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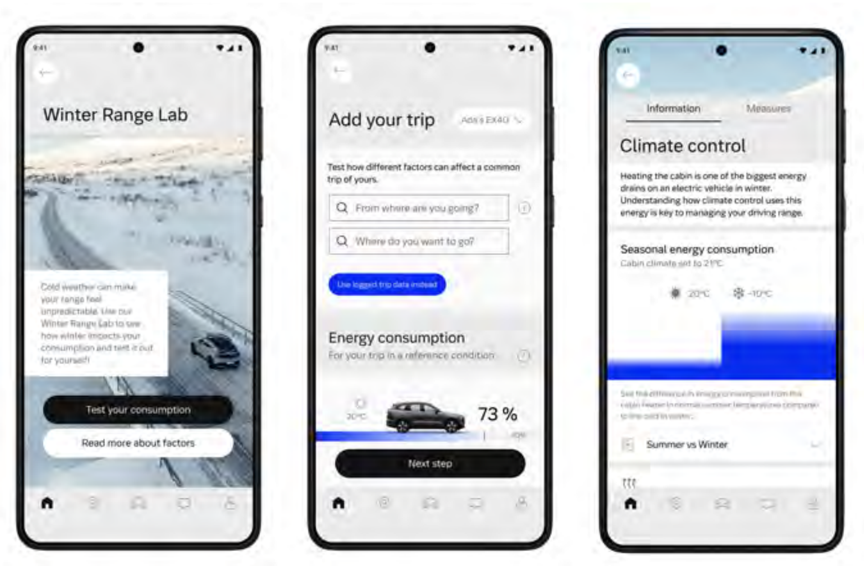

Bridging the Knowledge Gap of Cold Temperature Range Impacts

A Design Framework for Educating Battery Electric Vehicle Drivers

Master's thesis in Computer science and engineering

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Gothenburg, Sweden 2026

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Cover: The title image shows three wireframes from the final concept introduced in section 5.5.

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Abstract

As the automotive industry accelerates towards Battery Electric Vehicles (BEVs), understanding their efficiency has become a central challenge for modern drivers. BEV batteries are heavily affected by cold temperatures, which often lead to range anxiety in drivers as it drastically lowers vehicle range during the winter. This thesis addresses this issue by exploring the knowledge drivers need to manage winter driving efficiency, specifically focusing on the impacts of HVAC systems (Heating, Ventilation and Air Conditioning), driving speed, and temporarily unavailable battery capacity, and identifying the most effective strategies to deliver this information. By translating these complex technical data points into an intuitive user interface, this research aims to bridge the gap between BEV technical factors and the driver's real-world experience.

To achieve this, the project utilized a user-centered methodology guided by the British Design Council's Double-Diamond framework. The problem space was iteratively explored and narrowed down through four data collection phases: an exploratory study, a survey, semi-structured interviews, and interactive co-design sessions. The qualitative and quantitative insights were combined into user personas and a list of user requirements. These assets informed the development of two initial low-fidelity design concepts, which were ultimately merged into a single, cohesive interface concept based on user feedback. The final results led to eight design recommendations addressing the visual and functional architecture of a driver education concept. Specifically, the findings show that information should be integrated into a mobile framework, such as the Volvo Cars app, using a layered approach that prioritizes clean, intuitive visuals over dense text. Further, an interactive parameter in combination with clear information and actionable measures is recommended to make technical insights and variables feel trustworthy and directly relatable to the driver's daily life. Lastly, the research results indicate that this educational concept should be introduced during the initial vehicle onboarding phase, while seamlessly integrated within the application for contextual, on-demand use.

Keywords: battery electric vehicle, user onboarding, climate control, speed, battery capacity, cold temperatures, winter climate, interaction design, user experience, user-centered design

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Britta Christensson & Ebba Lindholm, Gothenburg, May 2026

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1 Introduction

Battery electric vehicles (BEVs) are increasingly becoming part of everyday mobility. As BEVs progress along the diffusion of innovation curve [1], from innovators towards early-majority, expectations regarding their reliability, predictability, and perceived ease of use also increase accordingly [2]. A central aspect within this transition is driving range. Although range is often presented as a relatively fixed value, it can vary considerably between trips. In real-world use, BEV range is affected by the combination of multiple environmental and operational factors. While the variability of range is technically understood and reported, it often is seen as uncertain to users as the variability itself leaves users without a clear intuitive explanation which can contribute to range anxiety [3].

1.1 Research Problem

A substantial body of research addresses the subject of range anxiety, consistently identifying driving experience as a key factor mitigating it [3], [4], [5]. However, experience is often treated as a cumulative outcome rather than as something that can be actively supported or facilitated. Despite extensive technical knowledge about battery behavior and range-related factors [6], there appears to be limited understanding of what BEV drivers actually know about these aspects and how it is supported through existing information systems.

As a result, there is a lack of insight into how knowledge-based support could be designed to complement experience and contribute to more confident BEV use, particularly in cold climates where ambient temperatures introduce additional energy demands and amplify the variability of range outcomes [7]. For Nordic context, these additional effects are not occasional edge cases but recurring and seasonally persistent aspects of everyday driving.

1.1.1 Research Questions

RQ1: What specific knowledge do BEV drivers require to make informed decisions regarding both pre-trip planning and real-time energy management in cold temperatures?
RQ2: Through what interaction medium can this information be communicated as trustworthy and actionable advice to drivers with varying technical literacy in cold

temperatures?

1.2 Delimitations

In order to conduct research on the topic, certain delimitations have been considered. First, this study will only look at BEV (Battery Electric Vehicles) and not at HEV (Hybrid Electric Vehicles) PHEV (Plug-in Hybrid Electric Vehicles) or any other type of car that uses another source of energy other than an electric battery. Secondly, due to the high load of factors affecting an electric vehicle and its driving range, this study will primarily focus on factors that are relevant while driving in cold temperatures. To guarantee experience with driving in cold temperatures, participants in surveys will be inhabitants of the Nordic countries, while case studies will take place in Gothenburg, Sweden. This means that the results may not be applicable to other regions, even though they have a similar cold climate.

1.3 Expected Contributions

This masters thesis aims to contribute to the field of electric mobility through research regarding user knowledge of factors affecting BEV driving range. Previous research has extensively documented the technical effects of cold temperatures on BEV range, but there is a gap regarding user awareness about these factors. Therefore, it also explores how to communicate relevant cold-weather variables to BEV drivers to enhance their understanding and facilitate more reliable trip planning. The aim of this thesis is to provide a concept for an information medium designed to deliver relevant information about cold factors to drivers across different degrees of technical knowledge.

1.4 Ethical Considerations

Since this research project consists of several qualitative studies, it is essential to adhere to GDPR regulations and informed consent. This ensures that all participants confirm their participation with a full understanding of the study's nature and the right to withdraw at any point. As such, the research will follow the ethical regulations and authorship guidelines of Chalmers University of Technology, including responsible data handling, participant consent, privacy, and transparent acknowledgment practices [8].

The primary deliverables of this project are expected to have effects limited to the immediate term due to the specific scope of the study. Depending on the subsequent implementation strategy it might also lead to long-term effects, of which some examples are presented in this section. While this project does not aim to directly solve these long-term factors, it remains closely related to them. Consequently, it is difficult to determine precisely how the project, within its defined scope, will influence these broader developments in the future.

This project is situated within the context of Battery Electric Vehicles (BEVs), a product category often associated with environmental sustainability efforts, as further discussed in section 3.3. The continued technical advancement of these vehicles is a significant factor in improving environmental outcomes, as it allows for more efficient resource utilization. The project is directly linked to the environmental aspects of BEVs by focusing on driver education regarding the various factors that affect driving range in cold temperatures. By providing this knowledge, users become better equipped to manage their energy consumption effectively, which not only optimizes the driving experience in challenging climates but also contributes to the broader goal of energy conservation. The project also relates to social sustainability, as the driving experience of a BEV is closely tied to range anxiety, a topic further discussed in section 3.4. By providing drivers with additional information, the project offers tools that allow them to manage their driving more effectively and, as a result, positively influence their remaining range. Lastly, while the goal of this project is to support drivers by informing them of factors affecting their performance, providing additional information risks increasing the cognitive load. This strongly depends on how the project is implemented and how data is introduced to the drivers.

2

Background

This chapter introduces the relevant background to the thesis, including battery electric vehicles, factors affecting range and Volvo Cars and their applications.

2.1 Interaction Design (IxD)

Interaction Design (IxD) is a multidisciplinary field often related to User Experience Design, mentioned in section 3.2. As established by Cooper et al. [9], IxD is the systematic practice of defining the behavioral logic of complex interactive systems. It focuses on the interactivity of a system or product while simultaneously trying to understand the needs of the user and how it relates to content and form. To broaden the perspective, Jon Kolko has defined it as:

> *Interaction Design is the creation of a dialogue between a person and a product, system, or service. This dialogue is both physical and emotional in nature and is manifested in the interplay between form, function, and technology as experienced over time* [10].

Driving a car is a prime example of a complex interactive system, characterized not only by the driver operating the vehicle but also simultaneous interaction with other areas such as mechanical controls and electrical systems [11]. The aim of this project, introduced with the research problem and research questions in section 1.1, is to facilitate BEV driving in cold temperatures and as such influence the way drivers interact with their vehicles.

According to Jon Kolko, Interaction Design is fundamentally about creating a dialogue between a person and a product or system. Within the domain of Human-Computer Interaction (HCI), a multidisciplinary field focused on studying how humans communicate with computerized systems and developing the interfaces that facilitate this connection [12], this dialogue is focused on specific interfaces. Today, HCI's primary objective has expanded beyond the desktop to include topics such as visualization, information systems and many areas of design [13]. This evolution from basic graphical user interfaces has naturally led to the integration of many interaction techniques and complex, multi-modal interactions. Augstein and Neumayr [14] classify the different modalities of interaction design within a comprehensive taxonomy. They sort these modalities into two fundamental categories based on the human sensory loop: input modalities, which represent conscious human actions directed at the system, and output modalities, which represent the sensory channels through which the user perceives system feedback. Within this classification, the modalities are sorted at the highest level into direct and indirect processing categories, after which the human sensory capabilities neural oscillation, galvanism, vision, audition, kinesthetics, touch, olfaction and gustation are included. For the scope of an interface that is automotive-related but place outside of the vehicle's the focus naturally shifts towards a group of these modalities, specifically vision, sound and touch.

2.2 Battery Electric Vehicle (BEV)

Vehicles can generally be categorized into internal combustion engine (ICE) vehicles and electric vehicles (EV). While ICE vehicles have dominated the market/ been present for over a century, EVs have seen a recent surge in popularity with the global electric car fleet reaching 58 million vehicles in the end of 2024, a more than threefold increase since 2021 [15].

EVs are further classified by their energy sources and powertrains, with two of the more prevalent types being BEV, battery electric vehicles, and HEV, hybrid electric vehicles [16]. While HEVs utilize both an internal combustion engine and an electric motor, BEVs rely exclusively on a battery, making their performance dependent on battery capacity, charging infrastructure, and thermal management [17].

In 2025, BEV accounted for 19% of the 11 million new car registrations in Europe in 2025, an increase of 4 percentage compared to 2024. However, the adoption rate varies significantly across countries. While the European average for combined registrations of BEV and PHEV (Plug-in Hybrid Electric vehicle) is 28%, the highest percentage of is found in Norway with 97%, followed by Denmark (71%) and Sweden (63%). This suggests that while the shift is accelerating, it is heavily affected by regional differences [18].

2.3 State of Health (SoH) and State of Charge (SoC)

Battery State of Health (SoH) is a key metric used to describe the long-term condition of a rechargeable battery, including those used in EVs and other battery-powered products [19]. SoH is typically expressed as a percentage that represents the batterys current maximum energy capacity relative to its original, maximum capacity, when new [20], [21]. It captures the irreversible battery degradation over time rather short-term and is used as an indicator of the batterys ageing and remaining usable time [19].

To indicate the usable amount of energy remaining in a battery at a given moment, the concept of State of Charge (SoC) is commonly used. SoC represents the ratio between the batterys current stored energy to its maximum capacity and is typically presented as a percentage [22]. A SoC of 100% conventionally denotes a fully charged battery, while 0% refers to a depleted state [22], [23],i.e., the remaining capacity as a percentage of total battery capacity.

While the conceptual meaning of SoC is widely agreed upon, there are multiple methods to estimate SoC [22], [23], [24]. In practice, SoC is not directly measurable and must therefore be concluded through estimation algorithms based on multiple related parameters such as voltage, current integration, and battery chemistry [22], [23], [24]. As the SoC is directly related to the chemistry of the battery, factors like ambient temperature will affect the estimations [23].

Furthermore, in many battery-powered products, including EVs, the displayed SoC may not always translate to the batterys absolute limits of capacity [23], [25], [26]. To protect battery longevity and preserve state of health (SoH), as it is more degrading to charge and discharge a batterys absolute limits [25], manufacturers often implement operational buffers at both high and low levels [25], [27]. This means that the displayed 100% or 0% does not necessarily reflect the true electrochemical limits of the battery.

2.4 Factors affecting range

The BEV's SoC is also an indicator of the remaining available driving range. The range of an EV can vary substantially depending on several factors, both internal and external. While BEVs are often advertised with a fixed range, real-world driving reveals a more complex picture. Ambient temperature, speed, payload, and heating or cooling use significantly affect how far a BEV can travel on a single charge [28]. The driver can actively affect some of these factors, such as adopting a non-aggressive driving style or lowering the cabin temperature, while others are static, such as the initial battery capacity or the vehicle's curb weight [6].

Some factors impact the driving range in the short-to-medium term by lowering the SoC. This includes momentary consumption spikes during a single trip, as well as reduced efficiency over extended periods, such as during the winter season [29]. While these effects are significant, they are temporary and fluctuate based on the environment and usage. In contrast, certain factors contribute to accelerated battery degradation, which leads to a permanent and unrecoverable reduction in the battery's State of Health (SoH) [24]. Because the SoH defines the total capacity the battery can hold, this degradation directly and irreversibly lowers the maximum available range. Understanding the factors and their dimensions may help drivers optimize their driving to decrease energy consumption and facilitate trip-planning.

2.4.1 Cold weather conditions

One of the major factors affecting SoC and subsequently the available driving range is the ambient temperature [30]. In cold climates, vehicles must warm both the battery and cabin, reducing usable battery energy and increasing consumption [28]. The increased demand of thermal comfort while using the BEV stands for a large part of energy consumption in cold temperatures, with studies showing number as high as 45% [31]. While the increased use of the auxiliaries in cold weather conditions lead to a significant increase in energy consumption, several other factors also increase in severity with the lower temperatures. The regenerative breaking of the BEV loses effect [30], battery degradation rate increases [32] and increased effect from aerodynamic drag [33], to mention a few. The cold temperature can lead to significant increases in energy consumption, with range reductions of up to 50% as a result [6].

2.5 Volvo

Volvo Cars is a multinational company that originated in Sweden [34]. The Volvo brand has been around since 1927 but divided into Volvo Cars and Volvo Group in 1999 [35]. Today, Volvo Cars is working on the transition from producing fossil-driven cars to electric cars, EVs. The long range goal is set to be a fully electric car company and by 2030 be 90-100% electrified [34].

This was carried out in collaboration with the Vehicle Energy Management (VEM) department at Volvo Cars, Gothenburg, which focuses on optimizing energy consumption, battery performance and real-world range behavior in BEVs as well as presenting the concerning information to the user to minimize range anxiety. As the automotive industry electrification [15], [34], this department plays a big role in bridging the gap between advanced battery technology, predictive energy modeling and the everyday experiences of BEV drivers.

