mostly provided the drivers with historic data by explaining where the energy went or how high the energy consumption was. One BEV model included feedback on how the energy consumption was affected by the outdoor climate. Little active help with lowering the consumption was put forward. However, one brand provided the drivers with actual tips in the car and compared the range consumed with a potential consumption. Also, another brand provided feedback on optimal speed. More active help in lowering the consumption would be beneficial for more inexperienced BEV drivers, who do not know yet how their actions reflect in the data displayed.

Takeaways for smartphone features

Below are the main takeaways from the smartphone benchmarking.

- Four out of six benchmarked smartphone applications had energy statistics from previous trips. However, the metrics shown in the statistics varied. Mercedes-Benz also provided tips to optimise range in their Mercedes me app.
- All six brands could send planned routes from smartphone to vehicle either through their own app or a third-party e.g., Google Maps.
- Ford's app was the only one where the drivers could have the most energy-efficient route as a default suggestion
- Two out of six smartphone applications provided trip-scores and range gained from efficient driving.
- Mercedes-Benz motivates and coached efficient driving through challenges and gamification.

All applications enabled sending the planned route to the car, which indicates the importance of this feature. Only one app had the option to suggest the most energy-efficient route for the user. Statistics from previous trip where a common feature in several smartphone applications and some gave further insights into the energy efficiency of the trip by displaying range gained and trip-scores. Mercedes-Benz' gamification with challenges is a fun way to heighten the motivation for energy-efficient driving. However, the users should be informed in what ways their score affects their range.

Since it was difficult to find information about all the available functions in the mobile applications and cars, the mapping between the two for the benchmarked models are hard to decipher. However, by only looking at the interfaces it was evident that the design language differed from the car. This made the devices look like they were not part of the same experience. The design language is only one component in the mapping of the two, where what type of functions they have and the usability of those are more important in the user experience. What could be found regarding the smartphone application functions was that they included, more often than not, additional data and features which did not exist in the car.

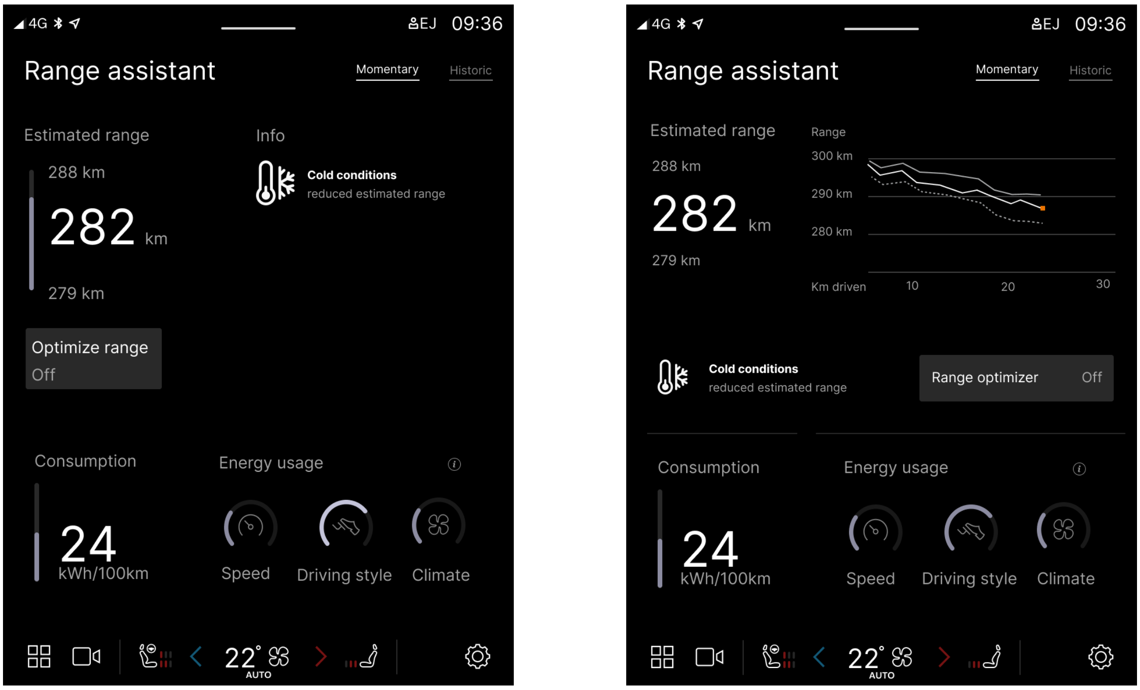
7.2.3 Low Fidelity Prototypes

The lo-fi prototypes developed are presented below. The in-car application has a momentary view and a historic view, and the smartphone application consists of a planning view and a statistics view. One design suggestion was created for each view, with the exemption of the momentary view for the in-car application where two options were proposed.

7.2.3.1 Range Assistant

Momentary Feedback

As stated, two versions of a view with momentary feedback were designed, shown in figure 7.5a and 7.5b. Most of the information available in the two prototypes is the same, except for the addition of a graph that displays the range over the distance in option two. The metrics in the current Range Assistant application continue to be present but with some changes in layout and minor added features to better comply with the user requirements.



(a) Option one (b) Option two

Figure 7.5: Lo-fi prototypes of momentary views in Range Assistant

The estimated range and instant consumption are feedback based on the context, [U2], which helps the users understand and plan their driving ahead. The drivers can relate to the feedback [U9] since the metrics are already established among EV drivers. The energy usage bars allow for supportive feedback [U1] together with informative or coaching notifications. If any of the bars have high consumption for an extended period of time, the user will be notified. Other types of notifications that are essential for the drivers can be seen here as well. In the prototype, an example of a cold condition notification was implemented, indicating that there are external factors that significantly influence the range which allows for more transparent feedback [U4]. Furthermore, text indicating the status of the button was added. This is due to drivers having difficulties understanding whether the button was on or off, written in the third takeaway of the observation study [O3].

Historic Feedback

The historic information introduced, see figure 7.6, was completely new and did not exist in the current application. Statistics from either the driver's last trip or since their last charge are displayed here. The purpose of this page was to present the users with aggregated information about one or a few trips to give the users an overview of their consumption, which otherwise could be hard to attain from instantaneous feedback exclusively, as supported by [U3]. Additionally, a graph of the declining range over the driven distance, and information about how energy efficiently they drove compared to their potential and broken-down consumption can be viewed here. Lastly, there are range tips which give the drivers information about what actions they can take to further lower their consumption or how their actions helped them increase their range [U2].

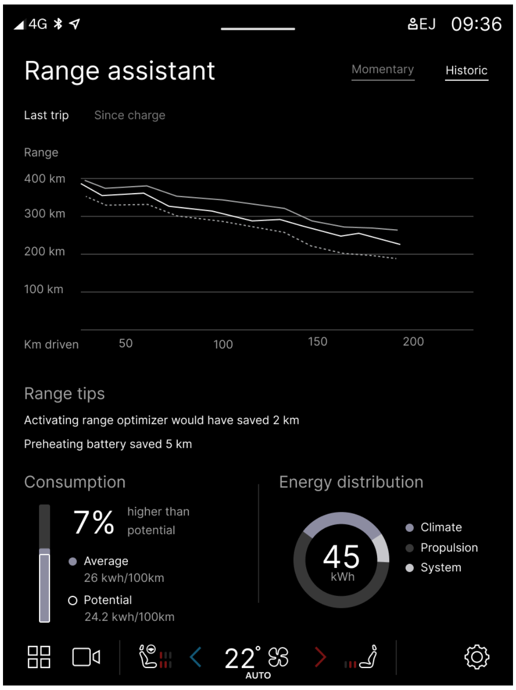
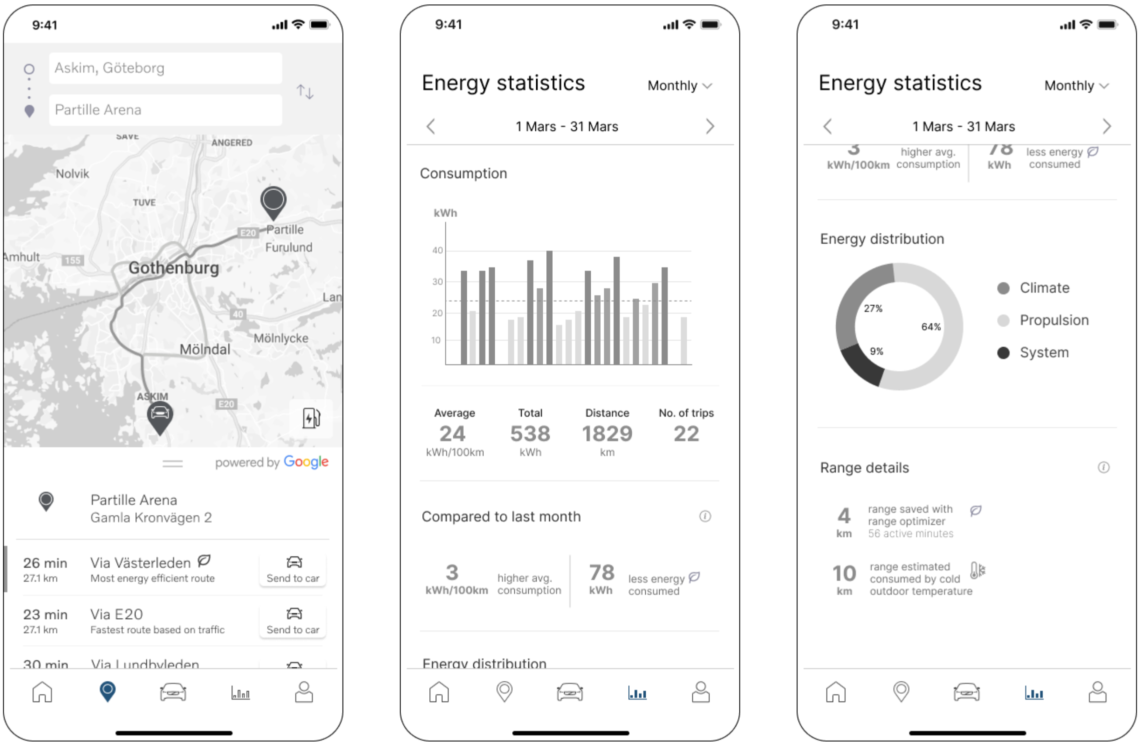


Figure 7.6: Lo-fi prototype of historic view of Range Assistant

7.2.3.2 Mobile Application

The planning view seen in figure 7.7a, with a map, was created where there is an option to send the route to the car, which allows the users to plan their trip in advance. This enables a more seamless transition between the devices [U7]. Moreover, statistics regarding energy consumption, see figure 7.7b and 7.7c, are available over a longer time period than in the Range Assistant application, motivated by [U5]. Comparisons for average and total consumption for the selected time period can be seen here as well.