2.5.1 Volvo Car's Application

The Volvo Car's Application is connected to the driver's vehicle and contains information about the vehicles status and functionality, as well as a trip planner and support [36]. The user can get information about things such as where the car is located and if it is locked, charging status, and the available energy and range. It uses Google Maps as a trip planner where it also is possible to find charging stations, and the planned route can be sent to the car by different methods depending on the specific vehicle. For some car models it is possible to send the navigation to the center display directly from the application, while some models require you to go through Google Maps' mobile application to send it to the car [37]. As demonstrated by Derrow-Pinion et al. [38], Google Maps breaks down real-world road networks into precise segments and supersegments, continuously calculating data such as distance, road connectivity, and expected driving speeds. This shows that complex journeys can be broken down into clear, localized data points. Consequently, these Google-calculated variables can be utilized as inputs needed to calculate and simulate trip-specific energy consumption. Finally, in the Volvo Cars application it is also possible to change climate settings and air condition. The app is designed using Volvo's minimalist interface.

2.5.2 Range Assistant

Volvo offers a built-in application called Range Assistant in their electric vehicles as a way of helping the drivers understand and manage their driving (see Figure 2.1). It contains overviews of the current range and energy consumption shown based on time when standing still and distance while in motion [39]. That means that it continuously updates to reflect the current consumption rate. The Range Assistant shows the current energy consumption in three main factors affecting range; speed, driving style (acceleration and braking behavior) and climate (energy consumption from the current climate settings) as well as dialogs to explain the different categories.

Figure 2.1: Volvo Car's Range Assistant application. From [40]. Used with permission.

The range assistant also contains the Range Optimizer, a tool that maximizes range by lowering the energy consumption. It turns on eco-setting for the climate and changes driving performance setting to prioritize range over power. Lastly, the range assistant provides information and statistics about trips taken and the historic consumption.

2.5.3 Volvo's Range Calculator

Volvo also offers a Range Calculator, located under the chapter *Range* under electrification at their webpage [40]. It allows the user to compare the range of on a car model in different conditions by choosing a model, a type of motor and change three parameters to see how far the car could drive on one charge. The three parameters are *Driving Profile*, where the user can change percentages of City, Mixed or Highway driving, *Outside Temperature* and *Climate Control* on or off. An image of the vehicle is shown next to the range number. The tool enables comparison between car models and their range in different conditions to help the user understand the difference between different models and conditions. It is also used as a selling point to help users identify the car they would need and as such minimize range disappointment, and includes a direct link to the configuration page.

3

Theory and Related Work

This section will cover knowledge and insights from previous research in related areas encountered during the conducted literature studies. The studies are described in this chapter and include research findings within range anxiety and trip planning in cold temperatures. Furthermore, studies on how driving range is affected by cold temperature factors, including Locked Capacity, HVAC Systems, and Speed, are presented.

3.1 The Double-Diamond

The Double-Diamond design framework is a methodology developed by the Design Council and consists of four distinct phases: Discover, Define, Develop and Deliver [41]. The first initial phase, Discover, is about understanding the problem and the user needs. The second phase analyzes the discovered needs and defines the problem based on the insights. Thereafter, the Develop phase in the second diamond is based on an iterative approach to developing and testing concepts. Lastly, the final phase is about refining the solution and finally introducing it together with a plan for its implementation [42]. Each stage and decision point within the Double Diamond framework can be iterated until a satisfactory outcome is achieved.

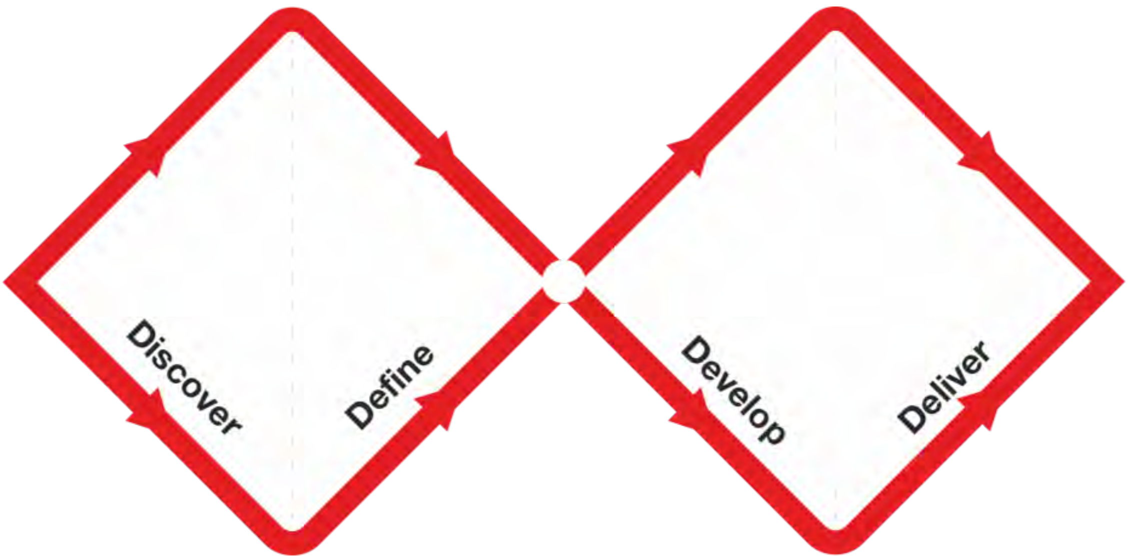


Figure 3.1: The Double-Diamond design framework. Source: Design Council [41]

3.2 User Experience (UX)

According to Norman and Nielsen [43], User Experience "encompasses all aspects of the end-user's interaction with the company, its services, and its products," aiming to meet the exact needs of the user without friction, while still being simple and delightful to use. In User Experience Design, the *Why*, *What*, *How* and *Who* of a product, including the entire user journey [44]. The *Why* comes first, and involves the motivation of the user for adopting a product as well as their values and views of the product. The functionality of the product is captured by the *What*, and the *How* addresses the functionality in relation to aesthetics and accessibility. According to [45], there are seven factors that influence UX-Design. The seven factors are:

- **Useful:** Fills a purpose for the user.
- **Usable:** Allows the user to reach their end objective efficiently.
- **Findable:** The product and its content should be easy to find and access.
- **Credible:** The user needs to be able to trust the product.
- **Desirable:** Is conveyed through branding and identity to spread desire.
- **Accessible:** Allows users with different abilities to access the product.
- **Valuable:** Provides value to the user as well as to the business behind it.

These seven factors serve as a comprehensive evaluation framework, ensuring that the user experience of a product is not only functional but also attuned to the user's emotional and practical expectations.

3.2.1 User Interface (UI) Design

User Interface (UI) Design is the design of the part of the computer system that the user interacts with, focused on style and with the aim of creating interfaces that are easy and pleasurable to use [46]. While UX design covers the users entire journey, UI design focuses specifically on the visual surface and the overall feel of the interface. Having a good UI design is significant in a computer system, since it can encompass diversity both in users and in use context [47].

To develop a functional user interface for a digital product, or to identify improvements in an existing one, heuristic evaluation is a valuable method. Jakob Nielsens ten usability heuristics for UI design provide a foundation [48] for building interfaces that are accessible, user-friendly, and enjoyable. By applying these principles, potential friction points that might otherwise be overlooked during the initial design phase becomes easier to spot. This systematic approach ensures that the final concept is grounded in proven usability standards. These ten heuristics are:

1. Visibility of System Status
2. Match Between the System and the Real World
3. User Control and Freedom

4. Consistency and Standards
5. Error Prevention
6. Recognition Rather than Recall
7. Flexibility and Efficiency of Use
8. Aesthetic and Minimalist Design
9. Help Users Recognize, Diagnose, and Recover from Errors
10. Help and Documentation

3.2.2 User-Centered Design

User-Centered Design (UCD) is a design philosophy where the user is at the center of every step in the design process. That means that from the beginning of the product life cycle user personas, scenarios and needs are evaluated, and that user testing and inputs are used as a basis for development [49]. It is crucial in UCD to fully explore the needs and desires of the users, and how the product is intended to be used. It is also of importance to consider all types of users; *primary users*, that use the product, *secondary users*, that sometimes use the product, or use it through someone else, and *tertiary users*, that are affected by the use of the products [50]. By involving primary, secondary, and tertiary users along with relevant stakeholders, designers can utilize techniques like interviews, questionnaires, and usability testing to identify essential usability criteria. This inclusive process ensures the final product is not only functional but also accessible, effective, and enjoyable for its target audience.

3.3 Benefits and critical perspectives of BEV

A primary benefit of BEVs is their reduced environmental impact. As demonstrated in both [51] and [17], BEVs have significantly lower emissions compared to ICE vehicles, largely because of the absence of fuel cycle emissions. As such, electrification fosters a more sustainable model aligned with global environmental goals, a benefit which in turn can be enhanced by the shift towards cleaner energy sources in power grids. A life cycle assessment (LCA) conducted by [52] showed that when comparing an ICE vehicle and an EV under the same usage conditions, the electrification resulted in 22.6% decrease in carbon footprint. The study highlights that while EVs have higher initial carbon footprint in manufacturing due to the raw material used for battery production, ICE vehicles have significantly higher operational emissions and lower overall powertrain efficiency. Ultimately, the environmental advantage of an EV grows as the vehicles lifespan increases. This suggests that maximizing the life of the vehicle and its battery is essential for achieving the full sustainability benefits of electric mobility.

Several other benefits of a BEV are documented, such as lower noise pollution [53] simplicity with fewer engine elements [16] and a higher well to wheels efficiency. [54] Another benefit of BEVs to consider is the economic factor. BEVs have a higher initial cost mostly due to the production of the battery [51], but even considering the higher upfront cost compared to traditional ICE vehicles, they offer potential lifecycle cost savings. A study by Liu et al. [55] found that due to the low operating and maintenance costs, a BEV with shorter driving range can reach the point where operational savings cancel out the higher purchase price within 5 years, and heavier BEVs with higher range within around 7 years.

However, despite the many benefits of BEVs there are critical limitations of the technology to consider. One of the primary concerns is battery safety, as structural or thermal failures can lead to catastrophic consequences. Several actions are currently being taken to mitigate this, such as integrating advanced safety features directly into the battery design and developing novel battery materials [56]. However, the latter is still in need of a major breakthrough, as many new materials tend to negatively affect overall cell performance. Sanguesa et. al. [16] also point out the disadvantages originating from the EV production. For example, they mention the emissions from mining and processing the materials required to create a battery, noting that some studies report this footprint to be twice as large as that of conventional vehicles. Additionally, correct disposal of EV batteries by recycling is essential, as the battery cells can constitute an environmental hazard.

3.4 Range Anxiety

While the benefits of BEVs are well-documented, their unique powertrain introduces several variables that impact performance, factors that are either non-existent or less significant for ICE vehicles. These factors primarily affect the available range of a BEV, which can lead to range anxiety. Range anxiety refers to the apprehension that a battery electric vehicle (BEV) will lack sufficient range or access to charging infrastructure to complete a planned journey, a concern extensively documented in transportation research as a primary psychological hurdle to EV adoption [57], [58]. A recent study conducted by Iogansen et al. [59] shows that the unlikelihood of BEV adoption is linked to underestimation of electric driving range and overestimation of the cost of battery replacement, with higher levels of anxiety connected to higher odds of perceived likelihood of BEV adoption. Even though the public charging infrastructure and battery technology have gone through significant developments, range concerns remain the foremost barrier to overcome for increased BEV adoption [58]. Range anxiety continue to be an issue even after the purchase of a BEV. Even though BEV experience is liked to a higher minimum acceptable range, it is still a barrier for acceptance [60]. Range anxiety while driving a BEV can be linked to the type of trip, with more common and regular trips setting found related to moderate levels of range anxiety and less frequent trips, such as long-distance journeys or extreme weather conditions, resulting in higher average levels [4]. This can be associated with requirements of more mental effort and preparation, where better applied range coping skills, extended comfortable range and increased driving experience allow for a more confident management of the vehicles limits. It is most noticeable in the less frequent scenarios, like extreme weather conditions.

3.5 Driving Range

To address range anxiety effectively, one must first identify the underlying variables that create unpredictability in a BEV's performance. These can generally be categorized into several different groups, with environmental conditions, driver behavior, and vehicle factors being three of the main categories [29]. Other characteristics, such as travel type, including route and terrain, and cultural factors, are also proven to influence the remaining driving range [6], [61]. Technical factors include battery capacity that directly affect range where the higher capacity a battery has, the longer the vehicle can travel on a single charge [6]. Other technical aspects include, for example, charging time, aerodynamics, and vehicle weight, where a heavier vehicle has been shown to lead to higher energy consumption. In regard to the second category, driver behavior, aggressive driving styles have recorded higher levels of energy consumption and as such can lead to lower available range [29]. Driving style also influences the amount of energy recovered through regenerative braking, as this process is triggered by the driver releasing the accelerator pedal or lightly braking.

3.6 Environmental factors

As of the environmental factors, while there are several factors affecting the driving range such as weather and topography, one of the main factors to consider is the ambient temperature [61]. Several studies prove the impact temperature and thermal management solutions have on BEV performance and driving range, with cold temperatures being extensively documented since the vehicle is affected at many different levels. The electrochemical effects the cold temperatures have on the battery together with numerous other factors result in a significantly shorter available driving range. For example, in temperatures of 10 °C, the available driving range can be up to 40% less than in room temperatures [62]. This significant reduction is supported by broader literature reviews, who confirm that colder ambient temperatures lead to range losses in this magnitude, or even more [6]. Beyond this, another factor affected by cold temperatures is regenerative braking, which significantly loses its effectiveness. At 0 °C, the effectiveness of the regenerative breaking system is reduced by more than 50% compared to moderate temperatures [30]. [63] found a lower limit for any regeneration of energy at 4 °C for a Tesla Model 3, and showed that the impact of reduced regenerative breaking on driving range could be losses of up to 21.7%. Other factors affecting the energy consumption of a BEV include wind [33], and driving style [29]. However, three of the most significant factors are *Locked Capacity*, *HVAC* (heating, ventilation and air conditioning), and *Speed*, which are explained further in the following three subsections.

3.6.1 Locked Capacity

BEVs primarily use lithium-ion batteries, with LFP (lithium iron phosphate) and NCM (lithium nickel cobalt manganese) being the most common variants [7]. Both types of batteries are largely affected by cold temperatures because low ambient temperatures cause crystallization of the liquid electrolyte in the batteries. This results in a higher energy consumption rate in both NCM and LFP batteries, with NCM showing slightly better performance [64].

The battery's capacity is the amount of electricity that can be stored via electrochemical reactions in the battery, and depends on several factors such as the current, temperature and chemistry of the battery [32]. As the temperature lowers, the electrochemical reactions slow down. This results in increased internal resistance, which in turn significantly reduces battery capacity. At −10 °C, the usable energy in Li-ion cells is only 75% compared to room temperature according to [32], a reduction that exists even before the driver starts the trip. Similar research shows that a Li-Ion cell can lose up to 23% of its original capacity at -15 °C, compared to a SoC of 100% at 25 °C ambient temperature [65]. Consequently, drivers face reduced driving ranges and require higher charging frequencies to travel the same distances in winter conditions.

However, as the battery warms up, the previously restricted capacity becomes available again as the electrochemical reactions recover their standard rate. This recovery can be achieved before a trip by preheating the battery, which uses the grid to supply the power needed to heat the battery pack before driving [62]. Because this process lifts the battery closer to its optimal temperature window, it can mitigate the effects of the cold temperature restricted battery capacity [66].

3.6.2 HVAC Systems

In sub-zero temperatures, the demand for the HVAC (heating, ventilation and air conditioning) systems also increases as drivers prioritize thermal comfort. Unlike ICE that can utilize waste heat from the engine to warm the cabin, BEV must draw auxiliary energy directly from the battery. This further increases energy consumption and the subsequent loss of available driving range. In temperatures below 4 °C the auxiliaries used up to 38% of the energy consumed by the vehicle, compared to less than 10% in temperatures between 14 and 22 °C [30]. Several other studies show similar results. For example, [63] found that up to 31,9% of total energy consumption is because of heating, and [31] showed that with the cabin heater set to 22 °C at −10 °C ambient temperature, the heater used 45% of the total energy consumption. The specific thermostat setting also plays a large role, since at −10 °C, lowering the cabin heater to 16°C reduced the heaters impact to 21,4% of the total energy consumption. As such, the heater settings selected by the driver can significantly impact the vehicle's available driving range.

3.6.3 Speed

The driving speed of a BEV greatly affects its energy consumption. For instance, [67] found that the minimum energy consumption for a BEV lies between an average speed of 40-60 km/h. As the average speed increases above 60 km/h, the overall energy consumption significantly increases. Another study highlighting the impact of speed on energy consumption is [68], which used an empirical simulation model validated by real-world driving data to show that increasing an urban speed of

50 km/h to a highway speed of 110 km/h can slash a BEV's driving range by approximately 48-50%. This range reduction drops even further due to aerodynamic factors, such as headwinds. As the driving speed increases, so does the air resistance; according to [67], this resistance increases four times as fast as the driving speed. The effects of higher driving speed worsen in cold temperatures, where rolling resistance increases due to the accumulation of snow and ice on the roads [31]. Furthermore, colder air density increases, leading to both greater drag forces acting on the vehicle and higher tire rolling resistance due to decreased tire pressure [69]. Puusepp et al. [31] further highlight this severe speed penalty using a mathematical model validated by real-world driving tests in winter conditions. Their model shows that an EV's power demand spikes quadratically as speed increases, from just 2.9 kW at 40 km/h to 32.65 kW at 130 km/h, highlighting the severe effect of aerodynamic drag on energy consumption at higher speeds.

3.7 User knowledge and trip planning in cold temperatures

While BEV adoption does lead to an increase in knowledge, there is still a widespread lack of consumer knowledge about factors such as range and battery health [59]. Several studies have been conducted to understand what leads to BEV adoption and what makes drivers choose an electric vehicle, but there is a research gap in understanding what the users know and understand about how SoC is presented and affected by different factors, specifically cold temperatures. The various factors affecting the available driving range and energy consumption due to cold temperatures, combined with the non-linear behavior of the Li-ion battery, make accurate estimations of SOH and SOC challenging [32]. For the driver, this results in a more complex trip-planning scenario, as the range estimates provided by the vehicle dashboard lose predictive reliability compared to performance in moderate temperatures. While battery physics and affecting factors are well documented in literature, there is a lack of empirical data on user comprehension of these factors. This is highly relevant, since the drivers themselves can actively affect energy consumption and available driving range by, for example, lowering the use of the HVAC system and changing their driving style. Evidence also shows that drivers tend to struggle with estimating their energy consumption. A study by [70] showed that while there seems to be an abstract understanding of energy consumption among drivers, they still struggle with accurately estimating their trip energy consumption, especially when putting magnitude in relation to time. Studies have shown that direct experience with BEV leads to generally more positive attitudes and higher purchase intentions [60]. However, even for experienced drivers, range is still seen as a barrier when driving a BEV. This suggests that experience alone cannot compensate for the technical unpredictability of cold-weather performance.

Another question that is raised is about how to deliver this information to the drivers to increase their knowledge and as such mitigate the effects of range anxiety and simplify trip planning in cold temperatures. Research in Human-Computer Interaction suggests that interfaces which present range with high precision (for example, using multiple decimal points) can actually be counterproductive [71]. Ambiguous displays give the user an indication that the available driving range shown is indeed a best estimation and not an absolute fact, which increases user trust. This indicates that increasing the user's knowledge of affecting factors and consequently being transparent about the uncertainty of the SOC in cold temperatures can have advantages. While the ambiguous display of range information is a valuable psychological tool for managing trust, it does not fully address the driver's need for actionable data. Recent literature highlights that the way we present energy data must match the specific needs of different user types and that in order to reach intended effect, it is more effective to use data that explains the reasons behind the specific consumption [72]. For example, this could include techniques like comparisons or behavioral prompts instead of static numbers.

3.8 Mental models

A mental model represents the users internal conceptualization and knowledge of a systems components and processes [73]. It serves as a framework for explaining how the system functions, why specific actions yield certain results, and the underlying logic of those outcomes.

Research on mental models is challenging since they are stored within user's heads, but many studies have shown a correlation between mental models and user performance with results ranging from positive effects to adverse effects. One example is Schmettow & Sommar that found that mental model similarity had no effect on browsing performance [74]. Meanwhile Bußwolder [75] found that, for complex systems, mental model accuracy and access to a structured method had a positive effect on performance. Another example is provided by Gary & Wood [76], who showed that individuals who possess more accurate mental models have better decision strategies and subsequently show higher performance. Their results also showed that models of core principles are sufficient, instead of knowledge about every single technical detail of a complex system.

These varied results highlight that the effectiveness of a mental model depends entirely on how well it represents the specific task at hand. This representation is particularly critical when a significant gap exists between the engineers technical model and the drivers intuitive one. An clear example of this discrepancy can be found in cold weather driving, where a drivers expectations of vehicle performance and range may not match the physical reality of the system. Even if previous research shows different connections between mental models and user performance, a user's mental model is not static; it can be changed to more closely align with the actual constraints of the system [73]. This could for instance be done through direct driving experience or by providing users with targeted knowledge of how cold temperatures affect battery usage and available driving range, as well as with clear behavioral guidelines. The goal is to increase the efficiency and effectivity of the driver's interaction with the vehicle. Xie, Zhou, and Wang [77] found that focusing on directional similarity improves interaction performance by helping users develop a more accurate mental model. This allows users to understand not only which concepts are connected but also the underlying causality within the system. For example, interactions with controls such as the HVAC system, the effect of which is introduced in section 2.4.1 and further explored in section 3.6.2, can change as the driver understands how it influences the available driving range.

3.9 Research Gap

During the review process, cold temperatures emerged as a recurring and significant factor connected to multiple aspects of range loss, contributing to the project gradually narrowing its scope towards winter driving conditions in the Nordic region. An apparent gap was identified regarding users existing knowledge of winter-related range factors, which this thesis aims to address through RQ1 (Section 1.1.1). As such, understanding which specific factors drivers need knowledge of is essential to make informed decisions about both pre-trip planning and real-time driving actions. While the user-centered literature was considered relevant to the project, particularly in relation to how users interpret and react to range-related information, relatively limited research was identified regarding how drivers learn about range-affecting factors outside of the vehicle context, and how such information could be communicated through external educational or informational media. Consequently, how to effectively communicate this information to drivers (addressed by RQ2 in Section 1.1.1) appears to be largely unexplored in the existing literature. For this information to reach the user as trustworthy and actionable advice, it is also essential to investigate the optimal resolution and how the information could be tailored to match the technical literacy of the user.

4
Methods

This research project followed the principles of the Double-Diamond design framework, introduced in section 3.1, and in the following sections methods related to each phase, Discover, Define, Develop and Deliver, are presented.

4.1 Discover

This section will handle methods related to the first phase of the Double-Diamond design framework, Discover. The phase has the goal of researching and understanding the problem space, and collecting empirical data.

4.1.1 Literature Review

A literature review is a collection of prior, relevant knowledge conducted in order to review and synthesize existing theories, evidence, or other topics [78]. It is essential as a method of mapping the background and research area for further scientific research within a specific field, but can also be conducted as a stand-alone project. It creates a firm foundation for a research project by providing an overview of relevant areas and a justification for the chosen research questions.

4.1.2 Exploratory study

When formulating a study, there might be a need to conduct an exploratory study. Whilst literature reviews are of importance to get hold of the subject at hand, there might be gaps or questions which are not covered but needed to conduct a relevant hypothesis or formulating valid research questions within the scope. An exploratory study is a method meant to create further understanding in areas which may not be as well explored previously or not to the right extent as what would be relevant within a main study [79], [80]. Typically, exploratory studies are based on qualitative methods, such as interviews or focus groups, to gain a broader understanding of a subject within social studies [80]. However, it is also possible to include more quantitative approaches. The method includes literary research, forming of questions and collection of data to start with. The data collected is analyzed and may be used to form a suitable hypothesis or research question.

4.1.3 Questionnaire

A questionnaire is a widely used method for data collection that consists of a list of questions distributed to respondents with the aim generating data that can be interpreted and generalized [81]. The method is often used in conducting quantitative research and in surveys when the aim is consistent data collection from a large sample, but can also be adapted for interview-based contexts [82]. The first step in designing a good questionnaire is to clearly define the research questions in order to phrase valid questions that are clear to the respondents [81]. Questionnaires can include different types of questions, where two of the most significant categories are *Closed questions*, that always are followed by a set number of options to choose from, and *Open questions*, that allow the respondents to provide qualitative insights [82]. By integrating clear navigational paths, precise wording, and intentional visual design, such as scales, researchers can effectively capture data across a wide range of distinct topics [83]. Closed questions can use scales for answer options, for example an ordinal scale. An ordinal scale contain qualitative variables that have a logical ranking [84]. However, the distance between the variables are not necessarily equal, or possible to quantify. The Likert scale is often counted as ordinal and contains a set of statements for real or hypothetical situations, where participants are asked to show their level of agreement with the given statement on a normally 5 or 7 point scale [85].

4.2 Define

This section outlines the methodologies related to the Define phase, which represents the second stage of the Double Diamond design framework. These methods were utilized to analyze the initial research data and, through iterative cycles, gather further insights to better understand the identified problem space. The results were also analyzed to shape needs and define the problem.

4.2.1 Interview

An interview is a method for qualitative data collection that resembles a conversation between the researcher and the interviewee. A qualitative research interview can cover both factual information and meaning, with the possibility to gather knowledge that is qualitative, descriptive, and specific [86]. It also allows the researcher to identify where ambiguity or contradictions in the research topic lie in order to clarify them.

A qualitative interview can be conducted in various ways. They can be one-on-one, or in different group constellations [87]. They can also be sorted into categories based on their level of structure [87], [88]:

- *Structured interview* - Consists of specific, predetermined questions asked according to a tightly set schedule, with open-ended responses being minimized and with no room for improvisation. All interviewees are asked the same questions, and often the choice of answers is also set in advance.

- *Semi-structured interview* - In a semi-structured interview the researcher follows a set list of questions, but they are open-ended instead of closed. The researcher also has the possibility of asking follow-up questions that can differ between respondents in order to get the interviewee to elaborate, and to collect attitudinal information.
- *Unstructured interview* - An unstructured interview completely lacks structure, and the researcher instead wants to discuss a limited amount of topics and frames questions according to the responses. Can also be called *In-depth interview*, and can be repeated several times with the same interviewee in order to gather extensive data.

In qualitative research, it is essential to consider data saturation. This is the point at which new data collection no longer yields additional insights or new themes regarding the research question [89]. The aim of this study is to balance the pursuit of saturation with pragmatic considerations, such as time availability and cost, to reach an appropriate amount of participants. This approach ensures that sufficient depth is gathered to address the research questions while remaining within the practical boundaries of the project.

4.2.2 Data analysis

The data collected throughout the project may consist of both quantitative and qualitative material, and will be analysed using methods appropriate to each data type [90]. Quantitative data, is analysed descriptively to identify general trends, distributions, and patterns in user perceptions and experiences. This type of analysis is primarily used to provide an overview and to inform subsequent stages of the design process rather than to support statistical generalisation. Qualitative data, such as open-ended user responses, interview material, or observations from user testing, is analysed using an inductive and exploratory approach. The purpose of the qualitative analysis is to gain a deeper understanding of how users reason about BEV range, uncertainty, and energy-related information, as well as how they interpret and act upon such information.

Insights from both quantitative and qualitative material are used to inform problem framing, ideation, prototyping, and design decisions, and may be revisited as the project develops [90], [91], [92].

4.2.3 Thematic analysis

Thematic analysis is a widely used qualitative analysis approach that aims to identify, analyze and report recurring patterns (themes) within a dataset [93]. The method typically involves an iterative process where data is first familiarized through repeated reading to build an understanding of the data, followed by the generation of initial codes that capture meaningful features of the material [94]. The purpose of the codes is to break down complex data into manageable pieces that then serve as the foundation for developing themes. These codes are then iteratively examined and grouped into broader, meaningful themes, which are refined through comparison across the dataset to ensure coherence and relevance. Lastly, the themes are defined and analyzed beyond surface-level descriptions.

4.2.4 Affinity mapping and the KJ method

Affinity mapping may be employed across various stages within the qualitative data analysis process. The method involves breaking down observations, interview excerpts, or survey responses into discrete units, which are then iteratively grouped based on perceived relationships and similarities [95]. Through this bottom-up clustering process, higher-level structures and themes can emerge without imposing predefined categories. A specific type of affinity mapping is the *KJ-analysis*, created by Jiro Kawakita [96]. It consists of four main steps; label making, label grouping, chart-making and verbal or written explanation. Information based on observations is written down on cards or adhesive labels such as post-it notes. The cards are then randomized and iteratively grouped without adding prior bias. When groups have been identified they are given titles and sorted into larger groups, or families. Finally, the families are sorted spatially into a chart based on, for example, relations, order of occurrence and contradictions.

4.2.5 User Persona

A user persona is a description of the different user types that is fictional but realistic. Personas are based on user research gathered early in the process to accurately represent a diverse user base, with unique personas created for different users [97]. The aim of using personas is to create a shared understanding of the users' needs, behaviors and goals, and as such better understand who the design is for [98]. Personas can be used as a tool to ask the right question and to understand patterns in the research. A user persona often includes information such as name, age, general demographics and a photo, as well as user context, goals and concerns regarding interacting with the product.

An alternative method to user personas is the use of *archetypes*. While both tools serve a similar purpose, they differ in their execution. Unlike personas, which incorporate humanizing traits such as fictional names, faces, and detailed personalities, archetypes strip away these demographic details [99]. Instead, they rely on abstract labels to represent the distinct characteristics and core behaviors of a specific user group, focusing entirely on functional behavioral patterns rather than individual profiles.

4.2.6 Needs and requirements analysis

Needs and requirements analysis serves as a mediating step between empirical user insights and design decision-making. While user research often reveals a wide range of expressed wishes, concerns, and expectations, not all of these can or should be treated equally within the design process [100]. This analysis therefore focuses on structuring and prioritizing findings in a way that supports informed and deliberate design choices [101].

User needs are understood as expressions of underlying goals, motivations, and perceived problems in users interactions with the system or context. These needs are typically broad, situational, and not tied to specific solutions. Requirements, by contrast, represent a further interpretation of these needs, where certain aspects are articulated as conditions that a design solution should fulfill. This distinction makes it possible to carry user insights forward into design work while avoiding premature commitment to specific implementations [100], [92].

Beyond identifying baseline requirements, the analysis also considers how different needs contribute to perceived quality and user experience. In this regard, requirements are not treated solely as minimum conditions for system acceptance, but are examined in terms of how they may differentially influence user satisfaction. To support this distinction, the Kano model is used as an analytical lens for understanding how different types of requirements relate to user expectations, ranging from basic needs to features that enhance perceived value [101].

4.3 Develop

This section will handle methods related to the third phase of the Double-Diamond design framework. The Develop phase contained several rounds of ideation and concept creation, until the fourth phase of the Double-Diamond framework, Deliver, that contains the presentation of the final concept.

4.3.1 Ideation

Ideation refers to a structured yet exploratory phase of the design process in which multiple potential solution directions are generated, articulated, and developed [102]. Rather than aiming to identify a single optimal solution, ideation seeks to deliberately expand the solution space by exploring alternative interpretations, framings, and possibilities. Building on insights from earlier research and data analysis, ideation functions as a bridge between problem understanding and concept development[103].

In line with user-centered design and research-through-design practices, ideation is understood as an iterative and non-linear process that may be revisited multiple times as new insights emerge [92], [104]. Concepts generated during ideation may therefore be refined, discarded, or reformulated in response to continued analysis, prototyping, or evaluation activities [103]. This iterative character allows ideation to function as an ongoing mechanism for sense-making and exploration rather than as a discrete, one-off phase.