(a) Planning view (b) Statistics view (c) Statistics view

Figure 7.7: Lo-fi prototype of mobile phone application

7.2.4 Feedback From Focus Group

The focus group resulted in insightful discussions and feedback about the design concepts from end users. The received feedback was analysed and the conclusions were utilised in the iteration phase that followed. The lists presented below consist of the insights from the focus group, where some were used as motivation for applying changes in the prototypes, whilst others provided a better holistic view of the user needs:

Planning in app

- Users liked the planning view in the mobile application for planning and regarded it as a basic requirement
- Important metric when planning is the estimated battery at arrival (visible in car). However, this metric only becomes accurate after a few kilometres of driving making it difficult to predict and display this number accurately beforehand in the mobile phone

Historic view

- Historic view with aggregated data is interesting and provides more valuable information than only instant consumption according to the users
- Drivers would use this data
- Users appreciated the graph over the decay in range over driven distance. However, they thought it might be more insightful to have consumption instead of range on the Y-axis

Cold condition feedback

- Drivers liked the cold condition alert to know when the cold decreased the range
- Drivers want the range to be recalculated based on external conditions and for the Range Assistant to be transparent when an update based on external conditions has been made
- Feedback on how much the range decreased from the external conditions was something drivers saw as valuable
- Users want to understand how efficient the battery is in different temperatures
- Drivers want information when the battery's charging efficiency is not optimal due to cold internal temperature. This is to avoid frustrating the users and wasting energy by charging for a whole night during cold conditions resulting in only a few percentages of increase

Understand efficiency and consumption

- Users found the overview of consumption for different months in the mobile phone to be useful in order to understand and compare the seasonal fluctuations in consumption
- Feedback showing what is causing the high or sometimes low consumption and efficiency was of interest

Reliable range

- User liked the minimum and maximum range displayed to know the "worst case scenario" range. This is because users want to have a range they can trust to know if they will make it or no to their destination

- Do not want the metrics visualised to contradict each other. Car metrics, Range Assistant metrics and Google Maps metrics should all align

When to analyze data

- At the end of trips, users find it interesting to evaluate them, especially long or new trips. However, drivers usually do not want to spend much time in the car after a drive to analyse data

Other

- Likes the simplicity of one button in the in-car application
- Drivers want confirmation on how much one gains from actions such as turning off climate
- Drivers do not want feedback that is changing and moving too much, since it is distracting

The conclusions drawn from the feedback collected from the focus group were firstly, that the mobile application is suited before a drive, in the planning stage, and also after a drive to get further information and coaching about the trip. Since users do not want to spend too much time in the car to analyse data, having information in the phone is useful. In the planning stage, it is valuable to see the estimated battery level at arrival, similar to the in-car Google Maps application. However, this metric is challenging to display accurately prior to the trip since this value usually becomes accurate when driving, after necessary re-calibrations.

Secondly, feedback from the focus group confirmed that a historic view was appreciated and valuable to drivers for evaluation. Although it could be beneficial to visualise an overview of the trip as a graph with consumption at the Y-axis instead of the range. Since drivers do not spend much time evaluating in car, the historic view in-car has to be easily understood and provide valuable information that is easy to digest from a quick glance. Having complementary statistics placed in the phone for users who need further insights was considered good.

Thirdly, notifications in critical scenarios, such as cold conditions, were liked by the participants since understanding what causes low, or high, efficiency is of interest to them. In addition, if the estimated range was updated in accordance with how much the external factors influenced, this would be of high value to end users. Also, providing feedback on how cold temperatures are affecting the efficiency of the battery even when charging was mentioned as useful feedback. This is to avoid wasting energy by charging outdoors during the coldest temperatures.

Lastly, feedback providing an overview of how the range fluctuates during different seasons was liked by the end users and was suitable to place in the mobile phone. They also mentioned how in critical situations when driving, the feedback on "worst case scenario" range shown in the design concept was valuable. Especially if a reliable range could not be displayed. In addition, showing how much range can be gained by turning off climate in these situations would be of interest.

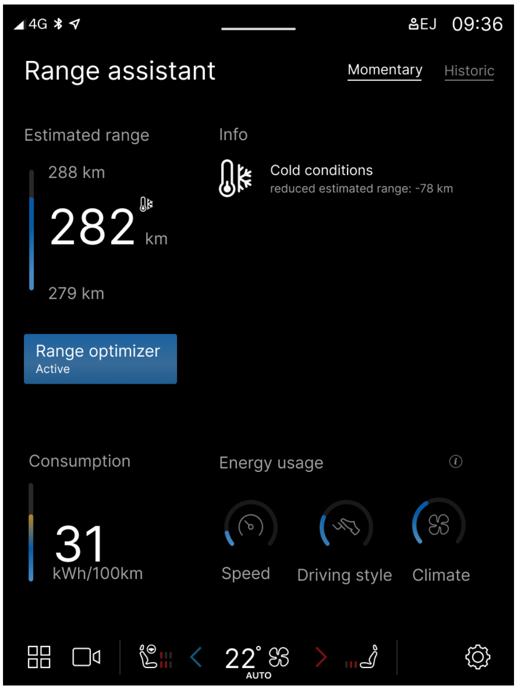
7.2.5 Mid Fidelity Prototypes

The mid-fi prototypes developed are iterations of the previous lo-fi prototypes and are designed with a higher fidelity. Here, two variants of the historic view were developed, in contrast to the other views which have one prototype variant each.

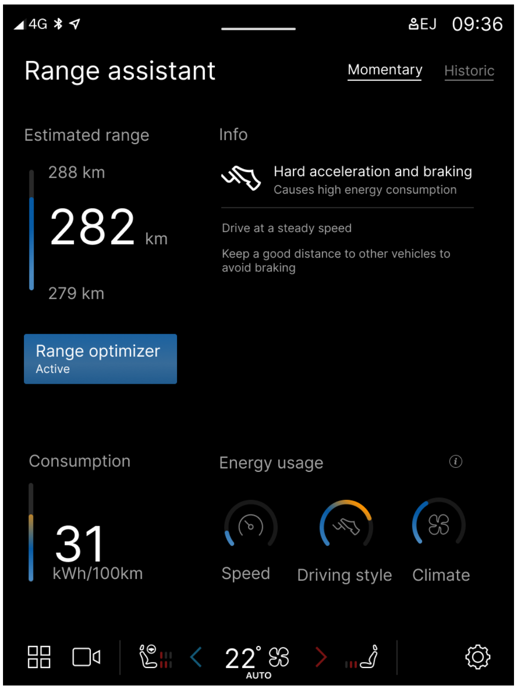
7.2.5.1 Range Assistant

Momentary Feedback

The momentary view was designed based on option one from the lo-fi prototypes. Option two was eliminated as a consequence of the feedback from the focus group, indicating too much movement in the feedback displayed should be avoided, and to the design preference of avoiding duplicate graphs in the momentary view and historic view. Two variants of feedback in the momentary view were also implemented under *Info*. The first variant, figure 7.8a, shows feedback when cold conditions are significantly affecting the range and how much the range has decreased. In addition, the icon was also implemented beside the estimated range number to indicate that an update of the range was made which considered the impact of external temperature.



(a) Info: Cold conditions



(b) Info: Hard acceleration and braking

Figure 7.8: Two variants of mid-fi prototypes of momentary view in Range Assistant

The second alternative, figure 7.8b, on the other hand, shows the feedback displayed when a driving behaviour, e.g. driving style, has been draining energy at an abnormally high rate for an extensive period of time. Here, tips on how one can improve are also included in the feedback. Lastly, the colours already used in the Range Assistant today, blue and orange, were implemented in the momentary view. A slight change was applied by having a gradient between the two colours to visualise high consumption and high energy use instead of a binary switch between the colours used today. A gradient was also implemented in the range optimiser button to strengthen its pliancy hinting.

An additional feature implemented in the momentary view was an information card which is displayed as an overlay when taping the information icon *i* beside the energy usage title, see figure 7.9. This window provides further information on what the three different energy usage metrics mean. This feature is based on the 10th user requirement, [U10].

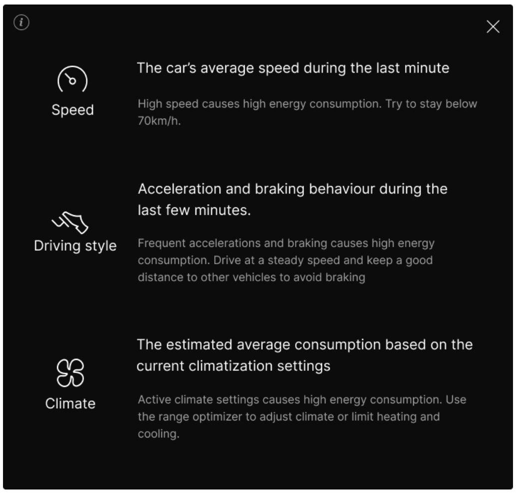
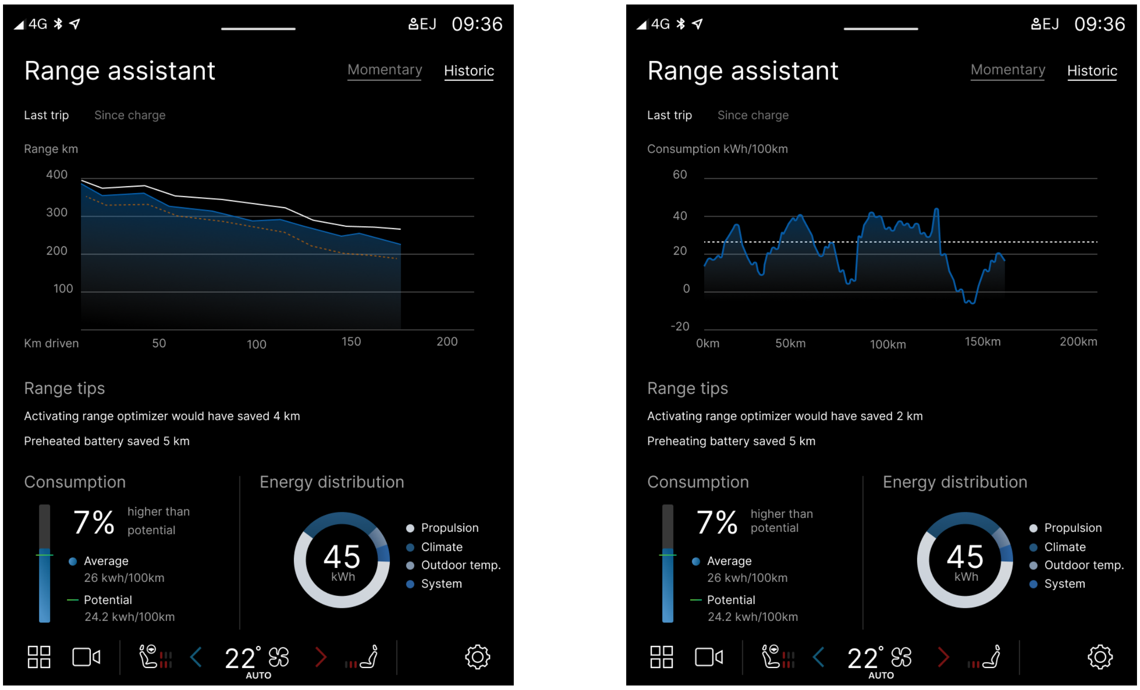


Figure 7.9: Information window displaying information about energy usage

Historic Feedback

Two mid fidelity versions of the historic view were designed. One visualises, similarly to the lo-fi prototype, a graph of historic data having range on the Y-axis, see figure 7.10a. The other version has consumption as Y-axis and was created based on feedback from the focus group, see figure 7.10a. Besides this, the energy distribution chart was updated by adding outdoor temperature as a fourth factor. This change was inspired by the benchmarking of Ford Mach-e which includes this factor as well. The standard blue colour used in the current Range Assistant application was implemented in the mid-fi prototype as well, where the energy distribution chart was provided a set of additional colours to enable distinguishment in the chart. Green was also implemented to visualise the potential consumption with the motivation that the potential is energy efficient and green signalises eco-efficiency.