4.3.1.1 Brainstorming

Brainstorming is a technique for ideation that involves a group of participants generating a large amount of ideas by sketching or writing them down on paper. The method utilizes collective thinking by ensuring members interact, allowing them to refine each other's suggestions and spark new ideas through collaboration. A problem statement, point of view or question is decided before the session starts, and the aim is to generate a large set of ideas within the problem space. This includes experimental thinking and wild ideas, and no evaluation is added during the session. Each session has a set time-limit, typically around 15-60 minutes depending on the problem and the motivation [105].

4.3.1.2 The Dark Horse Method

The Dark Horse method is a strategy used to uncover unconventional solutions by challenging the standard assumptions of a project. It begins with a divergent ideation phase, for example brainstorming, but with the specific goal of pursuing a space that is more risky or radical, with solutions that might usually be dismissed as infeasible [106], p. 143. The method expands the solution space and acts as a driver of innovation.

The Dark Horse method involves further developing one of the unconventional ideas into a prototype that adds a level of complexity to the design thinking process. It can be used for testing the concept and to support the process ensuring that the final design is informed by a broad exploration of what is possible [107].

4.3.2 Prototyping

Prototyping is a central activity within user-centered and design-oriented research, serving as a means to explore, communicate, and evaluate design ideas through tangible or representational artefacts. Rather than being limited to the validation of finalized solutions, prototyping is understood as a way of thinking through making, where ideas are externalized and examined through interaction [108], [100].

In this project, prototyping is approached as an exploratory and iterative process that supports both design development and knowledge generation. Prototypes are used to investigate assumptions, clarify design intentions, and reveal opportunities or limitations that may not be apparent through analysis alone. As such, prototyping functions as a tool for inquiry as well as a mechanism for refinement, allowing insights from testing and reflection to inform subsequent design decisions [91].

Prototyping is treated as a cyclical activity that may be revisited throughout the project. Prototypes may therefore be iteratively revised, replaced, or abandoned as new insights emerge from user testing, analysis, or shifts in problem framing. This flexible approach allows prototyping to support ongoing learning rather than serving solely as a final verification step. The prototype medium may vary according to the findings throughout the project, in alignment with the ISO 9241-210: 2019 [92] definition of a prototype.

4.3.3 Usability testing

Usability testing is an integral part of user-centred and participatory design processes, aimed at evaluating how potential users understand, interact with, and make sense of proposed design concepts. Rather than focusing solely on performance metrics or task efficiency, usability testing is used to explore users experiences, interpretations, and expectations in relation to the design artefact [100], [109].

Usability testing is not treated as a final step, but as a recurring activity that accompanies design development. Findings from testing may lead to revisions of prototypes, reframing of design assumptions, or further exploration of alternative concepts. This iterative integration of testing and design allows usability evaluation to function as an ongoing dialogue with users rather than as a one-off assessment [91].

4.3.3.1 Co-Design

Co-Design workshops are sessions of collaboration where designers work together with non-designers, such as stakeholders or end-users, to create solutions [110]. The first step is to identify relevant participants and ensure a diverse group that represent all aspects of the user base. A goal for the session is set and communicated to all participants to guarantee everyone has understood the main objectives. During the sessions, creative materials is provided and techniques such as ideation can be used. A session can contain user testing for evaluation as well as prototyping, where users themselves turn ideas into tangible prototypes. Finally, designers use the iterations and feedback to finalize the design.

5

Results and process

This chapter contains the execution, analysis and results of each step in the interaction design process. It follows the framework of the Double Diamond with the phases Discover, Define, Develop and Deliver, further explained in Section 3.1. How the methods in each phase was applied and conducted is described, as well as the result of each method.

5.1 Author's Positionality

This work was conducted by a team of two researchers who collected, analyzed, and interpreted all the empirical data. Both authors are final-year Master's students in Interaction Design and Technologies at Chalmers University of Technology, and both hold a Bachelor's degree in Industrial Design Engineering. The research team consists of two women, aged 26 and 27. Due to this, all data and insights presented in the following sections have been viewed through the lens of the two researchers' backgrounds. This naturally shaped how the data was interpreted, which provides important context for the analysis presented in this work.

5.2 Discover

The Discover phase aimed at gathering data to understand the problem space and identify existing knowledge gaps and insights of the users. The phase began after a literature review and contained an exploratory pre-study with subsequent analysis to deepen the understanding of user knowledge and refine the research direction.

5.2.1 Exploratory Pre-Study

As an initial Exploratory Pre-Study, a survey was conducted to gain an understanding of users' existing knowledge regarding factors affecting BEV range during winter conditions in the Nordic region. The aim of the study was to investigate what drivers currently understand about winter-related range factors, while specifically identifying areas of confusion or misconception. Additionally, the Pre-Study served as a basis for comparison between an internal Volvo user group and an external group of drivers within the Nordic region.

5.2.1.1 Study Design and Procedure

Two identical questionnaires were created using Microsoft Forms. One questionnaire was distributed internally to BEV drivers at Volvo Cars, while the second questionnaire was distributed externally through BEV-focused forums, social media communities, and online discussion platforms within the Nordic region, including Reddit and Facebook groups.

The decision to separate the questionnaires into an internal and external version was made to assess whether the internal respondents at Volvo Cars could be considered representative in relation to a broader BEV-driving population for subsequent data collection activities.

The questionnaire consisted of three sections. The first section was used to determine the respondents' relevance in relation to the delimitations of the study. Respondents were required to currently drive or regularly access a BEV and possess driving experience within the Nordic region. Participants not meeting these criteria were thanked for their participation and directed to the end of the questionnaire. The second section collected background information regarding demographics, vehicle brand, and self-estimated technical level related to BEVs. These questions were primarily included to support later comparative analysis between different respondent groups. The participants were asked to estimate their technical level on a five-level descriptive ordinal scale where no numbers were shown to the users. Instead, each step was explained according to Table 5.1. This was done in with the aim of getting the participants to choose the level that they felt was the best match to their real-life experience, instead of focusing on the meaning of a specific number.

Table 5.1: Definition of the different technical levels.

Technical Level	**Description**
Novice	I know how to operate the car and charge it.
General	I understand the common factors that affect driving.
Informed	I pay attention to the car's data and am interested in how different factors affect performance.
Technical	I have a strong grasp of how battery systems in my BEV work.
Expert	I have a deep technical understanding of battery technology and electronics.

The final section in the questionnaire focused on respondents' knowledge and experiences related to winter range impact. Participants were asked to estimate the impact of different factors on BEV range using a word-based Likert scale with five steps ranging from No or negligible impact to Very large impact. Respondents were additionally asked to indicate whether any of the listed factors were previously unknown to them. Estimations rather than numerical values were used, as the exact impact of individual factors may vary between different BEV models and driving conditions. Lastly, respondents were asked about specific issues they had experienced when driving in cold temperatures, as well as the practical measures they take to mitigate these cold-temperature effects.

5.2.1.2 Analysis

The collected responses were analyzed through descriptive comparative analysis using Microsoft Excel. Responses considered outside the delimitations of the study were removed prior to analysis. To facilitate quantitative analysis, the Likert scale representing the estimated effect of the cold temperature factors was translate into a numerical scale from 1 to 5, with 1 representing *No or negligible impact* and 5 representing *Very large impact*. This allowed for calculation of mean values and statistical comparisons between the two groups. Comparative diagrams and pivot tables were then created to visualize response distributions between the internal and external respondent groups. Since the number of responses differed between the questionnaires, the results were primarily compared using percentage distributions rather than absolute numbers. Particular attention was also given to the respondents' self-estimated technical levels when analyzing questions related to knowledge and factor estimation, in order to identify potential differences between respondent groups.

5.2.1.3 Participants

In total across the two questionnaires, 345 respondents participated in the exploratory questionnaire study. 211 responses were collected internally at Volvo Cars and 134 externally through online communities and forums. Following the initial automatic selection process in the questionnaire, the number of respondents were narrowed down to 179 and 127 respectively, with all remaining participants meeting the established selection criteria. Respondents from all predefined technical experience levels were represented in both questionnaires, although participants self-identifying with higher technical experience were more common than novice users. A similar distribution of technical experience levels could however be observed across both respondent groups. Distribution of age, gender and technical level is visualized in Table 5.2. The data illustrates that a majority of respondents identified as male (72% for the internal Volvo questionnaire and 79% for the external questionnaire). For the Volvo internal form, 62% of respondents were between 45 and 64 years old. The corresponding figure for the Open Forums respondents was 51%, with a slightly higher percentage of respondents falling between 35-44 years old. In regards to the technical level, the primary distinction between the two cohorts were that the largest segments of Volvo respondents identified as Informed (46%), whereas the largest portion of Open Forums respondents identified as Technical (39%), the second-to-highest level on the scale.

5.2.1.4 Results

As the project's focus was narrowed down, several questions from the questionnaire fell out outside the project's scope as it was narrowed down to maintain a clear focus on the research questions. For comprehensive documentation all questions in the

Table 5.2: Exploratory pre-study demographics

Demography	Category	Volvo n (%)	Open Forums n (%)
Gender	Male	128 (72%)	100 (79%)
	Female	48 (27%)	26 (20%)
	Prefer not to say	3 (2%)	1 (1%)
Age	18-24	1 (1%)	7 (6%)
	25-34	22 (12%)	13 (10%)
	35-44	45 (25%)	37 (29%)
	45-54	55 (31%)	32 (25%)
	55-64	55 (31%)	33 (26%)
	65-74	1 (1%)	3 (2%)
	75+	0 (0%)	2 (2%)
Technical level	1 (Novice)	4 (2%)	3 (2%)
	2 (General)	32 (18%)	21 (17%)
	3 (Informed)	82 (46%)	37 (29%)
	4 (Technical)	46 (26%)	50 (39%)
	5 (Expert)	15 (8%)	16 (13%)
Total respondents		179 (100%)	127 (100%)

survey have been preserved in Appendix A.

When asked to estimate effects of different factors on energy consumption, the responses indicated a relatively high awareness regarding factors affecting BEV range during winter conditions. Across both questionnaires, respondents generally rated the impact of different range-affecting factors similarly, with only minor variations between the internal and external respondent groups. The similarities are visualized in Figure 5.1. When mapped against the numerically translated Likert scale from 1 to 5, the mean average difference between the two groups was a minor 0.29 across all ten factors. The highest difference between the groups was only 0.52 for the option *Less usable energy/capacity in the battery*, while the smallest difference was 0.04 for the option *Increased rolling resistance from winter tires*. The highest estimated factor for both groups was *Faster driving speeds*, with 3.99 for the Volvo respondents, and 3.78 for the Open Forums respondents. This indicates that drivers estimate that the factor has the highest effect on energy consumption.

The experience-based questions also showed similar response patterns between the internal and external questionnaires. Some variations could be observed regarding specific experiences and perceived issues, which were suspected to partly relate to differences in vehicle brands among respondents. The internal questionnaire consisted of mainly Volvo drivers, while the external represented a broader range of BEV brands. A main variation found in the data regarding experienced issues was that Volvo respondents reported a higher frequency both of *The car started with a lower battery percentage than when I parked it* and *When it's cold the battery's state of charge decreases fast, especially when it has gone below a certain percentage*, as seen in Figure 5.2. However, the most and least common issues were shared among the two cohorts. Regarding measures taken in cold temperatures (see Figure 5.3),

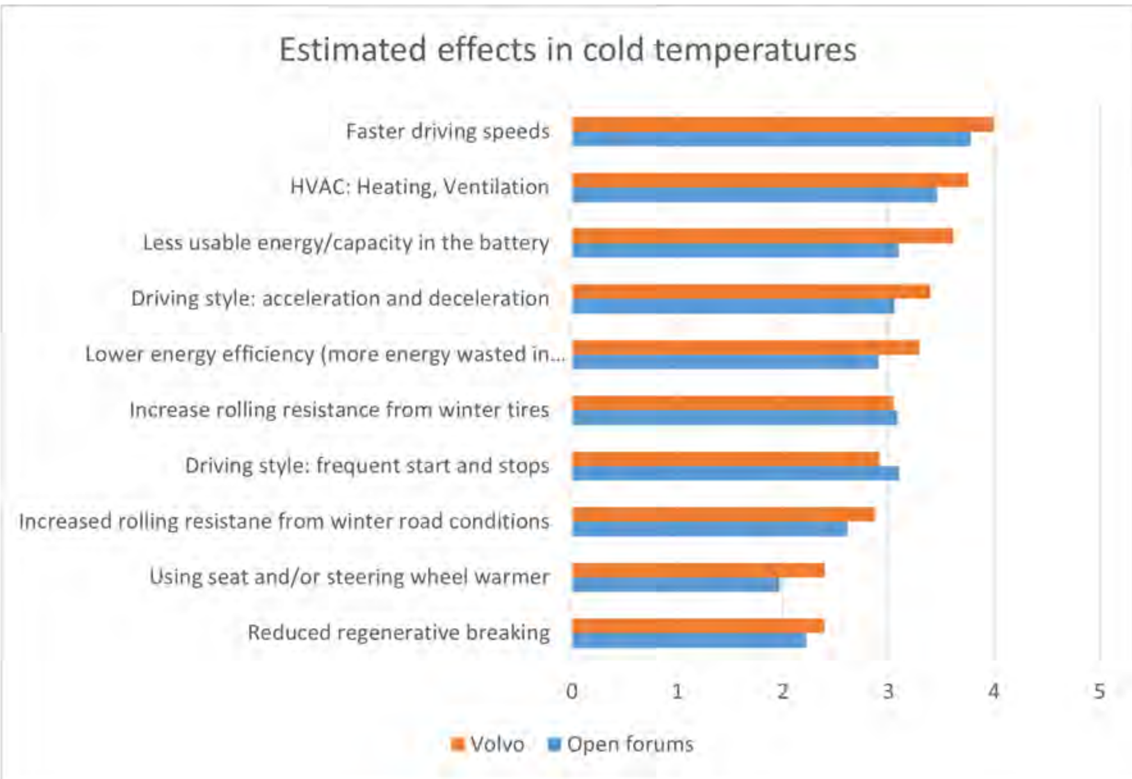


Figure 5.1: Comparison between the Volvo and Open Forums cohorts of the estimated average effect of cold temperature factors numerically translated from Likert scale ratings.

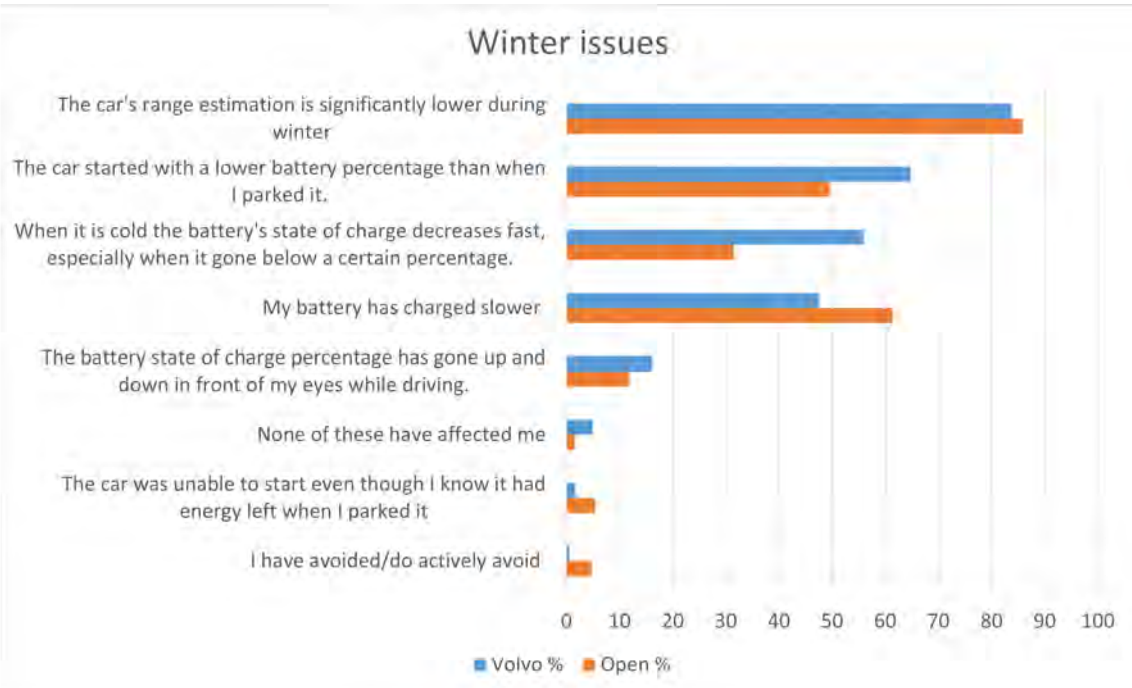


Figure 5.2: Experienced winter issues across both cohorts.