(a) Graph with Range as Y-axis

(b) Graph with Consumption as Y-axis

Figure 7.10: Mid-fi prototypes of historical view in Range Assistant showing two different energy usage graphs

Range Alert

Figure 7.11 shows a pop-up designed for the Range Assistant with the purpose of providing supportive feedback and navigation if the range is estimated not to be enough to reach the destination or the planned charging station. As soon as the car predicts this being the case, due to either external factors, changes in driving behaviour etc. the pop-up will be shown offering redirection to Google Maps and updated navigation to a suiting charging station. This feature is based on the first user requirement [U1] and from focus group feedback.

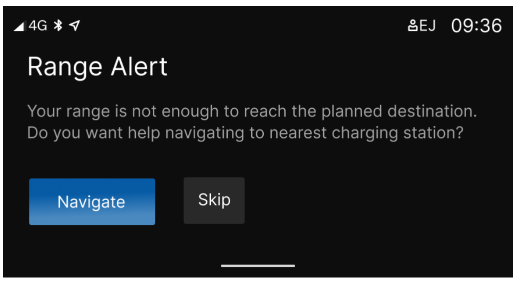
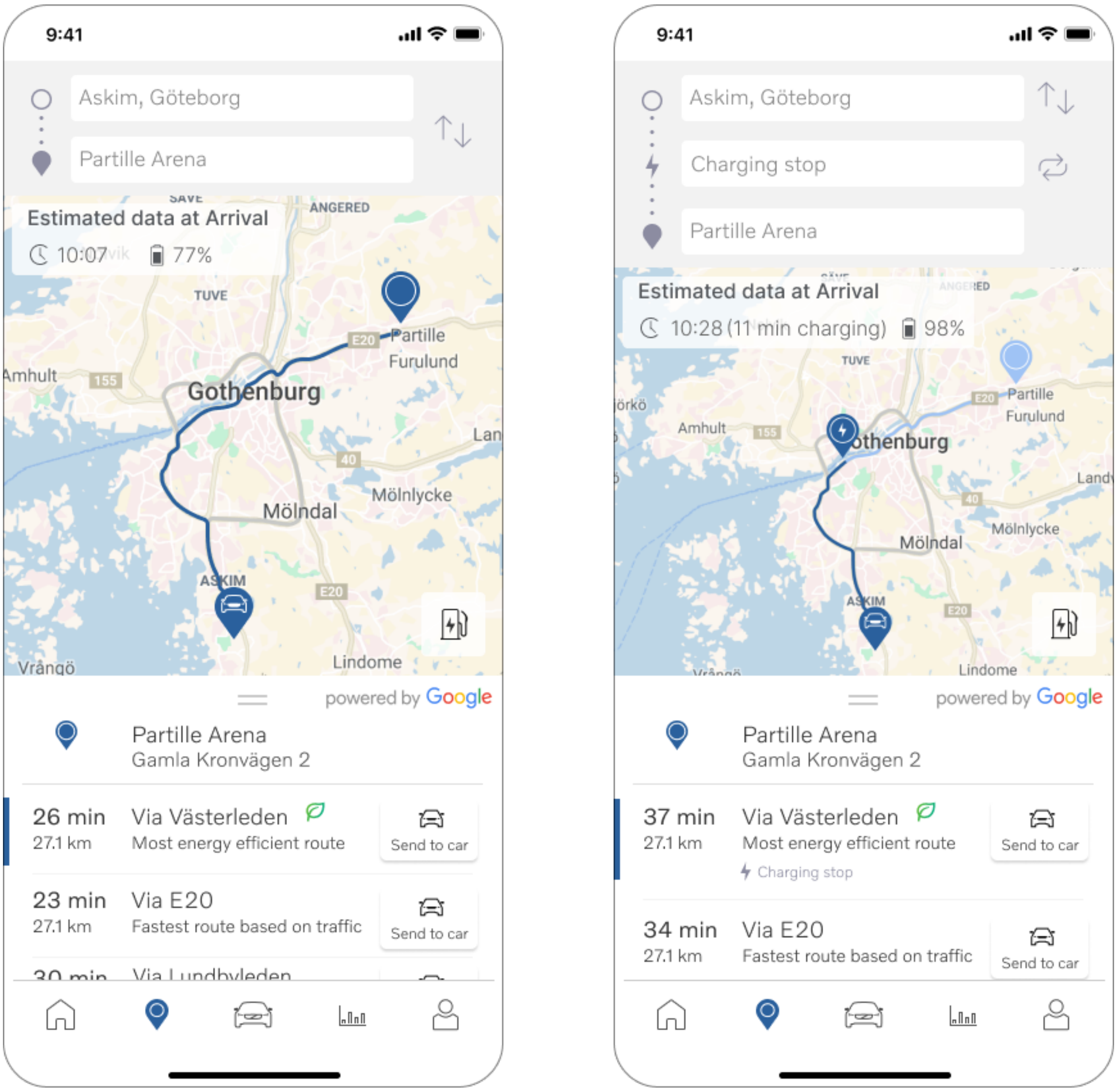


Figure 7.11: Range alert pop-up when the energy is not sufficient to reach the destination

7.2.5.2 Mobile Application

Planning View

The planning view of the mobile application, figure 7.12a, was updated with information on estimated data at arrival, shown in the upper left corner of the map, and stems from the feedback collected from the focus group. A second view, figure 7.12b, was also designed to visualise how it might look when a charging stop has been added. The added colours in the prototypes are in accordance with the current Volvo Car application.



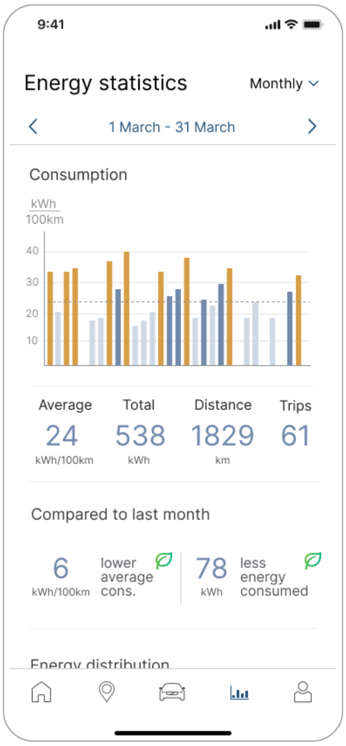
(a) Planning view

(b) Planning view with charging stop

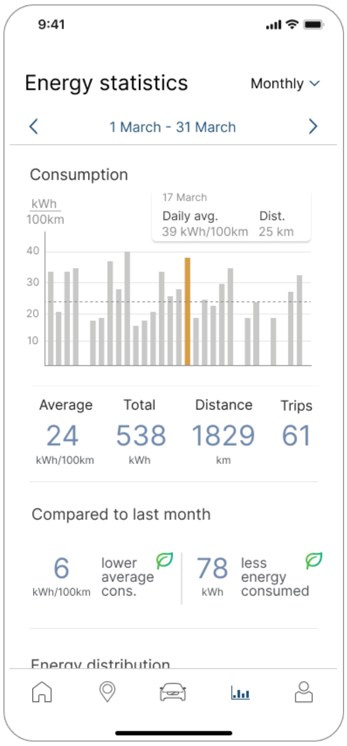
Figure 7.12: Mid-fi prototypes of planning view in phone

Statistics View

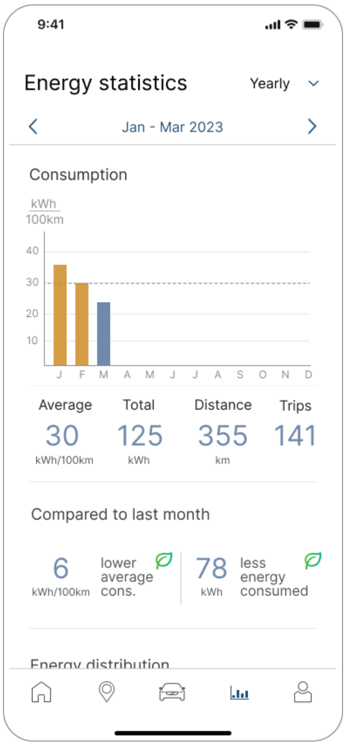
Minor layout changes were done in the mid-fi prototype of the statistics view. Here, colours were added to provide further feedback and fidelity. Blue and orange were used to provide continuity between the mobile and in-car application, where high average consumption is indicated with an orange staple and lower average consumption is indicated with blue or light blue colour in the graph. Figure 7.13a shows a monthly overview of consumption, figure 7.13b shows the selection of a specific day in the monthly view with additional daily data, and figure 7.13c shows a yearly overview. By scrolling vertically, further data is shown, see figure 7.13d. Here, the energy distribution chart is updated with outdoor temperature as a fourth factor.



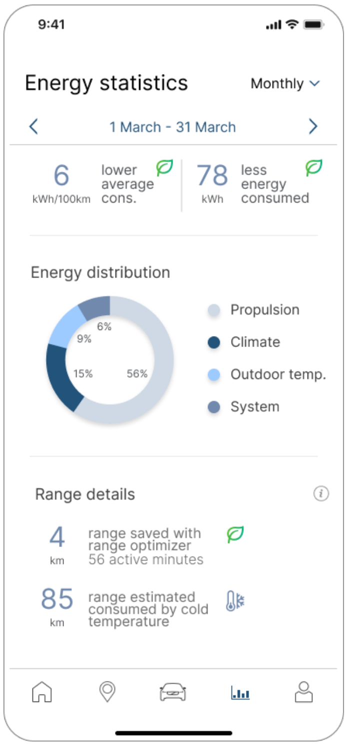
(a) Monthly overview



(b) Selected day in monthly view



(c) Yearly overview



(d) Energy distribution and range details

Figure 7.13: Mid-fi prototype of statistics view in phone

7.2.6 Feedback From Evaluation Study

The six evaluation sessions with end users of the mid-fi prototypes resulted in in-depth feedback on whether the content of the concepts derived from the user requirements was valuable and provided usable coaching regarding energy efficiency. Takeaways regarding the planning view in smartphone, in-car application, phone statistics and potential improvements were found after analysing the feedback through thematic analysis, which are presented below:

Planning view in smartphone

- Sending the trip from phone to car was a fundamental requirement
- Valuable to see data such as SoC and estimated time in phone, for touchdown points such as charging stops and final destination
- Options for the most energy-efficient or fastest route were appreciated. The drivers had personal preferences on which one they would usually choose