Volvo respondents reported a higher use of the measures *I warm the steering wheel and/or the seat instead of the cabin*, *I lower my use of cabin heating* and *Slower driving speeds* than the external respondents. Conversely, Open Forums reported a slightly higher use of *I precondition the battery from the car's own energy* and *I dedicate more time to charging*. Overall, the largest divergence in adoption of these measures was 11 percentage points for the strategy of warming the steering wheel and/or seat instead of the cabin. In the data presented in both Figures 5.2 and 5.3, the option to select *Other* has been excluded from the visual representation. This decision was due to a very low volume of open-ended responses, which either fell outside the project's scope or did not directly answer the question. The qualitative responses that did align with the question were rephrasings of the already existing options, and were therefore consolidated into those matching categories.

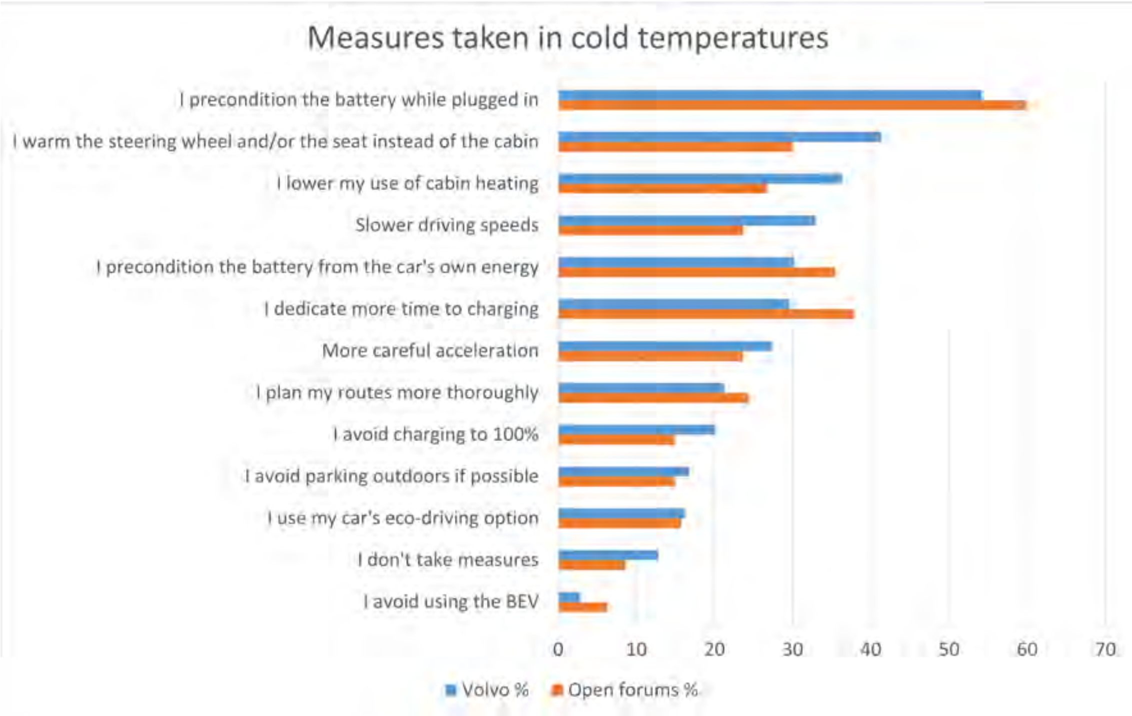


Figure 5.3: Measures taken by respondents across both cohorts in cold temperature conditions.

Regarding technical level, no clear relationship could be identified between self-estimated technical experience level and the respondents' ability to estimate the impact of the listed factors. Figure 5.4 presents how the respondents from both groups across the different technical levels estimated the effects of the ten cold temperature factors. As seen in the Figure, the lower technical levels tended to estimate a more severe effect, with an exception regarding HVAC, where the Novice group (the green line in the figure) average estimate is lower. Overall, there was a minimal difference between the groups. The average estimation across all factors for each respective technical level ranged from a low of 2.91 for Technical to a high of 3.63 for Novices (with Expert at 2.98, Informed at 3.10, and General at 3.26). These results indicate that less technical users experience the cold temperature effects more

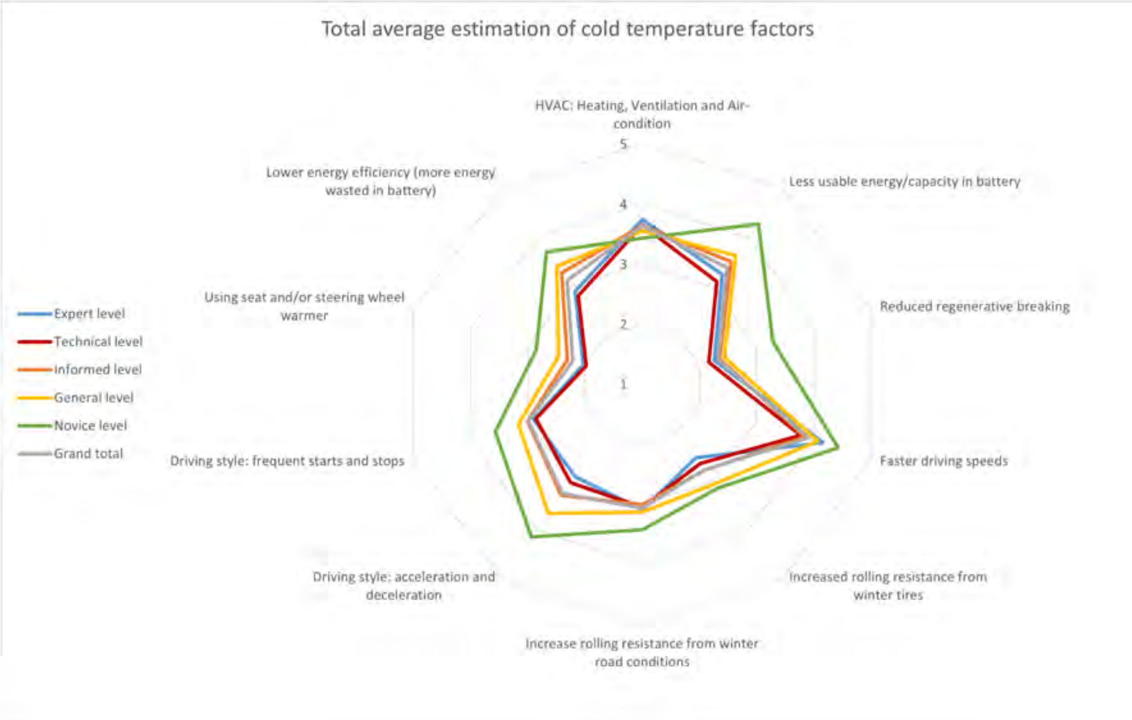


Figure 5.4: Comparison between the different technical levels of the estimated average effect of cold temperature factors numerically translated from Likert scale ratings

severely. However, the group of people that had chosen the technical level *Novice* was significantly smaller than the other groups, rendering their results more unreliable. Similarly, no technical experience group consistently identified more previously unknown factors than others. In general, relatively few respondents indicated that the presented factors were unfamiliar to them.

5.2.1.5 Main Takeaways, Pre-study

The result from the study shows that BEV drivers were relatively aware about the factors presented to them. Based on the similarity in response distributions and factor estimations between the questionnaires, the internal Volvo Cars respondents were considered sufficiently representative for use in subsequent stages of the project. Additionally, based on the results reported above and discussions with the project group and theme experts, the decision was made to focus the next steps in the project solely on communicating the effects of three factors: *Faster driving speeds*, *HVAC: Heating, Ventilation, Air Conditioning*, and *Less usable energy/capacity in the battery*. This decision was made to keep the project within a manageable scope and to facilitate the creation of a concept with an information level that would not overwhelm users. These three factors were chosen due to their higher estimated effect reported by participants in both questionnaires. Compared to other factors mentioned in the survey, these also offer more practical actions drivers can take to mitigate them, making them a better fit for the goal of the project.

5.3 Define

The Define phase aimed to establish an understanding of the experiences and attitudes of Battery Electric Vehicle (BEV) drivers regarding driving and trip planning in winter conditions. This phase began with conducting a survey, followed by twelve interviews, and a subsequent analysis of both data collections. The results were used to develop two user personas and derive a list of user requirements to outline the scope. The processes, analysis, and subsequent results are detailed in the following sections.

5.3.1 Communication Survey

Following the Exploratory Pre-Study, a second survey was conducted internally at Volvo Cars to further investigate how BEV drivers access, interpret, and prefer to receive information regarding winter-related range impact. The primary aim of this study was to gather quantitative data on user preferences for information delivery methods and formats. Additionally, the survey served as a recruitment tool to find and select participants for the subsequent interview phase of the project.

5.3.1.1 Study Design and Procedure

Similar to the previous questionnaire, an initial section was used to ensure respondent relevance in relation to the delimitations of the study, such as having access to a BEV and possess driving experience within the Nordic region. Respondents outside the scope of the study were automatically excluded. The questionnaire additionally collected demographic information, vehicle brand, and respondents' self-estimated technical level regarding BEVs. The same descriptive nominal scale as in the Exploratory Pre-Study (see Table 5.1) was used. The main section focused on current information sources, learning preferences, and preferred methods of communication regarding winter driving and battery-related range impact. Several questions were designed as multiple-choice questions to allow comparison between response frequencies, and one open-ended question was included. The full questionnaire is detailed in Appendix B.

The questionnaire concluded with a voluntary recruitment section in which respondents could indicate whether they were interested in participating in future data collection through interviews, related to the project. Participants could then choose to provide their contact information for recruitment to the subsequent project stages.

5.3.1.2 Analysis

The responses were collected and analyzed using Microsoft Excel. Response frequencies were visualized through comparative bar charts in order to identify recurring patterns regarding the topics. The findings were primarily used to support the formulation of interview questions and the development of early initial concepts used during subsequent interview sessions. These are explained further in Section 5.3.2.

In this survey, the technical level categorization was primarily used to support recruitment diversity for upcoming interviews.

5.3.1.3 Participants

In total, 67 respondents participated in the questionnaire. After the initial selection process in the questionnaire, 59 respondents meeting the established criteria remained. 28 of the respondents expressed interest in participating in further data collection. The demographics were similar to the Pre-Study questionnaire. A large majority of respondents, 73%, identified as male, and the largest age group was 45-54 with a total of 37% of respondents. 68% of respondents were between 45 and 64 years old, compared to 62% for the internal Volvo questionnaire and 51% for the external Open Forums questionnaire in the Exploratory Pre-Study. The distribution also showed that respondents who self-identified with higher technical experience were more prevalent. The largest group of respondents identified as Informed (51%), while only 20% in total classified themselves as the lower two levels, Novice and General.

Table 5.3: Communication Survey demographics

Demography	Category	Number of respondents (%)
Gender	Male	43 (73%)
	Female	16 (27%)
	Prefer not to say	0 (0%)
Age	18–24	0 (0%)
	25–34	8 (14%)
	35–44	11 (19%)
	45–54	22 (37%)
	55–64	18 (31%)
	65–74	0 (0%)
	75+	0 (0%)
Technical level	Novice	6 (10%)
	General	6 (10%)
	Informed	30 (51%)
	Technical	12 (20%)
	Expert	5 (8%)
Total respondents		59 (100%)

5.3.1.4 Results

The first question asked identified current sources for trip planning and cold-weather driving information. A majority of respondents acquired their information directly from driving the car, which is evident from the two top responses in Figure 5.5. Outside of the vehicle, 56% of respondents said they receive information by reading articles, webpages or blogs. Beyond this primary source, the remaining options were notably less popular, receiving a maximum response rate of 32%, which shows that online media is the primary provider of BEV winter knowledge outside the car.

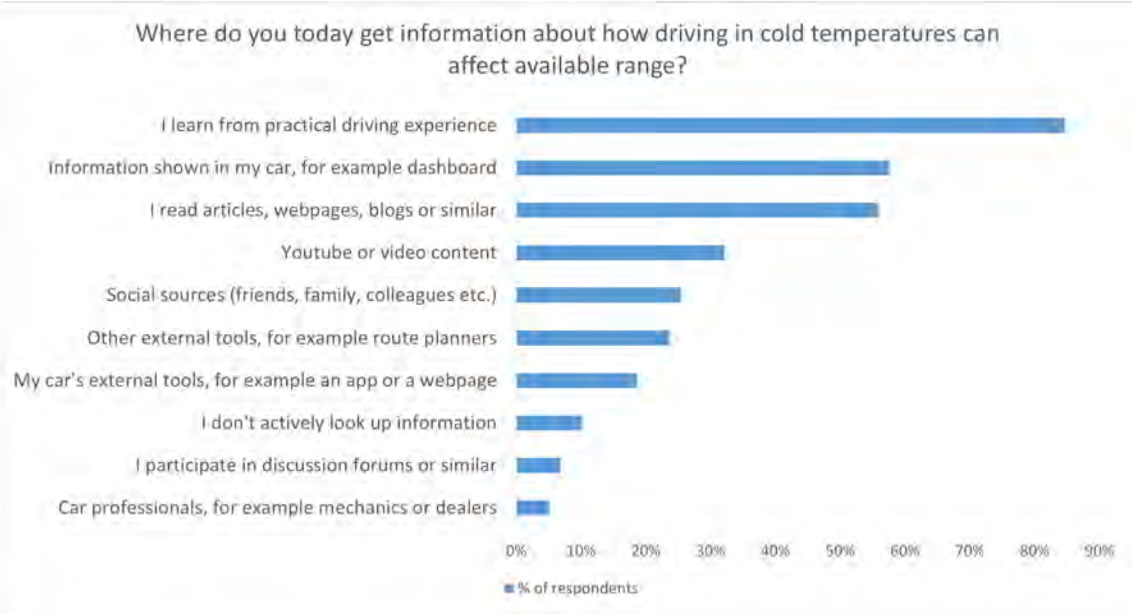


Figure 5.5: Answers to where respondents today get information about planning and driving in cold temperatures.

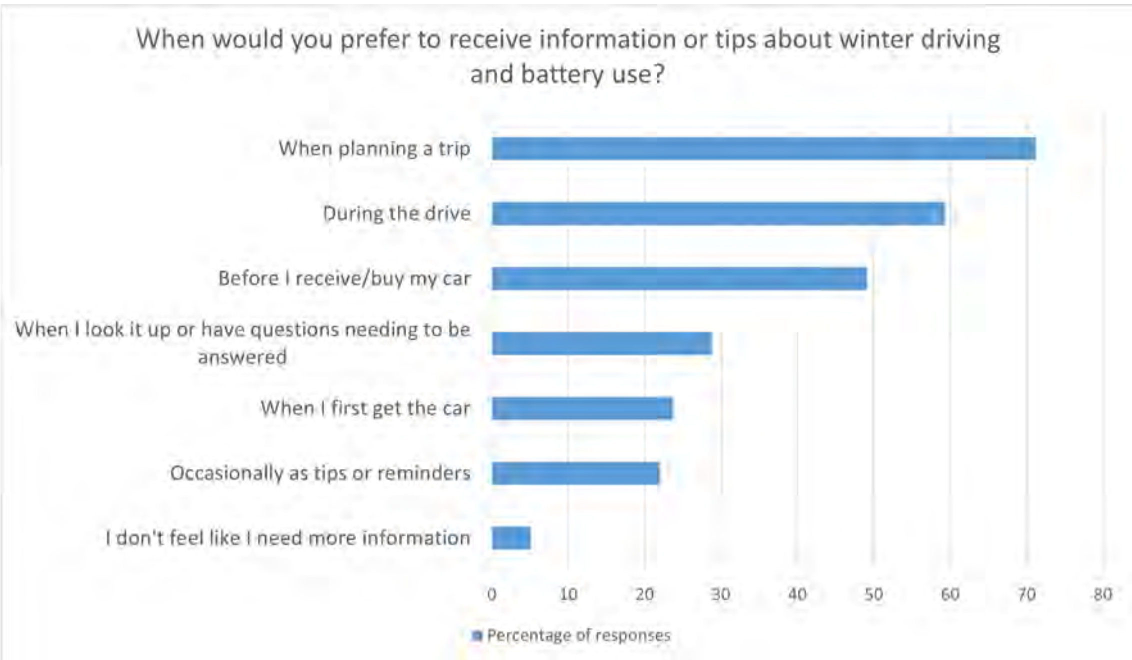


Figure 5.6: Distribution of answers to when respondents preferred receiving information about cold temperature factors.