In-car application

- Having the estimated range updated depending on external factors is of high value
- Information displaying causes for high consumption is good. However, information should be easy to digest and primarily focus on what one can do to improve.
- A historic view is of high value since it is educative and provides a good summary and overview of the energy consumption. It acts as a reference to adjust driving behaviour
- Displaying range tips, energy distribution and consumption potential are all of value to drivers. It supports the drivers to drive more efficiently and to better understand their energy consumption
- Providing a graph of the consumption over driven distance was more relevant to drivers than showing the range decline over driven distance. The motivation behind this is because consumption is more familiar and relatable to BEV drivers with experience. Also, consumption provides more valuable information to the drivers in comparison to the range decline
- The Range alert pop-up is of value to drivers since it supports them in critical situation. However, it should be displayed as soon as possible and only be

presented in a critical situation where a driver will not be able to make it to a destination or charging stop

- The clarification of the range optimiser-button's status was appreciated by drivers

Phone statistics

- The option to filter on month and year for the average consumption is valuable. The diagram covers different needs depending on the level of filtering
- The overview of average consumption is useful when evaluating and comparing trips. For example, insights on how the consumption has varied throughout the season or how the daily trips compare is provided
- The energy distribution diagram is informative

Mapping between phone and in-car application

- Providing historic data in both devices is appreciated by drivers
- Drivers see the value of having easily overviewed short term historic data in the car and long-term historic data demanding more analysis in phone
- The general distribution of features in phone vs in the in-car application was perceived as appropriate since it considered the context of the driver
- Drivers see the opportunity of implementing more interesting data points in phone since this is where they would like to find more in-depth data. However, not too much information should be present, resulting in endless scrolling

Improvements

- In the planning view, having the option to filter the charging stops on specific brands or AC/DC chargers is considered necessary. Moreover, instead of automatically choosing a charging stop, the drivers would like to see the charging options along the way when SoC is estimated to be in a span of e.g. 30-10%
- Disclose what the limit for cold condition is. Also, enable comparison between trips excluding cold temperature impact
- Add additional filtering options to the graph over average consumption in the phone, such as *daily* or *weekly*. This would allow for further analysis

7.3 Design Recommendations

All of the work up until this point has led to a list with 10 design recommendations, which is presented in this section. The design recommendations are proposals for how a cross-device coaching experience for BEV drivers should be designed. An overview of the recommendations is given in table 7.2 and includes a title, description and the sources from which it was derived. The recommendations listed are the final result from the data gathered from all the various research methodologies performed throughout all the design phases: user research, literature studies, focus group and evaluation study feedback. The aim of the design recommendations is to answer the research question for the thesis:

What are the design recommendations when developing a cross-device coaching experience for electric car drivers?

Table 7.2: List describing the 10 design recommendations for a cross-device coaching experience for electric car drivers. The list presents related sources to each recommendation and is divided into three categories: Feedback, Usability, and Device.

		Design Recommendation	Description	Source
Feedback	R1	Tailor the feedback and its placement to the context	Feedback in the car should concern driving behaviour and provide coaching useful for the context of driving, most importantly long trips, which is when energy-efficient driving is highly motivated to be applied. Feedback and functionalities in smartphones should instead focus on providing more in-depth coaching to provide an understanding of energy-efficient driving in a non-driving context outside car.	[I1], [I2], [I11], [E]
	R2	Combination of momentary and historic feedback	Momentary and historic feedback should be combined to give the user a holistic picture of their driving. This enables coaching both during but also after trips.	[Q3], [O7], [I8], [I9], [I10], [F], [E]

	R3	Transparent coaching	Provide transparent feedback about how both behavioural and external factors impact the calculated metrics. External factors such as cold weather conditions are of high interest, but also towing behind the car. When these factors impact range, it should be visualised and also to what degree they affect the range.	[I8], [I12], [I13], [F], [E]
	R4	Enable planning for efficient driving in smartphone and car	Assist the user with the planning of their trips to help them find the most optimal and efficient route for their needs.	[I7], [I15], [E]
Usability	R5	Support drivers in critical situations	Provide the drivers with supportive feedback to guide them through difficult circumstances, especially critical ones where the range decrease fast and the chance of not making it to the destination with the range available is high.	[I2], [I10], [I13], [E]
	R6	Seamless transition between smartphone and car	Allow the driver to start tasks in one device and complete them at a later point in the other device.	[24], [29], [Q9], [I17], [F], [E]
	R7	Relatable feedback	The feedback should be relatable to the users in terms of what is visualised and how. The metrics BEV driver can relate to are battery percentage, range and energy consumption and should continue to be used. Also, it should be visualised in a way users can put the feedback in relation to other situations to be able to decide how efficient their drive was.	[22], [Q4], [O7], [FiSt], [I5], [I9], [I14], [E]
	R8	Coaching tailored towards multiple user groups	The feedback should be insightful for users of varying experience levels. Users with no BEV experience should be able to find use in the feedback provided while experienced users also have to see value in the coaching simultaneously. Providing feedback that enables users to understand and become experienced BEV drivers easier leads to a better driving experience and less range anxiety.	[39], [O4], [I4], [I7], [I8], [I9], [I10], [E]
Device	R9	Enable performing time-consuming tasks in smartphone device	Coaching demanding analysis can with advantage be placed outside the car, such as planning and viewing statistics.	[25], [32], [Q9], [I11], [I17], [F], [E]

	R10	Non-exclusive information	The information provided does not need to be exclusive for each device, which enables a smoother transition between the two.	[23], [29], [E]

7.3.0.1 Feedback

R1: Tailor the feedback and its placement to the context
Whether a certain type of feedback is successful or not can be ambiguous. Its effectiveness must be put in relation to the context. There were two main types of trips identified, everyday commuting and longer trips. When talking to the users, it became evident that the user found different types of information useful for the respective trip. Their motivations to apply energy-efficient driving were the greatest for long trips [I2], thus it is important to provide them with the tools to do so for long trips. An example of this could be that hands-on practical tips are important for long drives. However, feedback for shorter trips should not be overlooked since they are the most common type of trip [I1]. Here, tools for evaluating and comparing different common trips could be more useful.

Moreover, the actions and preparations the drivers make vary depending on the type of trip they do. External factors also influence what the user journey will look like. It is important to consider in what device the coaching is provided, to increase its effectiveness. While in the car, the users appreciate tips connected to their driving behaviour [I11]. While on the smartphone, the drivers have more time to explore aggregated trip data [E].

R2: Combination of momentary and historic feedback
The drivers need to be supported in multiple ways to learn about energy-efficient driving. They want to be educated in *what* influences the range, but also *how* they can improve the range [I10] and drive more energy efficiently. The momentary feedback can provide the users with tips on how to improve their range at the moment, while also opening up the opportunity to get a first-hand learning experience and see in real-time how the range is affected. However, by only displaying real-time feedback the drivers do not get an adequate overview of their driving and the energy consumption [O7], [Q3], [I8]. Thus, historic feedback is a good complement to provide those insights [I9], [F], [E].

R3: Transparent coaching
When being coached, it is important that the drivers understand the feedback, what is accounted for and to what degree something is affecting it. If the drivers do not understand the feedback or how to improve it, the feedback loses its purpose while simultaneously making the users frustrated. What is taken into account and how the metrics are calculated are important so that the users understand how the metrics and feedback interplay and can put them in relation to each other [I13]. Knowing how great of an impact something has on energy consumption teaches the drivers what consumes the most energy and gives them a bigger freedom to tailor their driving experience to their liking. Moreover, having too gentle coaching and not showing the actual impact can make the drivers overlook the effect it has on energy consumption [I8].

Preferably, this is achieved by displaying the information in an intuitive way that is easy to understand for the driver. Whenever that is not possible, additional information should be easily accessible upon request if the users need a further explanation. If the average consumption for the daily trips fluctuates a lot, the users want the apps to acknowledge why that is. If it is due to cold climate, towing a trailer or other factors, the users want it to be reflected in the feedback [I12], [F], [E].

R4: Enable planning for efficient driving in smartphone and car
It became evident that the BEV owners spent a lot of time planning their longer trips. Making sure the SoC was set to 100%, planning the route and where to charge along the way are some examples of tasks made during planning. The apps should support the drivers in finding the most optimal route [I15], in terms of time, energy consumption and availability of charging stations along the way, amongst other things. This information should be available in both the smartphone and the car, with the option to plan the entire trip in the smartphone and thereafter send the route to the car [I17], [E]. In this way, the users can decide when to plan their trips without having to do the planning twice.

7.3.0.2 Usability

R5: Support users in critical situations
The BEV drivers learn a lot through experiencing different driving conditions as well as how to best combat these situations. Nevertheless, it is still important to provide the drivers with support and additional information whenever encountering unfamiliar situations [I10]. For instance, whenever the drivers are unsure of what

is causing the decay in range or if it is abnormal, the car should guide the user in these situations by telling the driver what is causing it, and what actions to take to solve the problem, if it can be solved [I12], [I13], [E].

R6: Seamless transition between smartphone and car

A seamless transition between the devices is crucial for creating the coaching experience. To lessen the frustration amongst the users, [24] and [29] establish the importance of the continuity of the task across devices and re-accessing information [F], [E]. This could include migration of tasks such as starting planning the trip on the mobile phone, and later continuing it in the car [I17]. Or the synchronisation of information such as remembering and displaying data from the car in the phone. Since the mobile phone is a device that is frequently used in the daily life of people and drivers [Q9], it can with an advantage be used in the user journey and user experience of having a BEV as a complimentary device for tasks outside the car.

R7: Relatable feedback

The feedback being familiar increases the chances of it persuading people [22]. How relatable the feedback is, depends on what information it entails and how it is visualised. Information that BEV owners already relate to and make use of to determine energy efficiency is battery percentage, range and energy consumption (kWh/100km) [Q4], [O7], [FiSt], [I5]. Drivers were also interested in their SoC level upon arrival to determine if they have to charge along the way [I14]. If a new type of metric is introduced, it should be related to something that the drivers already are familiar with. They do not have to be related to the specific metrics mentioned above, if the drivers are familiar with them. In addition, it should be visualised in a way which enables drivers to put the feedback in relation to other situations to be able to decide how efficient their drive was [I9], [E].

R8: Coaching tailored towards multiple user groups

BEV users of varying levels of experience have different needs and their objectives might differ. Inexperienced drivers are more likely to want to learn about what factors influence the range and how their electric vehicle work. By enabling fast adaptation and understanding of the vehicle through coaching, these users' experience of driving BEV will be enhanced [39]. Drivers who already know these things through experience [I4] are more interested in knowing how much certain things impact the range so that they can make an informed choice of how to maximise their range with regards to their comfort as some users prioritised that over driving energy efficiently [I7].

Some BEV owners thought that Range Assistant was not insightful for them and provided them with too gentle coaching, suggesting that they already knew the information provided by the app [I8]. One example is the energy usage bars where multiple drivers said that they understood how it worked and that if they drove at a high speed that metric would be high. Thus, they requested additional and more detailed feedback [I9], [E]. Not all the information can be displayed at all times. The most important and widely used features should be the most visible and accessible. However, the drivers should be given the option to gain further information when needed [I10].

7.3.0.3 Device

R9: Enable performing time-consuming tasks in smartphone device
There are some tasks that require more analysis of the content or are more time-consuming. Since the smartphone is already used by BEV users [Q9], such tasks can with an advantage be placed there since drivers rarely want to spend unnecessary time in the car [F], [E]. This includes historic data from trips, driving journal [I11] and planning of trips [I17]. By placing this in the smartphone, the driver has time to review the feedback whenever they have time to do so, which is not always when in the car [25]. The most important thing with feedback is that it is received by the drivers, rather than the timing of it [32].