Furthermore, the respondents were asked about timing for receiving information about winter driving and battery use. The distribution of answers are visualized in Figure 5.6. Specifically, 71% of respondents selected *When planning a trip* and 59% selected *During the drive*. Although the latter option technically fell outside the project's scope, it was included to capture conceptual insights into what matters most to drivers. These insights were subsequently used as inspiration during later stages of the development process for the concept outside of the vehicle. The answers also suggest that drivers want to feel more in control of their actual driving experience, using this information to handle the uncertainties of driving in cold temperatures. Additionally, almost half of the respondents (49%) selected the option *Before I receive/buy my car*, indicating a desire to make informed decisions and feel prepared prior to purchasing a BEV.

Table 5.4: Quotes from the open-ended question in the Communication Survey regarding perceived information gaps.

Participant ID	**Quote**
18	"Maybe some range vs temperature graphs, also, is there any setting in the car that I can activate to optimize range (I know there is one for Volvo cars but I stumbled on it by accident) - what does it do and what other settings can I optimize?"
24	"Some of the cars I drive lack the possibility to display current battery temperature (in degrees). This is a vital type of information in order to plan your long trip well."
28	"Defined winter condition driving range communicated at the dealer."
43	"Sometimes the expected range drops after starting to drive in cold weather. I.e. the system was not able to estimate the correct expected range."
46	"General data on how much energy is lost in cold temperature (and at what temperatures)."
58	"Informatory messages on how to conserve battery/improve range could be better"
69	"Unclear how pre-heating of the battery works."

The questionnaire included an open-ended question regarding perceived information gaps in cold-weather driving and trip planning. Of the 59 respondents, 29 answered that they lacked a specific type of information. A majority of respondents wanted more detailed information about topics such as preheating or charging, didn't trust the range estimation, or lacked information about how driving range was influenced by weather and temperature. There was no unified consensus among the responses and instead respondents brought up a wide range of topics, some of which can be found in Table 5.4. The responses indicate a desire to understand more deeply how the vehicle operates, as well as a clear demand for more comprehensive data in general.

Participants were asked a multiple choice question about which format they would find most helpful for communicating information. A vast majority of respondents preferred information in *Numerical Data (kWh, km, percentage etc)*, followed by *Short practical tips or advice* and *Visual Indicators (icons, illustrations, animations)*, as seen in Figure 5.7. The bottom five options all received 12% of responses or less. This indicates a clear preference for information to be clear, direct and briefly summarized.

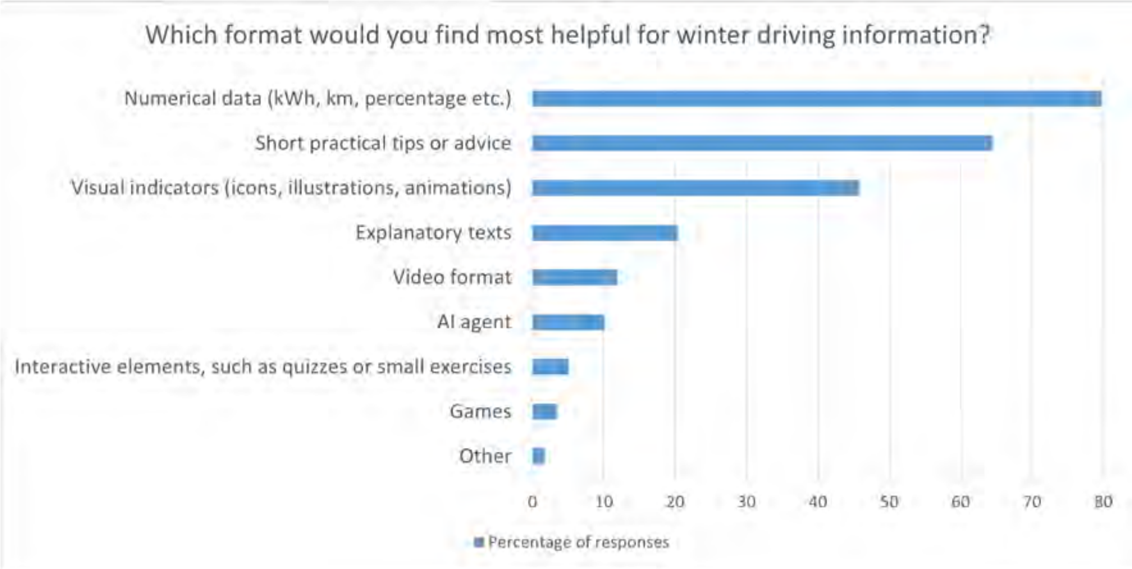


Figure 5.7: Distribution of answers regarding preferred formats for information.

Respondents were also asked with a single choice question about how they prefer the information being phrased. The choices focused on numerical data, with the options *Exact values (e.g. "This would change range about 10%")* and *Estimated intervals (e.g. "This would change range about 10-20%)*, or general guidance. As Figure 5.8 shows, the results indicate a clear preference for information being phrased using numerical data, either alone or in combination with general guidance. In total, 95% of respondents chose one of the three options containing some type of values, with *Exact values (e.g. "This would change range about 10%)* ranking highest at 47% of responses. Additionally, 30% of respondents wanted information that included general guidance, of which only 3% preferred it without values.

Lastly, Figure 5.9 shows respondent's preferences regarding which of their car's tools to look up information regarding winter driving. The respondents were highly aligned in their preference for using the vehicle's mobile application for receiving or looking up winter driving information, with 69% selecting this option. Only one respondent (2%) preferred using the webpage, and two respondents (3%) preferred the user manual. The remaining users were split between *None, I use/would use external sources* (8%) and *Other* (15%). Despite several mentions in the survey that the project was delimited to an out-of-car concept, and the deliberate decision to omit the in-car display option for this question, eight of the nine respondents choosing the *Other*-option specified that they wanted the information on the display in the vehicle. This, together with earlier preferences for numerical data and precise

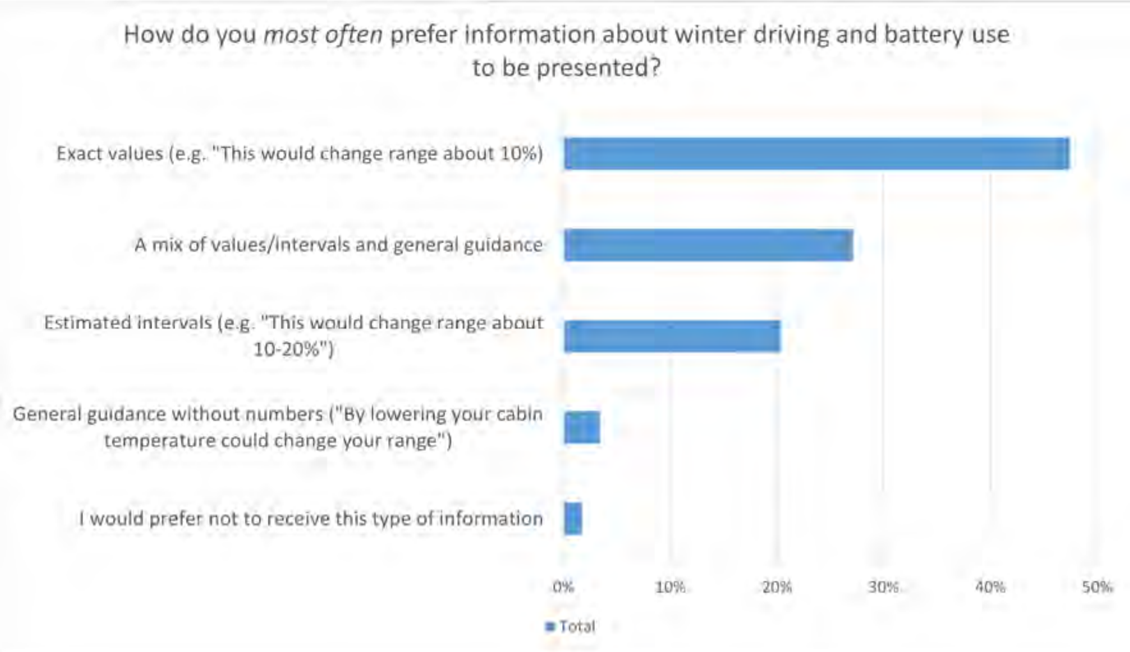


Figure 5.8: Answers to how respondents prefer information about winter driving being phrased.

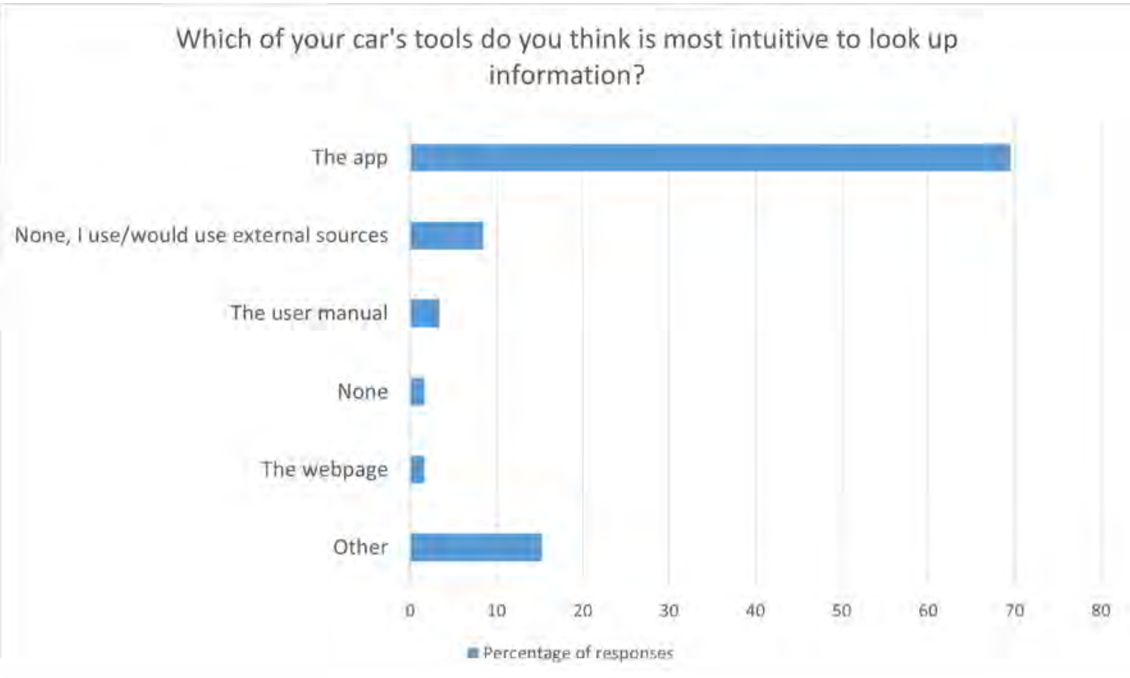


Figure 5.9: Answers to which of their car's tools respondents preferred for receiving information about winter driving.

information, suggests a strong desire to have a real-life connection to their actual driving experience, with data drivers can apply while on the road.

5.3.1.5 Main Takeaways

One of the main takeaways from the Communication Survey was that the most popular formats of receiving information were *"Numerical data", "Visualizations"* and *"Practical tips"*. When asked in regards of medium, a majority pointed out the car's application. However, there were signs that some respondents struggled to think outside of the car upon answering, for example as the car's interface was pointed out through the "Other" category.

5.3.2 Initial Concepts

To prepare for the next interview round, three distinct concepts were developed to explore alternative ways of visualizing the selected factors. The primary goal was to present concrete design directions for this range-related data, thereby prompting more diverse feedback. Additionally, introducing these varied visualizations aimed to push discussions beyond the participants' initial suggestions, encouraging deeper evaluation.

5.3.2.1 Prototyping Process

Once the three factors had been established (see Section 5.2.1.5), the process of creating the visualizations began with an ideation phase (see Figure 5.10). Several rounds of brainstorming were conducted, where the aim was to come up with ideas on how to represent the three factors with illustrations, icons and written information. After each iteration, concepts were evaluated against questionnaire results and topic-specific literature [31], [32]; where exact data was unavailable, estimations were made to facilitate the illustrations. This iterative process was repeated until a set of visualizations had been decided upon. During this phase, the decision was made to merge HVAC and Speed into one category. This was done to ensure the interview remained concise and to avoid information redundancy, in order to not overwhelm participants. The merging allowed the final visualization example to instead focus on generally introducing the cold temperature factors.

Each visualization was sketched with low fidelity on paper, after which the three visualization examples were created in Figma. Components from Volvo's pre-existing design system were used to match the visualizations to Volvo's minimalist interface. The three examples had low fidelity and were not interactive, as the primary focus was on the presentation of content rather than system functionality. Each topic was created in both a simple and a complex variation, providing similar information at different levels of detail. Despite a stated lack of interest in interactivity in the survey, one visualization example was illustrated as interactive. Since many respondents in the Communication Survey (see Tables 5.9 and 5.6) favored receiving information through the in-car interface, this deliberate design choice was made to mitigate potential bias in the survey results and to determine if the preference for static

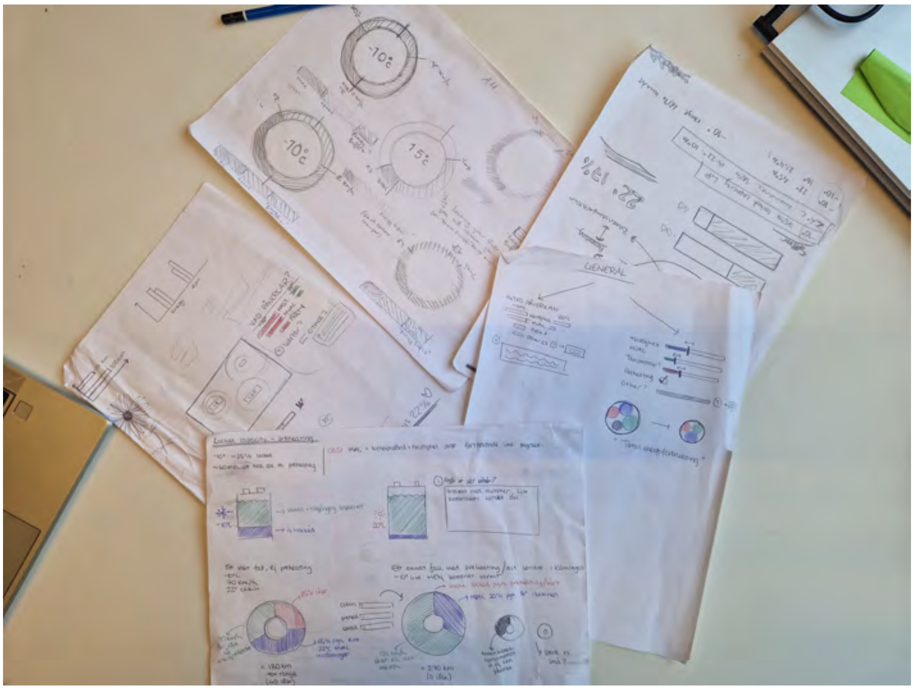


Figure 5.10: Photograph of ideation sketches for Initial Concepts.