R10: Non-exclusive information
The information and feedback provided in the device do not have to be exclusive but can be present in both devices. This will aid the user with the transition between the devices. Creating continuity can be achieved by synchronising or migrating the data, or a combination of the two [29]. If the feedback is migrated, the data has to be tailored to the device and context [23]. Drivers see the value of finding aggregated historic data from trips in both a smartphone device and in the car, where the car should display a compromised overview that is easily digested after a trip. The smartphone, on the other hand, can provide more detailed information for drivers to explore if needed [E].

7.3.1 Future User Journey Maps

The future user journey maps below communicate how the developed design concepts created improve the user experience for the three scenarios in relation to today's user journey seen in section 7.2.1.

Short Trip

In the future user journey map for short trip scenario, figure 7.14, evaluation is possible both in car via the historic view in the car application and in the smartphone for more detailed data. This is expected to increase the experience in the phase *after arrival*.

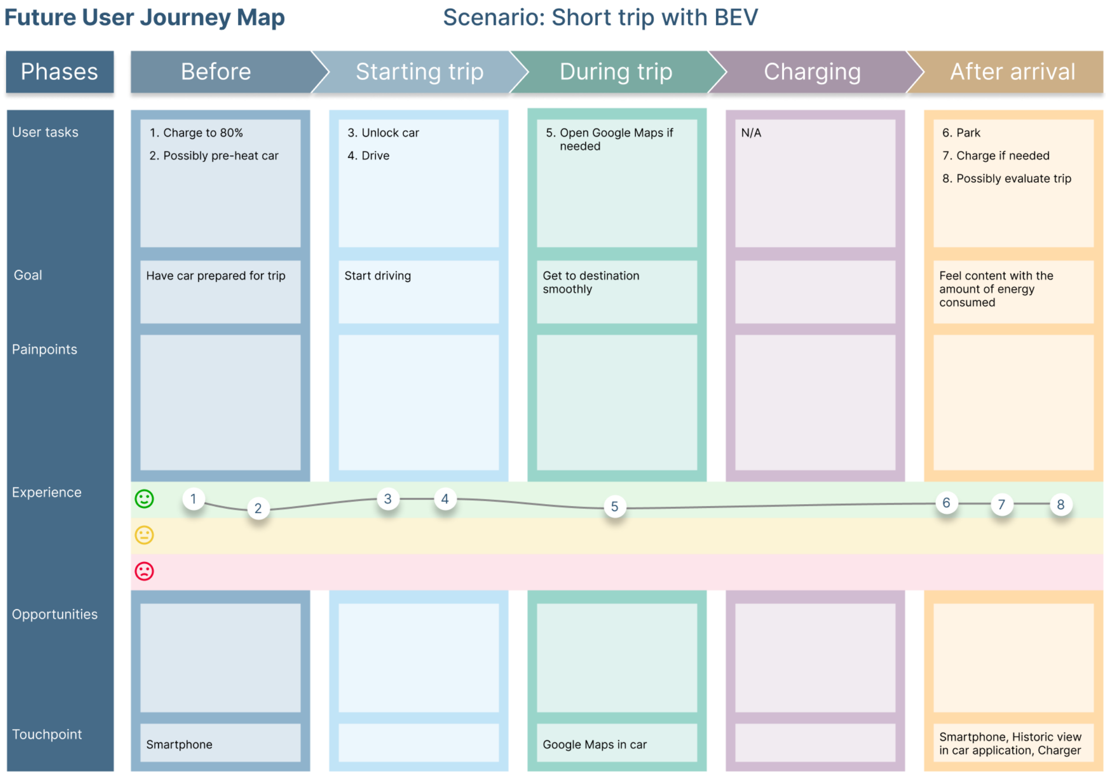


Figure 7.14: Future user journey map for short trip

Long Trip

For the scenario of long trips, illustrated in figure 7.15, the possibility of planning a trip beforehand via the smartphone is included as well as sending it to the car. The option of taking the most energy-efficient route is achievable too for the future user journey leading to an expected increase of the experience in the *planning* phase. In addition, the feedback during the trip is more transparent and informative and evaluation after arrival is doable. This is expected to increase the experience in both the *driving* and *after arrival* phases. Since the charging experience isn't within the scope of the research, the experience in this phase remains.

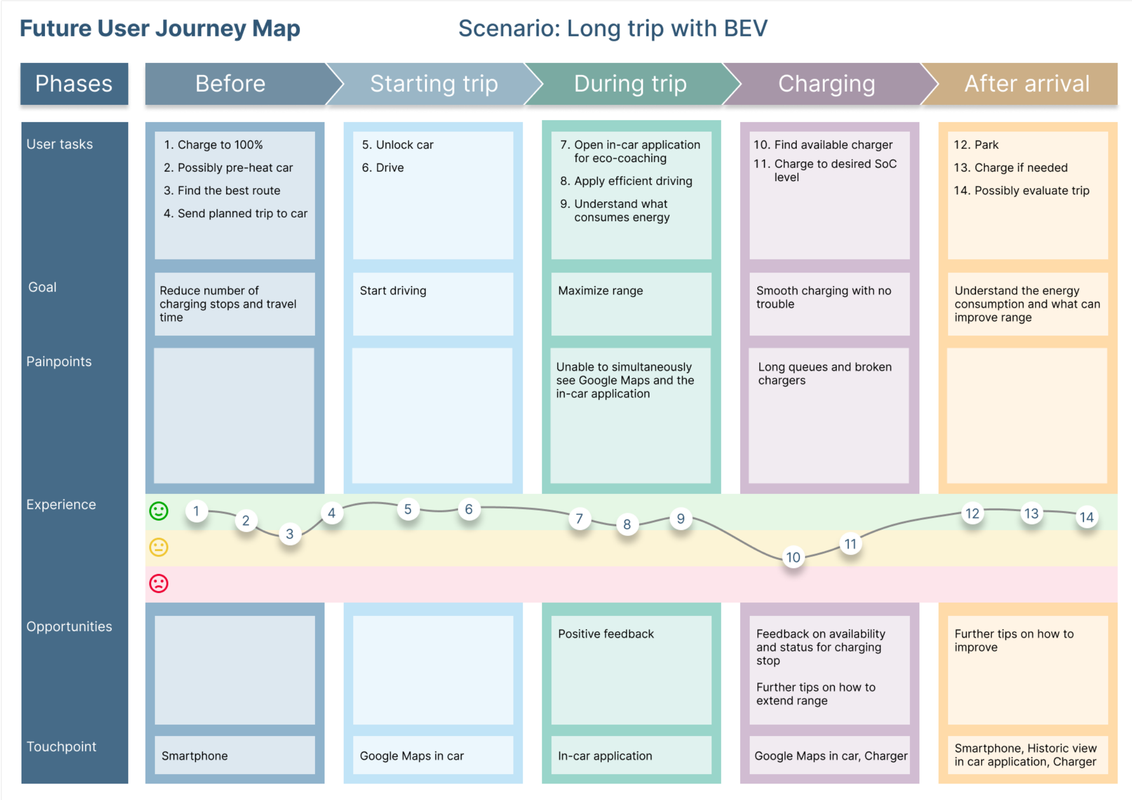


Figure 7.15: Future user journey map for long trip

Long Trip - Cold Conditions

The future user journey for the long trip, shown in figure 7.16, when external factors such as cold conditions are affecting, the *driving* phase's experience is improved due to the design concept taking the cold temperatures effect on range into account and being transparent on why and how much range is reduced due to these conditions. Also, the evaluation of the trip is possible after arrival where the driver can see how much energy the cold temperature consumed, and the planning of the trip can be achieved beforehand in smartphone. This results in an expected increase of the experience in both the *planning* and the *after arrival* phase.

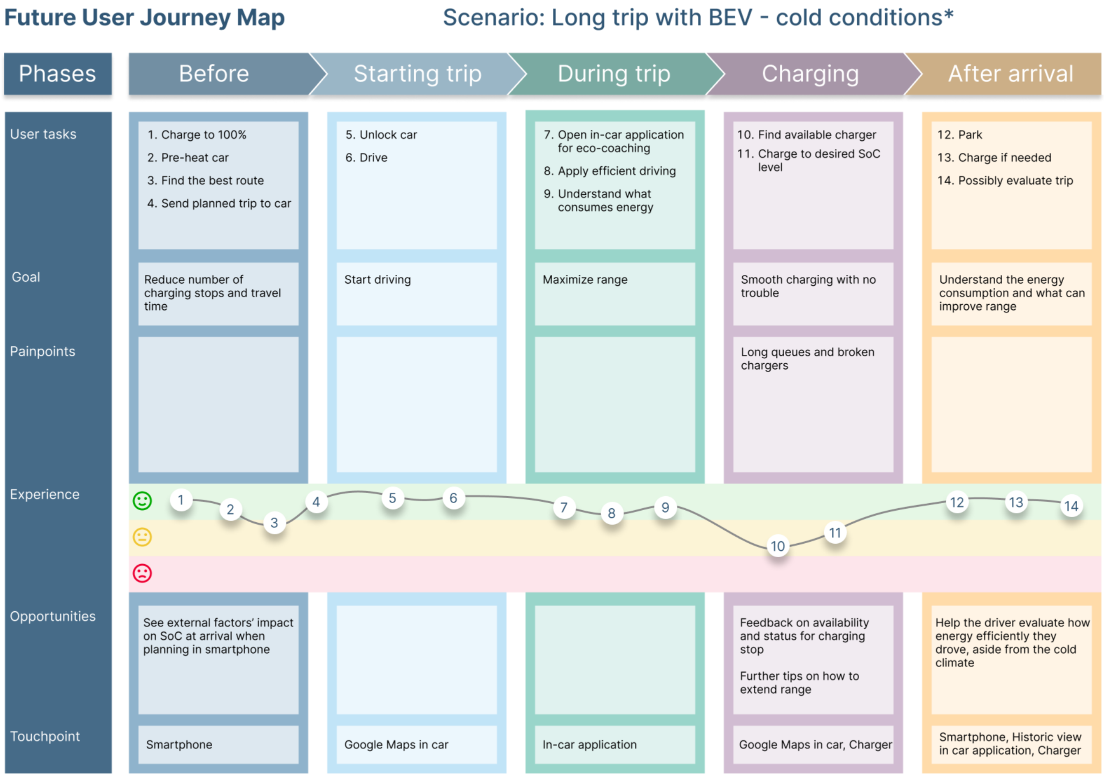


Figure 7.16: Future user journey map for long trip in cold conditions

**can be replace with other external factor*

8

Discussion

This chapter discusses the various aspects of the thesis, starting with the result of design recommendations and how they are relevant to related work and user experience. Thereafter, the execution of the research with connected theories is covered followed by ethical considerations that need to be addressed. Lastly, there is a discussion on identified future work.

8.1 Result

The purpose of this master's thesis was to identify how and in what device coaching of electric car drivers should be performed to teach them how energy-efficient driving can be achieved, in addition to increasing their understanding of energy consumption and range. The end goal was to establish design recommendations that would aid the development of a coaching experience across devices, utilising an in-car application and a smartphone. The result of the design recommendations aimed to answer the research question:

What are the design recommendations when developing a cross-device coaching experience for electric car drivers?