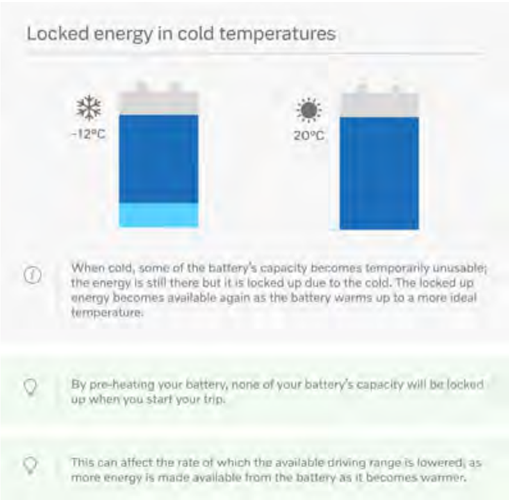
content was a general one, or if it was likely reflecting the need for clear and simple data specifically while operating a vehicle.

5.3.2.2 Visual Concepts

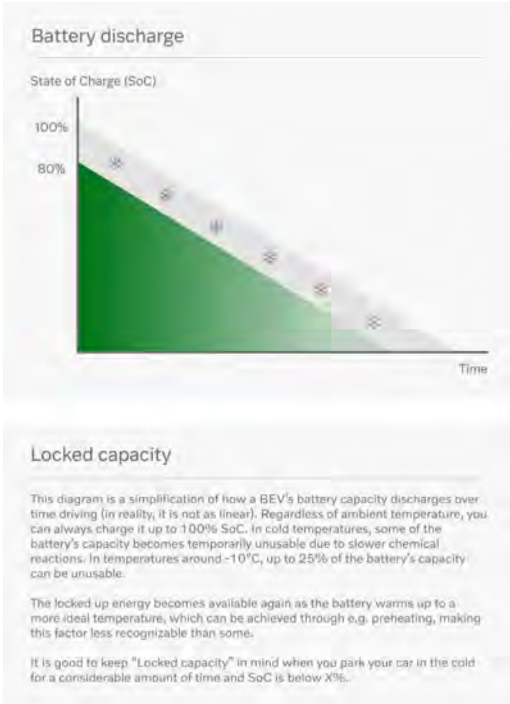
Based on the results from the Communication Survey (see Section 5.3.1.4), the visualizations were created mainly with numerical data, illustrations and icons, but accompanied with explanatory texts and actionable measures. The more complex versions included more text format, while the more simple versions focused on illustrations and measures. The first visualization example introduced *Locked Capacity*, and was created with a simple example using illustration of a battery to indicate the "frozen" energy, as presented in figure 5.11a. It also included two actionable measures. The more complex version included a diagram illustrating the energy consumption over time, together with a more information-dense and complex text, as seen in figure 5.11b.

The second visualization example introduced *HVAC* together with *Speed*. The simple version included only HVAC, and illustrated how a change in cabin temperature from 22°C to 16°C could save available driving range, as seen in figure 5.12a.

The more complex version (see figure 5.13) featured a graph illustrating momentary energy consumption at different speeds, alongside two additional graphs showing the percentage of energy used by the HVAC system across varying temperatures and speeds. The aim was to demonstrate that the HVAC system has a lower relative impact on total energy consumption at higher speeds, as the energy required for driving increases at a much higher rate.



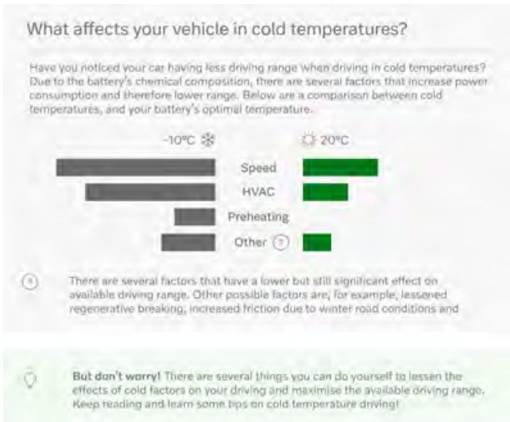
(a) Simple Locked Capacity visualization.



(b) Complex Locked Capacity visualization.

Figure 5.11: Visualization examples: Locked Capacity.

(a) Simple HVAC visualization.



(b) Simple General Factors visualization.

Figure 5.12: Visualization examples: Simple versions of HVAC and General Factors.

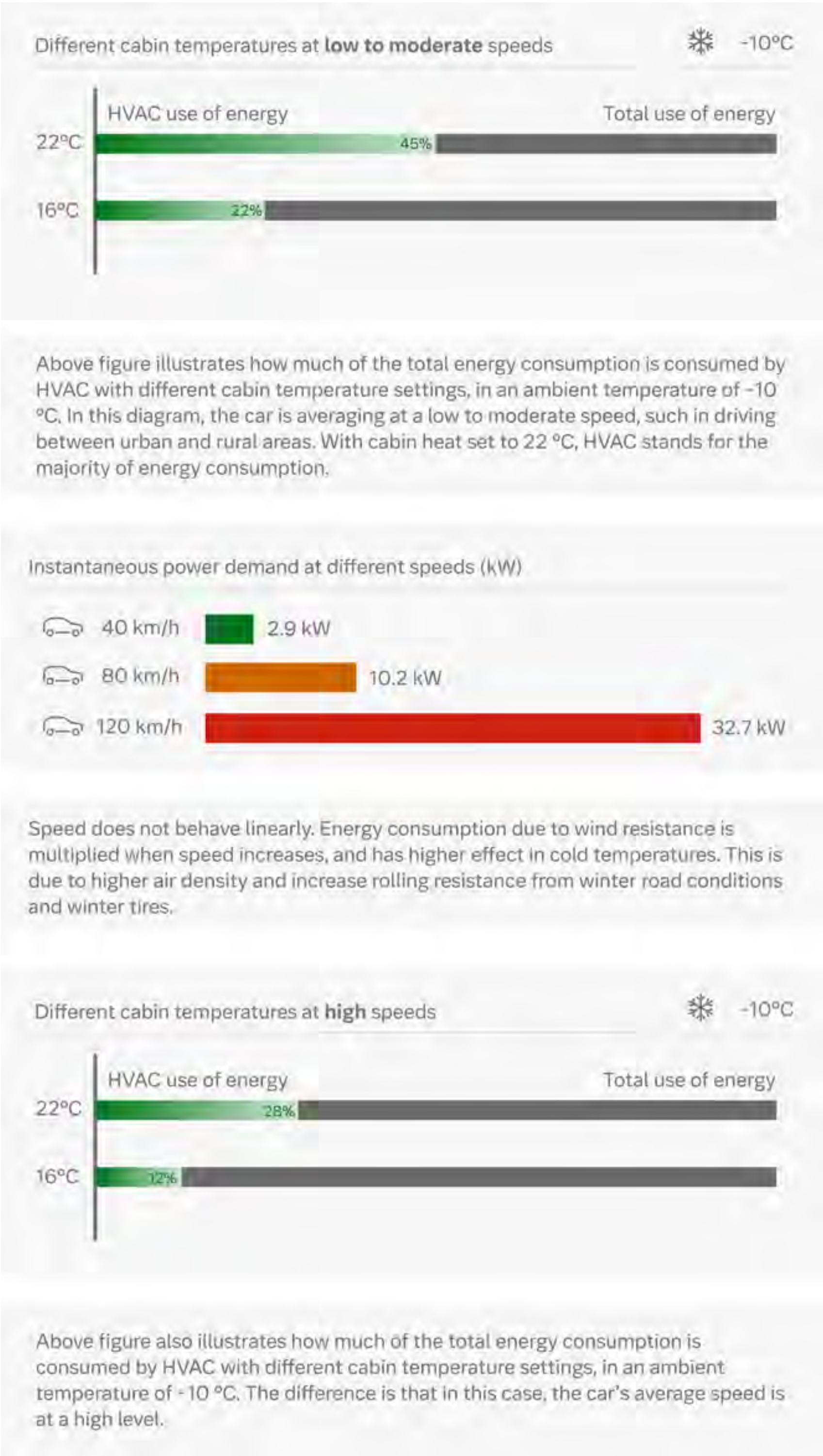
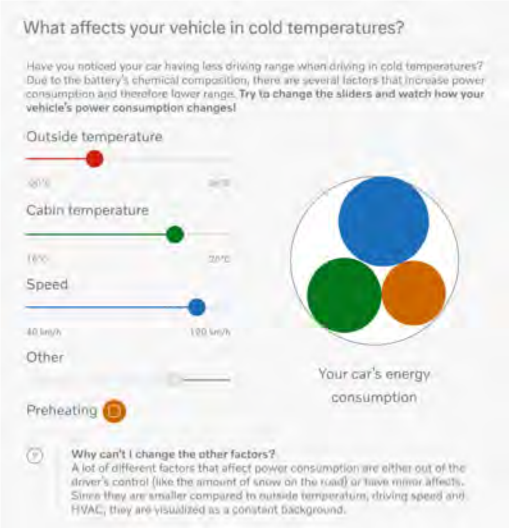
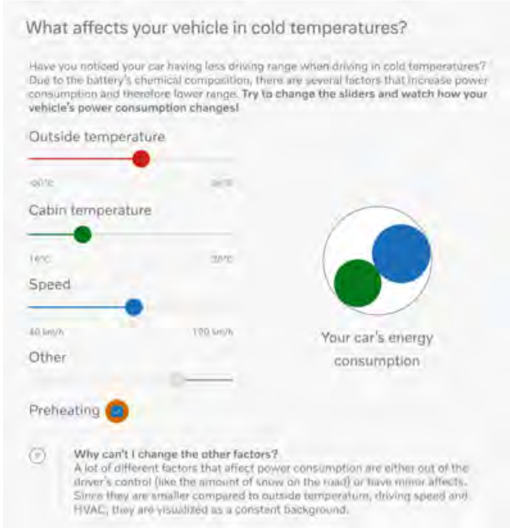


Figure 5.13: Complex HVAC visualization.



(a) Interactive General Factors visualization, before changes.



(b) Interactive General Factors visualization, after changes.

Figure 5.14: Visualization example: General Factors, interactive.

Finally, the third concept introduced *General introduction of cold temperature factors*. As shown in figure 5.12b, the simple version showed a static graph relating speed, preheating, cabin temperature and other factors to each other at different outside temperatures, as well as possible measure to take.

The more complex version, presented in figure 5.14, was illustrated as interactive, with one version representing the status before changes had been made, and one version representing the result. It included sliders for outside temperature, cabin temperature and speed as well as a check box for preheating. The outcome of these changes is visualized through color-coded circles that vary in size to represent each factor's energy consumption. To focus on the educational aspect of illustrating the relative impact of the different factors, no specific units were included. Both versions included information boxes explaining the 'Others' category, which represented additional factors that influence driving in cold temperatures. The goal was to ensure users understood that this category included variables beyond the primary factors displayed that either the driver's themselves can't affect, or that are too minor to have a significant impact.

5.3.3 Interviews

After the questionnaire, a set of twelve interviews were conducted. The interviews aimed to capture how BEV drivers today plan their trips in cold temperatures, to find gaps in their knowledge about cold temperature factors and to evaluate different ways of visualizing that information. The interviews were conducted with Volvo Cars employees in Gothenburg and took approximately 60 minutes each.

5.3.3.1 Study Design and Procedure

Participants were chosen from the respondents in questionnaire two who had agreed to take part in the interview session. Twelve participants were recruited with the goal of creating a varied sample, aiming for a diverse representation across age, gender, and technical expertise to the greatest extent possible. These remaining participants booked their interview time slots through Microsoft Bookings.

A semi-structured interview guide was developed (see Appendix C) consisting of ten primary questions. Several included follow-up sub-questions to ensure each participant addressed the same main subjects, maintaining consistency across the process. Following the results from the Communication Survey (see Section 5.3.1.4), the interview questions mainly focused on what knowledge participants lack when planning a trip or driving in cold temperatures, specifically regarding the three chosen factors (*Locked Capacity*, *HVAC*, and *Speed*). Additionally, the questions intended to uncover what information drivers wanted during the drive, with the goal of understanding how to translate those needs into an out-of-car concept. A question regarding whether participants preferred the solution to come from Volvo Cars, and through which medium, was included to investigate interest in an official application integration (see Table 5.9), compared to a separate, third-party platform. Participants were also asked to sketch their own visualization preferences. This exercise attempted to capture their ideas before they were influenced by the next stage, where the three pre-designed Visualization Examples were presented.

During the interviews, one person acted as moderator and the other as note-taker and observer. After giving informed consent, the interviews were recorded and transcribed using Microsoft Teams. Ten interviews were conducted on-site, and two via video on Teams. One participant preferred to speak English, while the remaining eleven were conducted in Swedish. After each interview, participants were offered a gift card as a thank you.

5.3.3.2 Analysis

After the interviews, the transcriptions were manually reviewed and refined to make them more accurate. Once the transcriptions were complete, the analysis process began using a thematic approach, utilizing the KJ Method as a structured tool for categorization. See Figure 5.15. Given the large quantity of data, the twelve interviews were initially analyzed individually. In an effort to strive for objectivity through the analysis and to add a different perspective, researchers primarily worked on the transcripts they had not transcribed themselves. After a discussion to align in what to select from the transcriptions was conducted, quotes and annotations from each one of the twelve interviews were placed on digital post-it notes in FigJam. The discussion was held in order to minimize subjective bias in the interpretations, according to Section 5.1. The selected quotes were kept in the original language to not get lost in translation over time, and were only translated for presentation purposes within this report. The post-its were numbered to be able to trace them back to each individual participant. At this stage, the notes were organized by their topics without any deeper interpretation of meaning or participant intent.

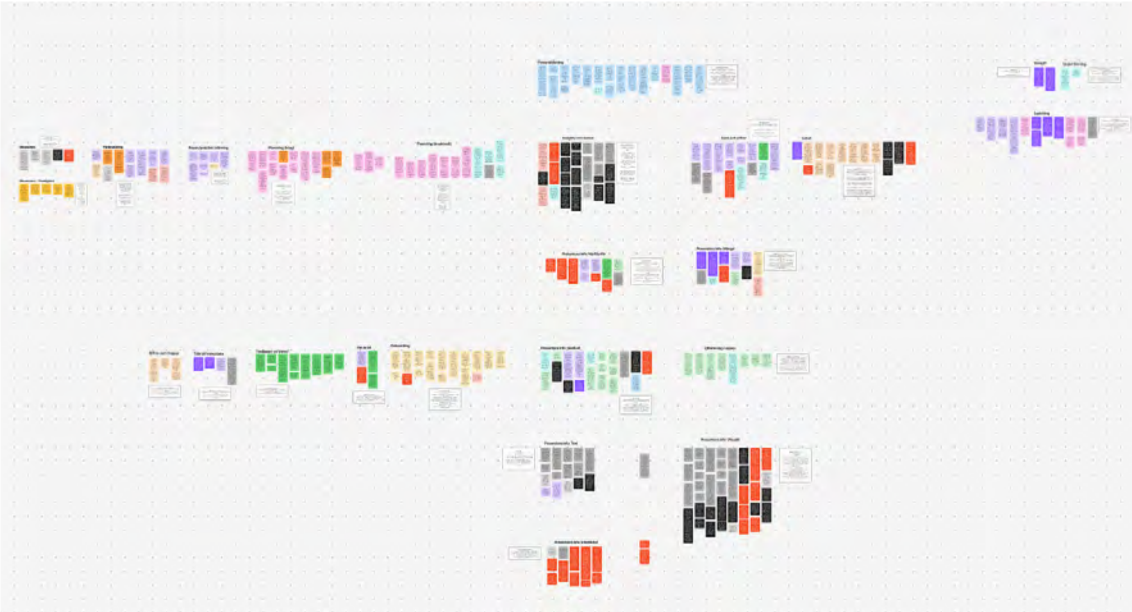


Figure 5.15: A zoomed out overview of finished KJ-analysis from the interview data.