Through the application of interaction design with a user-centric approach and through the perspective of user experience, the 10 design recommendations are considered as the answer to the stated question. By answering the research question, the purpose and goal set for the thesis are fulfilled. Since triangulation was used to develop the recommendations, using multiple research methods, strengthens the validity of the study.

The Usage and Future of the Design Recommendations

The design recommendations ought to be a tool for designers when developing a coaching experience. They can be used throughout the whole design process but are especially valuable in the early stages of the design process to create an understanding of what contributes to a good coaching experience across devices. The design recommendations do not explicitly state how information should be visualised or otherwise communicated, but rather what objectives are to be accomplished. Moreover, the recommendations are created specifically for a smartphone and an in-car device, with today's use of the devices as a reference point. However, in the far future, the interactions with these devices most probably will evolve or cease to exist, and the conditions in which they operate might change. Hence, the design recommendations will have to be reviewed and updated in the future.

Precisely how contemporary the design recommendations are is hard to predict. What argues for the recommendations being less relevant in the future is, for instance, the development of batteries resulting in the possibility of future BEV models having a drastically extended electric range, leading to the desire of optimising range to decrease. Consequently, the demand for coaching energy-efficient driving will be reduced. However, applying energy-efficient driving will most likely continue to be a strive if the supply of electricity, especially clean and sustainable electricity, is limited. If this is the case, the collective pursuit of reducing energy usage would most likely still be a priority. When it comes to the coaching aspect of teaching the driver about the electric vehicle peculiarities and the cause and effect of how their actions relate to energy consumption, this will still be highly relevant if the transition from combustion engine cars to electric cars is ongoing and the overall experience of electric vehicles is low. However, in the far future, the knowledge of BEVs will most likely be higher in the population, resulting in a decreased demand for feedback increasing the knowledge. The focus might then shift to *when* energy-efficient driving should be performed and not *how*. When this becomes the case, the design recommendations need to be updated and tweaked towards an experienced user group.

The Design Recommendations and Related Work

A handful of the design recommendations, R6 - R10, were not only supported by the user research but also by the literature. However, there are additional, interesting connections between the findings of the related work and the design recommendations of this thesis which will be further discussed in the upcoming paragraphs of this section.

The two interfaces are part of a digital ecosystem where they cooperate to create one cohesive coaching experience. When developing the design recommendations, the focus was not on the smartphone and in-car application as devices, but rather on what interactions they could provide. One important area of improvement when it comes to cross-device systems is the user experience [24]. The recommendations help the designers enhance the user experience, partly by achieving continuity within the system with the help of R1: Tailor the feedback and its placement to the context, R6: Seamless transition between phone and car and R10: Non-exclusive information. The continuity account for re-accessing the right information at the right time and allowing for the continuation of tasks on the other device. There are other attributes that contribute to the continuity as well. The design of the interfaces will have to share design language and present information in similar manners to create a sense of unity.

Atkinson et al. [19] deem the feedback to be more effective if the relationship between the coach and trainee is built on trust. R3: Transparent coaching opts to create trust between the driver and the digital interfaces, by showing that it is anchored in facts and therefore is credible. In the user research, many drivers thought that the car was "hiding" something from them when the feedback provided did not fully explain their energy consumption. This caused the drivers to not trust the feedback provided by their cars. One interviewee mentioned that they only trusted the battery percentage since that was the only thing that was not a calculation made by the car. Moreover, eco-feedback is related to persuasive technologies since the goal is to essentially promote or persuade sustainable behaviours. One attribute of the level of persuasiveness is perceived attractiveness. What makes a graph attractive is the familiarity and readability, according to [22]. Thus, R7: Relatable feedback is important to implement, where the drivers recognise and trust the information presented.

The primary intention of the design recommendations is not to minimise range anxiety per se, however, since they do intend to provide a pleasant coaching experience to the electric car drivers, they also indirectly strive to reduce range anxiety. According to [39], drivers who understand their electric vehicle and its abilities, characteristics, and functions, perceive lower range anxiety resulting in a better driving experience. By applying the second and third design recommendations (R2: Combination of momentary and historic feedback and R3: Transparent coaching) the driver is provided with information increasing their knowledge and understanding about their electric vehicles and energy management. Thus, the range anxiety and driving experience will most likely be changed for the better, according to the implication of [39] since the drivers, through these design recommendations, have the tools to become experienced BEV drivers quicker and easier.

Lundström [40] lays forward the argument in his study that the focus when visualising data to electric drivers should be to empower drivers by having feedback which they can act upon. The first design recommendation (R1: Tailor the feedback and its placement to the context) mentions how the feedback in the car during driving should concern driving behaviour which the driver can adjust. Further, the recommendation describes the opportunity for range tips to be present, which is included in the prototypes. Both for the current drive in the momentary view, see figure 7.8b and range tips for future drives in the historic view, see figure 7.10. This is to ensure the feedback drivers get when driving is something they can act upon. However, one type of feedback the recommendations do promote which users cannot impact directly is the external conditions linked to temperature, see figure 7.8a. Drivers are not in power to change the weather in which they drive which makes this type of informative feedback, e.g., when, and how much cold conditions affect the range, to be something the drivers cannot act upon and change. Even though this is the case, this type of feedback is still of value to drivers based on the research made. However, there needs to be a careful implementation of this type of feedback to avoid it being frustrating for the driver and therefore worsening the user experience. Further investigation on possible actions to suggest to the drivers that they can act upon during cold conditions, e.g., pre-heating battery, is of relevance here.

Historic trip data is a specific type of feedback the second design recommendation argues for to include when coaching electric drivers (R2: Combination of momentary and historic feedback). Pichler and Reiner [7] also mentioned in their study the opportunity of visualising historic data from previous trips to the driver and concluded that historic trip data on cause and effect can be used to motivate more energy-efficient driving. The research in this thesis goes further by revealing how electric drivers themselves need this data to be coached and understand their energy consumption.

The User Experience Created by the Design Recommendations

There are multiple aspects included in user experience design: Useful, Usable, Findable, Credible, Desirable, Accessible and Valuable [48]. The design recommendations address multiple of these, to provide cross-device coaching which enhances the user experience rather than diminishes it. Basing the design recommendations not merely on user research but also on end-user evaluation has resulted in them aiding the development of useful, usable, credible, and valuable coaching. Regarding accessibility, separate disabilities were not explicitly stated in the recommendations since they are a high-level framework to create a coaching experience. The European Accessibility Act is a directive constituted in 2019, that ensures that products are accessible to all people, including those with disabilities. The law has to be reinforced by companies by mid-2025 [68]. In practice, this inquires the designers who utilise the recommendations to make their products accessible to their customers based on their specific needs.

The level of findability and desirability is difficult to determine without switching the focus to the prototypes themselves since the design recommendations do not address aesthetics, brand image or how to find the product and its features. These two aspects of user experience have not been a primary focus of the research. Nevertheless, the first takeaway from the observational study [O1], actually points out findability as a potential problem with the in-car application since several users didn't use it due to them not knowing about it. This implies the importance of deliberately taking these factors into account when creating interfaces for a cross-device coaching experience.

What should be noted is the fact that the design recommendations are not specifying a precise way or specific features to include when designing the device interfaces. The prototypes created during the process are proof of concepts and have been used as tools when researching through design. Thus, when utilising the design recommendations, other varieties of interfaces are plausible to be developed and how well they will enhance the user experience of the cross-device coaching is hard to know beforehand.

8.2 Execution and Connected Theories

Sampling for User Research

During the thesis, only people employed by Volvo Cars were part of the user research, apart from the field study. This may have created biases, from multiple perspectives. Firstly, the majority of employees are men [69], which is reflected in the gender distribution of the participants involved in the research. Despite the authors actively trying to recruit women, the proportion of women participating was most commonly between 17-33%, with two exceptions. One is the observational study where 57% of the participants were women, and the other is the focus group where no women participated. In summary, this indicates that most of the data used for the research was from men, and their values and beliefs about sustainability and driving a car, in general, might not alight with those of women.

Another possible bias created due to the sampling was the fact that the majority of participants worked as engineers at Volvo Cars, implying that their prior knowledge about BEVs might be greater than that of the average driver. The short field study conducted was a good complement to scouting alternative BEV drivers' opinions and attitudes to see how they differed from the other participants. Nonetheless, this led to the user data collected being mostly from a technically informed part of the user group which could skew the result into fitting more knowledgeable electric car drivers.

The Utilisation of Research Through Design

When conducting the thesis work, the theory of Research through Design (RtD) was implemented as a tool in the process. By prototyping design concepts based on user requirements from the user research, and evaluating the concepts in between iterations, valuable insights could be gathered and used as a foundation for the development of design recommendations. Utilising artefacts when conducting research, as the RtD suggests, introduces the possibility of further discoveries in the design space which would not be attainable without the artefact [41]. What needs to be reflected upon is how and to what degree the prototyped interfaces affected the development of design recommendations and if they led to restraints. Perhaps other variants of design artefacts or concepts would have resulted in other design recommendations which could not now be discovered. Stappers et al. [70] reasoned in a similar way and stated: "your prototyping ability constrains the phenomenon that you can study". Therefore, the design recommendations should be seen as just recommendations and not guidelines.

The Interaction Design Footprint

The research conducted in this thesis has been carried out with Interaction Design as a foundation. Thus, the design recommendations developed from the research go beyond the interfaces prototyped and have been composed with user interaction, user needs, context, and limitations as a main focus [45]. This has been made possible by the various user research methodologies conducted. All the methods involving users, from the questionnaire to the evaluation, have been made with electric car drivers, resulting in the design recommendations having a primary focus on user needs and interactions for this specific user group the research question sought to address. Further, by conducting the observations in the context of driving an electric car with a coaching in-car application (Range Assistant, see figure 2.1 and 2.2), and by purposefully including questions in the questionnaire, interviews, focus group and evaluative research about the actions electric car drivers do in various situations and environments, the broader context and limitations of the user group in which they operate have been taken into consideration in the design recommendations.

The User-Centered Design Approach

The design process executed in the research makes use of the user-centred design approach to a great extent. First and foremost, users have been involved and consulted in the development of design recommendations, from the initial phase of discovering user requirements to the latest phase when evaluating prototypes. Through user research and by applying methods such as personas, scenarios and user journey mapping, the context of use, behaviours and activities of users have been discovered and defined in the process and have been largely considered when formulating the design recommendations. Further, through user journey mapping, the tasks and goals of the user were communicated in an early stage and used as a driving force when developing the prototypes.

8.3 Ethical Considerations

The Many Perspectives of Sustainability

One goal of the eco-coaching system is to educate and reduce people's energy consumption when driving a BEV. As always when designing products for sustainable behaviours, it can be hard to know if the product will provoke a desired behaviour that leads to driving in a more sustainable fashion. Moreover, persuading the users, by using eco-coaching, could potentially limit the perspective of sustainability. Brynjarsdottir et al. [71] explain that simplifying sustainability into a reduction of consumption, measured using a few metrics, will give the users an inaccurate picture of the situation and focuses too much on individual behaviour change, rather than a systematic one. Therefore, it is of relevance to bring light to the risk of the design recommendations mostly addressing coaching for individual change and the importance of also implementing systematic changes for sustainability in the automotive industry. In addition, possible rebound effects have to be considered. By reducing energy consumption, users might use their cars more frequently when commuting, which is not ideal for a sustainable society. Public transport is still the superior sustainable alternative for modes of transportation [72].

Road Safety While Interacting With an In-Car Application
Visual and cognitive distractions could potentially be caused by an in-car application, which is one of the devices used for coaching in this thesis. Klauer et al. [73] found that being distracted by secondary tasks while driving accounted for 22% of all crashes and near-crashes. Further, the study found that the risk of crashes increased if the driver glanced away from the road for longer than two seconds. Many of the users that participated the user study expressed a want to have immediate feedback connected to their driving behaviour in the car. Naturally, the drivers themselves might not reflect on or be aware of how distractions affect their driving. Some users even expressed their frustration about certain features being disabled due to safety reasons while driving. Both the designers and drivers have a responsibility for how an energy management assistant in the car is used. The designers can think about minimising distractions by only including the most necessary content that is easy to scan and process in the car. Whereas the drivers must make an assessment of when it is appropriate to use the application.

8.4 Future work

Further User Research
As discussed earlier, the participants were all employed at one company and may have had more technical knowledge than the average electric vehicle driver, therefore the study could benefit from conducting further user research. This is to investigate the perspective of new BEV drivers and thus deepen the understanding of the user group. During the interviews, the participants were asked about their knowledge, and how it had evolved, from when they were new BEV drivers up until today. Even

though it captured some of the struggles of beginners, other problems might have been forgotten by the drivers that otherwise would have been unveiled if they were interviewed when they were new to their BEVs.

Motivate Energy-Efficient Driving

While conducting the user research, it became evident that the drivers believed that sustainability was an important topic. However, some drivers stated that since they already had made the transition to an electric vehicle and mostly charged their vehicle with clean energy, they had a low motivation to prioritise driving more energy efficiently. Although the carbon dioxide equivalents are significantly lower for electric cars, a sustainable lifestyle calls for behaviour change, where the level of comfort for people must be reassessed. The drivers have reduced sustainability down to carbon dioxide emissions and do not see the big systematic change that needs to happen, as also discussed in ethical considerations. In Sweden, the energy demand is predicted to double until 2035 [74]. Energy production must significantly increase, which is a current societal challenge. The aim of this thesis was to enable drivers to learn more about the energy consumption of their cars and how to lower their consumption across devices. Future work would be to explore further how to increase the motivation of BEV drivers to drive more energy efficiently. As described in related work, there are many possible ways to heighten the motivation. Abstract feedback could be effective [18] and gamification are two examples of this [7]. Further, egoistic motivations, such as monetary savings are commonly seen [17]. The pro-environmental behaviour is complex, and the motivation can be overridden by other desires, such as taking the car to work when it rains, instead of biking [35]. Thus, there is not one correct solution to solve the problem. However, the design recommendations are not only meant to lower the drivers' energy consumption but more importantly learn about what factors are affecting the range. Therefore, monetary savings should not be the primary focus but could be an addition to heighten motivation.

The User Experience When Charging

A frequently occurring topic during the user research was charging, especially finding working and fast charging stations when having to charge during a trip. This is closely related to energy consumption and would be a natural progression of the research. The availability of charging stops affects the route the driver takes and how fast they will get to their destination, to name a few things. Choosing the best charging spot can be challenging, considering that the SoC of the car, route, availability and type or brand of charger, is to be accounted for. In addition, the many range-influencing factors make it more difficult to predict where the best charging stop is located. Further, there are additional factors to consider when charging. For example, to optimise the battery life length the users should try to keep SoC between 20-90% [75] and at what battery level users feel comfortable charging at, is individual. Preconditioning the battery before charging is also important for optimal performance, especially in cold weather conditions. Future work to assist the users with finding the right charging spot and how to care for the battery would further enhance the experience of driving a BEV.

9

Conclusion

This thesis aimed to identify best practices when coaching electric car drivers, utilising an in-car application and smartphone devices, to learn about energy-efficient driving and their cars' energy consumption. By providing them with the tools for doing so, BEV drivers can feel more in control of their cars and make an active choice to lower their consumption. The research question composed to answer this was the following:

What design recommendations are there when developing a cross-device coaching experience for electric car drivers?

The double diamond process by the British Design Council was facilitated to develop design recommendations, starting with literature studies and user research. The data collection resulted in a user requirement list, which was used for designing prototypes for the in-car application and smartphone. Feedback on these prototypes was gathered from end users and eventually, all collected data were compiled into 10 design recommendations, which answers the research question:

Feedback

R1. Tailor the feedback and its placement to the context

R2. Combination of momentary and historic feedback

R3. Transparent coaching

R4. Enable planning for efficient driving in smartphone and car

Usability

R5. Support drivers in critical situation

R6. Seamless transition between smartphone and car

R7. Relatable feedback

R8. Coaching tailored towards multiple user groups

Device

R9. Enable performing time-consuming tasks in smartphone device

R10. Non-exclusive information

The rapidly growing number of BEV owners makes the design recommendations highly relevant for other researchers and designers to use when developing a cross-device coaching experience. Knowing what affects the range of the car and how to lower the energy consumption is only the tip of the iceberg, and future work includes motivating electric car drivers to driver more energy efficiently but also improving the experience of charging on the road, which has been discovered during the research to be a pain point among BEV drivers. Hopefully, the design recommendations will contribute to a greater understanding of how coaching can be performed across devices for electric car drivers and prompt further research within the area.

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A

Appendix: Questionnaire

Section 1 - About range and energy efficiency

q1. Which **CoDev car** do you have?*

- ○ Polestar 2
- ○ XC40 recharge (BEV)
- ○ C40 recharge (BEV)

q2. **How long** have you had your current electric (BEV) car?*

- ○ Less than 6 months
- ○ 6-12 months
- ○ More than 12 months

q3. What is your **age**?*

- ○ 29 years or younger
- ○ 30-39 years
- ○ 40-49 years
- ○ 50-59 years
- ○ 60 years or older

q4. What is your **gender**?*

- ○ Woman
- ○ Man
- ○ Non-binary
- ○ Other

- ○ Rather not say

q5. How satisfied are you with your **range** of your BEV car?*

- ○ 1 - Not satisfied at all
- ○ 2
- ○ 3
- ○ 4
- ○ 5 - Very satisfied

q6. How important is it to you, to drive **energy efficiently**?*

- ○ 1 - Not important at all
- ○ 2
- ○ 3
- ○ 4
- ○ 5 - Very important

q7. What **motivates** you to drive more energy efficiently?*

- ☐ Economic reasons
- ☐ Environmental/sustainability reasons
- ☐ To improve range/charge less often
- ☐ Nothing special
- ☐ Other (text-based answer)

q8. **When** do you generally consider driving more energy efficiently?*

- ☐ I always think about it
- ☐ Only when driving long distances
- ☐ When I need to charge along the way
- ☐ When the battery is running low
- ☐ I never think about it
- ☐ Other (text-based answer)

q9. Do you generally **know how energy efficient** your current driving behaviour is?*

○ Yes

○ No

○ I'm not sure

q10. **How do you know** when you are being more or less energy efficient? (Text-based answer)

q11. How would you **prefer to receive feedback** on how to drive more energy efficient? (Text-based answer)

q12. Have you ever used **Range Assistant** in your car?*

○ Yes

○ No

q13. **If no, why** have you not used Range Assistant?

☐ Didn't know about it

☐ It didn't seem useful to me

☐ I prioritized other applications

☐ I don't like to be distracted while driving

☐ Other (text-based answer)

Section 2 - About Range Assistant

q14. **How often** do you use Range Assistant for your trips?*

○ 1 - Never

○ 2

○ 3

○ 4

○ 5 - Very often/every time

q15. When do you find the range assistant **most useful**?*

☐ Short trips (<30 min)

☐ Longer trips (> 30 min)

☐ Very long trips (> 3 h)

☐ Never

☐ Other (text-based answer)

q16. How easy is it to **understand the feedback** from the Range assistant?*

○ 1 - Very difficult

○ 2

○ 3

○ 4

○ 5 - Very easy

q17. Do you have any other comments regarding **Range Assistant**? (Text-based answer)

Section 3 - About your car's smartphone app

q18. Have you ever used the **smartphone app for your car** (Volvo Cars/Polestar app) at least once in the last 3 months?*

○ Yes

○ No

q19. **If yes, when** do you find the car app most useful?

☐ Before a trip

☐ During a trip

☐ After a trip

☐ Other (text-based answer)

q20. What are you **most satisfied with**, when it comes to the car app? (Text-based answer)

q21. Would you be willing to participate in a follow-up interview (on-site in Gothenburg or online) about range and energy efficient driving?*

○ Yes

○ Maybe, if I got some more information

○ No

B

Appendix: Form for Observational Study

Intro: Me and X are writing our masters thesis at Volvo this spring. We are examining how to best coach people to drive more energy efficiently and are currently doing observation studies on how people use an electric vehicle. During this observation, I will sit in the backseat of the car and try not to interfere with your driving. There is also a camera that will record you and the material will only be viewed by us and deleted right after data has been collected. If a thought crosses your mind, feel free to think aloud so we can follow your thought process easier. This observation will take around 30 minutes and afterwards, we will ask a few questions for you to answer.

Start: At the parking place right outside of Volvo PVD

Say that you are going to read a scenario for them and try to make the test person comfortable by assuring them that we are not testing them as drivers, but simply want to get some more insights into how people use electric vehicles.

Scenario: Imagine that you are going on a ski vacation to Sälen (northern Sweden) with your family. It is about a 6-hour drive, and I want you to interact with the car as you would in order to get there. Starting from here, youll take the route of Hisingsleden in the direction of north. You can use any tools that youd like to prepare for your trip. Whenever you feel ready you can start driving. And feel free to think out loud.

Things to take notes of:
What applications did they use to plan their trips?
Do they use range assistant on their way there?

What is their driving style like?
Miscellaneous notes

Ask driver to turn left and park at the gas station ST1!

On the way home: Now, I would like you to drive back to Volvo PVN-port and this time you shall use the Range assistant to optimize your range. When you feel prepared and ready, you can start driving back.

Things to take notes of:
Do they glance at the range assistant often?
Do they seem to adjust their driving behavior accordingly?
Misc. notes

Guide the drivers to a parking spot. Ask them about how they think it went.

Questions after observation
What does driving energy efficient mean to you?
If they didnt open it on the first trip: why didnt they?
How easy or difficult was it to interact with the range assistant app?
What did you understand from the range assistant? Were you coached by it?
Do you have any understanding of how energy efficient you drove?
What do you think would be the best way for you to learn about energy efficient driving?

C

Appendix: Field Study Questions

Which car do you have?

How long have you had your current electric car?

How satisfied are you with the range of your BEV car?

How important is it for you to drive energy efficiently?

What motivates you to drive energy efficiently?

When do you generally consider driving more energy efficiently?

Do you generally know how energy efficient your current driving behaviour is?

How would you prefer to receive feedback on how to drive more energy efficiently?

Does your car provide any coaching on how to drive more energy efficiently?

Are you satisfied with the app?

Does your car have a mobile phone app

If you use it, when?

What are you most satisfied with, when it comes to the app?

D

Appendix: Interview Guide

Warm-up questions (2 min)

For how long have you been a BEV user? Have you owned multiple BEVs?

What made you transition to a BEV?

How tech interest would you say you are in general?

Walk through of scenarios (5 min)

What are the most common trips that you make with your BEV?

If you were going on a trip from your home to X, could you tell me what you would do before the trip, during the trip, and after the trip? Any tools?

Are there any longer trips that you use your BEV for?

If you were going on a trip from your home to Y, could you tell me what you would do before the trip, during the trip, and after the trip? Any tools?

If not: If you were going on a longer trip from Gothenburg to Stockholm with your BEV, could you tell me what you would do before the trip, during the trip, and after the trip and if you use any tools when completing these things.

How would you determine if you drove energy efficiently or not on these trips?

General questions about energy efficient driving (10 min)

How has your knowledge about your car and energy consumption changed since you first got your BEV?

If anything, what have you done to educate yourself about BEVs and driving energy efficiently? Why did you take this approach?

Is there anything you feel like is missing when it comes to being coached to drive more energy efficiently and to understand how you can drive energy efficiently from your experience?

Since you got your BEV, have you ever noticed the range change unexpectantly, if so, how?

How did you react? How do you think you would react?

What do you personally think would be the best way to avoid this led to a negative experience?

Range Assistant (5 min)

How did you come in contact with the Range Assistant application?

How often do you use the range assistant? When, why?

What do you think is needed to make you apply energy efficient driving more often?

How would you be further motivated to drive more energy efficiently?

Mobile car application (10 min)

Do you think that the smartphone app is useful, and does it feel like a natural part when interacting with your car?

Are there any functions, and if so which ones, that you would like to include on the phone which arent there today?

What advantages or disadvantages do you see of having information being placed in the smartphone car application to help coach energy efficient driving?

Which information do you think is suited in the mobile to inform and coach energy efficient driving? Car?

Ending questions (2 min)

What is the best thing about driving a BEV?

What advice do you have for new BEV owners?

E

Appendix: Final Evaluation

Introduction Explain that they will evaluate, and give their opinion on, design concepts (which arent fully developed and fully interactable) and that we will provide context for each of them. Explain that the purpose is to coach energy-efficient driving and understand the cars range.

1. Before trip with smartphone (planning view)
Have the user walk through the concept and explain what they see and what information they are getting.

Questions to ask:

- Are the features easy to understand?
- When do you see this information being of most value when planning a trip? (short trip, long trip)
- Are any features of more/less value (why) (try talk about send to car feature and the transition between devices)

2. During trip with Range Assistant (momentary view)
Have the user walk through the momentary view and explain what they see and what information they are getting.

Questions to ask:

- Do you understand what are the factors that influence the range?
- What feedback, if any, helps you to lower your consumption?
- Are any features of more/less value (why)

Show cold conditions - do you understand what factors influence range here?

Show range alert

3. Right after trip with Range Assistant (historic view)
Have the user walk through the historic view and explain what they see and what information they are getting.

Questions to ask:

- Is this screen of value? any features of more/less value? (why)
- Show consumption and as y-axis concepts and ask which one they prefer or both.

4. Afterwards with smartphone (statistics)
Have the user walk through the concept and explain what they see and what information they are getting.

Questions to ask:

- Does the information provided give you a good overview of your trips?
- When do you see this information being the most valuable?
- Is this screen of value? any features of more/less value? (why)

Show filtering

F

Appendix: Benchmark

Tesla Model 3/S/X/Y

In the Tesla smartphone application [76, 77], the state of charge (or estimated range) is displayed. The information in the app is very much centred around charging and the energy consumption connected to it, as opposed to the energy consumption for trips. E.g., what type of energy source and how much energy was used when charging is displayed. Other charging statistics about price and monetary savings are also present. The app itself does not contain a navigator, but it is possible to send routes to the car from third-party apps such as Google or Apple Maps.

The information in the car [78] deals more with energy consumption related to trips. The car has an Energy application where drivers can see real-time range consumption and how well the actual range consumption aligns with the car's trip projection through colour coding. Where the energy has been allocated is broken down and presented, where each post is compared to the car's projection. There are also range tips displayed concerning how to decrease consumption. The range tips and comparison with the projection show the users how much they saved or could have saved, measured in distance. However, benchmarking has shown the Energy app can present the data on battery consumption too, in percentage instead of range. This seems to be a setting which can be changed by the driver according to their preference.

Apart from displaying information about energy consumption for trips, drivers can also see the energy distribution for when the car has been parked. Broken-down consumption and relevant range tips are presented. A later version of the Energy application [79] in Tesla also shows an additional Consumption view which contains a graph of consumption over time. Besides the Energy app, there is navigation in the car which displays the estimated state of charge at arrival when used, similar to google maps.

Porsche Taycan

In My Porsche mobile application [80, 81], there is little to no energy data prompting for energy-efficient driving. On the landing page, vehicle information such as the current state of charge and range is displayed. Further, the application includes a navigator, where drivers can get assistance with finding charging stops with several filtering options available, and then send the route to the car.

No information about feedback in the car connected to energy management could be found. However, they did have some integrated functions to save energy that was automatically applied when using route guidance [82]. It optimizes the route by taking distance, traffic information and time into account to find the fastest route, which is not necessarily the most energy-efficient route. However, it also lowers the speed limit, preconditions the battery before charging and adjusts the climate in the car to save energy.

Nissan Ariya/Leaf

NissanConnect Services [83, 84], is a smartphone app for both combustion engine and electric cars, with additional EV features. The app includes some driving history reports that display consumption, regenerated energy, energy cost and how much carbon dioxide emission was avoided. In the navigation view in the app, it is also possible to send a planned route to the car.

Nissan Ariya has an intelligent route planner [85] in the car which helps the user plan trips. Factors such as traffic information, road inclinations and battery level are considered in the intelligent route planner to suggest the fastest route. If there is a need for charging, the intelligent route planner will provide guidance to charging spots. In Nissan Leaf, there exists an ECO-mode button [86] which moderates air conditioning and reduces accelerator response to maximize driving range. Additional energy management features for Nissan BEVs were not found.

Kia Niro/EV6

Kia describes their mobile app [87] and in-car features to be seamlessly connected [88]. The smartphone application has compiled trip data such as average speed and distance. There is an option to plan the trip in advance before sending the route to the car. The online navigation identifies the fastest route.

In the car, there is a physical button called "Driver only" which optimizes climate for only the driver, thus consuming less energy and extending the range. Additional energy information can be found in the infotainment. Two values for the range are visualized, comparing the range for when the climate is activated or not. On another page, a staple diagram of the total consumption and driven distance per trip is found. Moreover, the broken down energy consumption between *Driving*, *Climate*, *Electronics* and *Battery Care*, can be found too and is displayed in both kWh and percentage on a third page. It was found to be difficult to get an overview of the energy consumption when the information was distributed across multiple pages. Further, a range warning setting can be activated which enables a message to be displayed on the screen to warn if the destination cannot be reached with the remaining range.

Mercedes Benz EQS/EQC

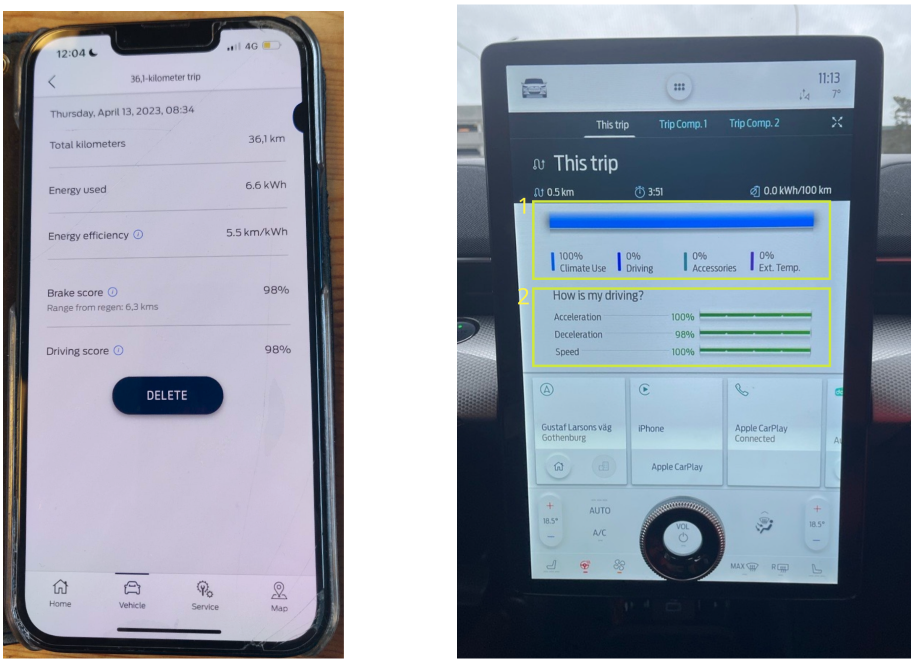
Mercedes Benz has a mobile application called Mercedes me [89] which provides vehicle information and enables sending the destination address to the vehicle from the smartphone. A feature in the Mercedes me application concerning energy management and eco-coaching is the ECO-score which displays how much range has been prolonged by driving energy efficient. Factors affecting the score are driving behaviours such as acceleration, coasting and regenerative braking. Further, the ECO-score display provides information and tips about the three factors, to coach drivers and help them adopt a more energy-efficient driving behaviour to get an even better ECO-score.

Mercedes Benz has also launched the Mercedes me Eco Coach application which according to the brand is "a personal trainer for environmentally conscious driving" [90]. It provides advice on how to make the most out of your electric drive based on data and information about energy-efficient use with regard to driving, charging and parking. The app also applies gamification through challenges. By mastering the challenges, drivers can collect points and redeem these points to prizes, e.g., charging vouchers. According to Mercedes, users of the Mercedes me Eco Coach app has significantly improved their driving style and charging habits [90]. For the Mercedes-Benz EQS SUV, the Eco Coach is integrated into the car display.

In the car, Mercedes-Benz BEV has ECO-indications in the instrument cluster which resembles the ECO-Score display in the mobile application. Its purpose is to motivate drivers to drive efficiently by evaluating the driving behaviour based on acceleration, coasting and regenerative braking. In the center stacked display, historic data on energy consumption can be found together with average consumption. Further, Mercedes-Benz has an ECO-mode button which shows optimal speed and give haptic feedback through the accelerator pedal when active.

Ford Mustang Mach-E

In the Ford mobile application FordPass, the user has access to a driving journal for all of their trips from the last 30 days. Metrics like distance, energy consumed, energy efficiency and brake- and driving scores are present, see figure F.1a. Energy efficiency is calculated in km/kWh, which is similar to the inverse of the average consumption in Range Assistant. Throughout the app, there are explanatory text, footnotes and information icons where the drivers can learn more about what is displayed.



(a) FordPass mobile app

(b) In-car Energy Management assistant

Figure F.1: Ford's energy management applications

Information about driven distance, time and average consumption can be found in the car display, and broken-down consumption in percentage is displayed beneath (1 in figure F.1b). The impact from the external temperature is included as a category. Separate driving scores for acceleration, deacceleration and speed are calculated, where 100% is the best score (2 in F.1b). The information can be viewed for the current trip or as compiled data from past trips. The trip compilation can be reset with a button to only include trip data from that point on.