After all quotes had been grouped by their surface-level subject, these notes were then collaboratively and iteratively clustered into affinity groups to identify recurring patterns. Through this, it was possible to develop the themes that defined the project's focus. The themes were developed through an iterative mapping process, which included several rounds of collaborative review to reach a consensus on the data, aiming to balance the inevitable subjectivity and potential bias inherent in a thematic analysis. Each theme was subsequently summarized into actionable insights. These insights were then reviewed and narrowed down into categories of different relevance to the project to align with the project's scope and to ensure the volume of data remained manageable, where a group of main themes was sorted out. A peer debriefing session was held with the project team, which resulted in a refinement of the thematic structure. Certain themes were moved between categories to better reflect the relationships identified in the data.

5.3.3.3 Participants

A total of 12 individuals participated in the interview stage of the study, of which ten were men and two were women. The participants were aged between 25-34 and 55-64 years old, with the majority (five participants) falling in the 45-54 years bracket. While some other brands of cars were present, most participants drove a Volvo as at least one of their cars. The participants had self-identified their technical level in the Communication Survey as they registered their interest in participation, and it ranged from Novice to Expert (see definitions in Table 5.1). The majority of participants identified themselves at the middle level, categorized as 'Informed'. See Table 5.5 for demographic data.

Table 5.5: Interview Participants Demographics.

ID	Technical Level	Gender	Age	Type of BEV
1	Technical	Man	25-34	Volvo, MG
2	Informed	Man	55-64	Volkswagen
3	Expert	Man	35-44	Volvo
4	Novice	Woman	55-64	Volvo
5	Expert	Man	55-64	Volvo, Renault
6	General	Man	45-54	Volvo
7	Expert	Man	45-54	Volvo
8	Technical	Man	45-54	Volvo, Tesla
9	Informed	Man	25-34	Volvo
10	Informed	Man	35-44	Volvo, Polestar
11	Informed	Woman	45-54	Volvo
12	Technical	Man	45-54	Tesla

5.3.3.4 Results

From the KJ analysis (see Figure 5.15), 25 themes were identified and grouped into three categories based on relevance. Three distinct categories were established: *Not Relevant*, *Secondary Considerations*, and *Primary Focus*, and are presented in Table 5.6.

Table 5.6: Groups of interview main themes.

Primary Focus	**Secondary Considerations**	**Not Relevant**
When and Why	Planning (wishes)	Charging
Medium	Choosing a car	During the Drive
Contents of the App	Measures	Numbers that change
Onboarding	Trust in Volvo and data	Measures, speed
Insights and Themes	Preconditioning	Energy Consumption
Amount of Information	Volvo or third party	Planning (today)
Interactive Information	Practical Experience	Other
Visual Information		
Text		
Data and Numbers		
Units		

The 'Primary' category contained the main themes of the project, while the 'Secondary' category comprised themes that, while valuable, were dependent on the concept's final design trajectory. These secondary themes represent factors that were considered to remain relevant to the broader user experience but require specific conditions to be effectively integrated, or could not all be accommodated together. For example, the choice of medium for the concept resulted in certain themes being moved to the 'Secondary' category. Additionally, while preconditioning is highly important in winter driving, the insights were mainly dependent on the specific functionality of preheating in Volvo vehicles, which falls outside the scope of this project. Some themes were deemed not relevant, as they fell directly outside the scope of the project. In the iterative process, one theme (*Contents of the app*) was moved from the secondary category to become a main theme as the decision was made to develop a concept specifically for the Volvo Cars app. Conversely, the category *Planning (wishes)* was moved to the secondary category. While it remained highly important to many users, it was deemed outside the immediate primary focus of this specific project phase. As seen in the results from the Communication Survey (see Section 5.3.1.4), many participants in both data collections wished for detailed data and deep trip-planning features. Since this concept aims to educate the driver about their car rather than serve as a planning tool, these features were moved to the secondary category. See the grouping in Figure 5.16.

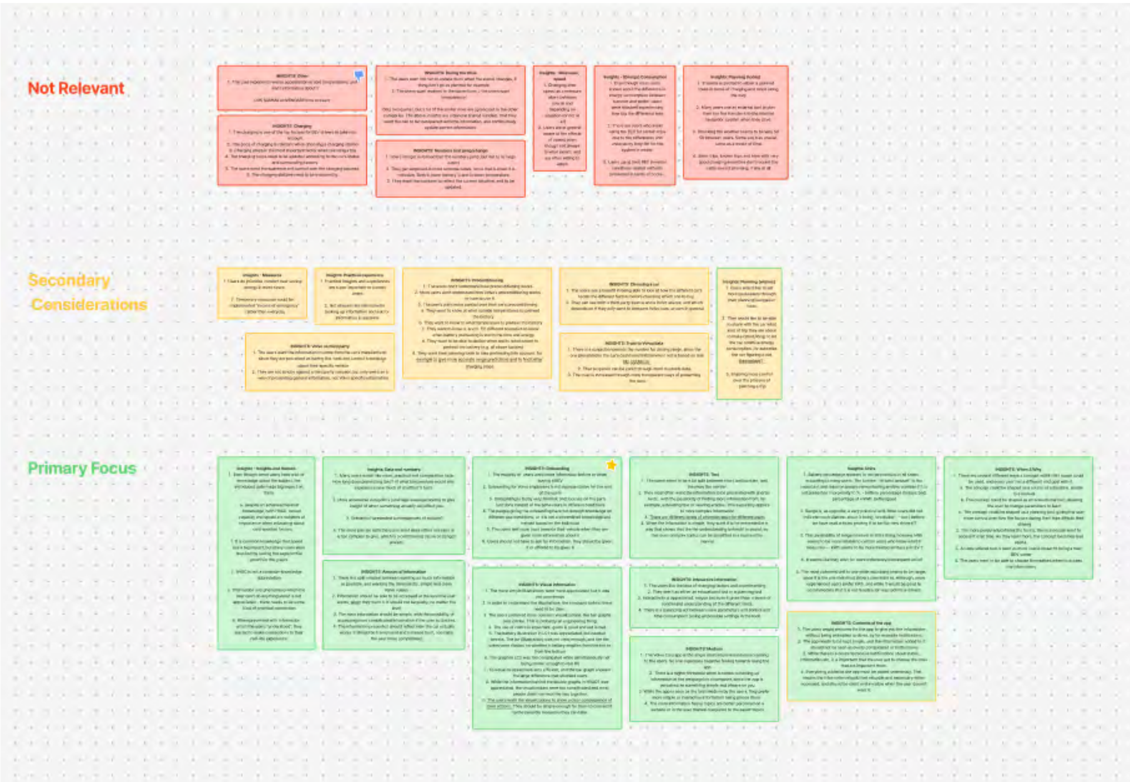


Figure 5.16: Overview of the categorized insights based on the interview KJ analysis data

The eleven main themes (see Table 5.6) are described below, together with quotes from the interviews belonging to each respective theme, where all have been translated to English for presentation purposes.

I1 - When and Why: This theme is about the purpose of the concept and the specific timing of its use, with quotes in Table 5.7. Because every participant had a different end goal, the concept could be shaped in several ways. First, it could serve as a source of static education, similar to a user manual, providing pure information about how cold temperature factors affect the driving. Second, it could also be shaped as an interactive educational tool, allowing users to manipulate parameters to learn rather than only reading about the effects of cold temperatures. Lastly, the concept could function as a more advanced planning tool than what the Volvo Cars application contains today, giving the user more control over how the cold temperature factors affect their driving and their trips. However, the advanced approach requires a significant level of data and primarily benefit experienced and more technical BEV drivers. Conversely, a more purely educational tool is most useful for novice BEV drivers or users less interested in the functionality of their cars. Additionally, a key challenge identified is that a purely educative concept risks being less useful over time as the drivers become more knowledgeable and no longer needs to access the information.

Table 5.7: Quotes from the main theme *When and Why*.

Participant ID	Quote
3	"It's probably like that for most customers in some way, that you should be able to choose if... How often, or in what way, you want to receive the information."
4	"I believe so, because then I would be able to see it easily and intuitively." *(Responding to whether they would plan more using the visual example in Figure 5.14*)
6	"I think I would perhaps play around with it a bit when I first got the car or the app. Just to learn how it all is connected. Then I'd have it in the back of my mind. I don't think I would use it more than maybe once or twice."
8	"Yes, but it's good to be able to pull it up and think, 'Wait, how did that work again?' You might have forgotten it by the time winter comes around again."

I2 - Medium: This theme is about the possible mediums of communication for the concept. According to the participants, a vehicle's dedicated mobile application is considered the most intuitive medium for accessing this type of information (see selected quotes in Table 5.8). No negative feelings were expressed during the interviews toward utilizing the vehicle's application for an informative concept; however, some participants did express negativity toward specific existing functionalities within the applications they currently use. Reflecting this general sentiment, the participants who drove a Volvo expressed similar feelings, explicitly highlighting the official Volvo Cars application as their preferred choice despite having wishes regarding certain features. The application is perceived as a tool that is both simple and highly accessible, as it is 'always close' to the user, while there is a higher threshold when it comes to looking up information at the webpage or on a computer. However, while the app is perceived by the participants as the best medium to receive information about how cold temperature factors affect their driving range, they preferred it for more simple or interactive information. The more information-dense topics were seen as a better fit for a website or the user manual compared to more simple information.

Table 5.8: Quotes from the main theme *Medium*.

Participant ID	Quote
10	"Through the app, then. The only way I can see, that is convenient."
3	"So I still think that the app can be a very powerful tool to use. Sure, you could of course enter a webpage, but that creates a different kind of threshold. Like, okay, do you have to send a link or exactly how do you get someone to enter the webpage?"
5	"You don't sit down at a computer just because now I am going to look up how far I can come when it's cold. "
2	"In the car, you want very quick information that is easily accessible with images, gauges, and things like that. In an app, you end up somewhere in the middle, and then perhaps on a website or in a manual, there could be even more information. So, I could imagine having three levels of information."
4	"Like, I am one of those who thinks that if I need to read the manual then it's a failure. So I don't read up on it in advance, and instead think that 'This must be able to solve itself'."

Table 5.9: Quotes from the main theme *Contents of the app*.

Participant ID	Quote
1	"If it's going to be connected specifically to me as a car owner, then I'd want the Volvo app to... well, it could send a notification even if I haven't planned a trip. Something like, 'Keep this in mind', or 'The winter months are coming, and this is how the car behaves.' On that level."
6	"That's exactly what is so difficult, that balance between getting too many notifications and getting the ones that are actually important."
9	"I mute most of them because they become too many, but yeah. Usually the Volvo app is quite silent, so I haven't muted it."

I3 - Contents of the app: This theme is about the Volvo Cars app and how the concept should integrate with it. This is because a vehicle's application was the participants preferred medium (as mentioned in [I2]), and this project is conducted in the context of Volvo Cars. Representative quotes are presented in Table 5.9. Participants welcomed the idea of the app presenting information about cold temperature factors proactively, by for example using notifications, rather than waiting for a user to prompt it. However, while there is a desire to receive these status updates, it is important that the users get to choose which notifications that are important them.

Placing the concept in the application means that it needs to be kept simple, the information should not be seen as overly complicated or bothersome. Finally, the concept must integrate seamlessly within the application. The information should feel valuable and necessary when accessed, but remain silent and invisible when not wanted.

I4 - Onboarding: This theme is about the onboarding when buying or leasing a BEV. The majority of users wanted more information before or when buying a BEV. The ones who had gotten onboarding had perceived it as minimal, and focused only on the car's functions. Also, participants felt that the employees responsible for onboarding lacked a consistent depth of knowledge regarding different driving conditions. However, many participants had leased their BEV through Volvo and as such taken part in a directed onboarding, which is not representative for the general BEV driver. In general, the users felt more trust towards their vehicle when they were given more information about it. They should not have to ask for information, it should be offered to them or available when they want it. Table 5.10 displays related quotes.

Table 5.10: Quotes from the main theme *Onboarding*.

Participant ID	Quote
2	"Definitely when you buy a new car, you should receive it. But then, if you could get access to that same information even before you've bought a car, that would also be interesting."
8	"It's about educating so that expectations become correct, because right now, I don't think they are. People expect one thing because the sales documents state a certain certified range. But that has nothing to do with reality."
7	"No, when it comes to information about... How the car behaves, or that it behaves differently when it's cold in terms of range and things like that, I don't think that has actually been mentioned. I haven't asked either, but yeah."
8	"And then I think it would make sense in the onboarding, when you get your car and are being educated on it. Because this thing with BEV range, it is a technical question, but it's even more of a pedagogical question."

I5 - Insights and Themes: This theme was about the topics and themes introduced to the user during the interviews, with representative quotes found in Table 5.11. Even though some users have a lot of knowledge about the subject of cold temperature driving, the introduced data made big impact on them. Despite an advanced level of knowledge, both HVAC, locked capacity and speed are subjects of importance when educating about cold weather factors. Participants already understood that higher speeds lead to higher consumption, but the visualization showing the big increase in energy consumption at higher speeds still made a big impact. Also, the term HVAC was not known by a majority of the users. Finally, it was perceived as important that the information shown to the user had a practical connection, in order for the user to relate to it. When they understood the information given to them, they started making real-life connections.

Table 5.11: Quotes from the main theme *Insights and themes*.

Participant ID	Quote
2	*(Regarding visualization example General 2 in Figure 5.14)* "But I suppose it's about gaining an understanding for when you end up in a difficult situation. What should I change right now? Should I lower my speed? Or should I lower the temperature in the car? And then you have that knowledge."
6	"*(Regarding visualization example HVAC 2 in Figure 5.13)* If there is a big difference in speed, if slowing down just a little bit means you can go further, it would have been interesting to see that."
7	"*(Regarding visualization example HVAC 1 in Figure 5.12a)* This is an estimate of range, and range depends on more parameters than just the temperature, right? I can see that I might go further, but... if I'm driving at 180 km/h, then the difference between 16 and 22 degrees might be tiny."
4	"I mean, ordinary people don't know what 'HVAC' is."
5	"*(Regarding visualization example HVAC 2, speed illustration in Figure 5.13)* That part you might take with you, but that *(regarding the other two illustrations in HVAC 2, Figure 5.13)*, I think it will be difficult for most people to really understand the big picture and just sit down and reflect on it. It becomes too complicated."

I6 - Amount of Information: This theme is about how much information to give to the users, with quotes representing participants opinion in Table 5.12. There was a split mindset between wanting as much information as possible, and wanting the minimalist, simple and clean Volvo values. The main information presented needs to be simple, with the possibility of accessing more complicated information if the user so desires. The data showed that access should be user-driven; information must be available at the desired level of detail without being perceived as pushy. Participants emphasized that for a tool to be trustworthy, it needs to be transparent about the car's underlying processes. The information presented in the content should reflect how the car actually works. It should be transparent and increase trust, not make it more complicated for the user.

I7 - Interactive Information: This theme focuses on interactive information and highlights a strong user preference for the interactive examples shown during the interviews, see Section 5.3.2. Participants appreciated the ability to experiment and change different factors and see concrete results. It was noted that it gave them a sense of control and a better grasp of the vehicle's limits. However, perspectives

Table 5.12: Quotes from the main theme *Amount of Information*.

Participant ID	Quote
5	"Yes, I think it's interesting, or rather, I think it becomes better if you give some information to the customer, to the driver. To not withhold so much, you know; to actually include, like, what is happening in the car?"
9	"All the tips. Yeah. (...) The more the better so that we can optimize, but maybe it's my engineering bias. I don't know."
6	"I mean, I can feel that 'less is more', it shouldn't get to the point where you're frustrated and tapping things away, like 'that damn thing, I just want to get to where I'm going.'"

on the purpose of such a tool were split. While some users valued experimenting for an educational benefit, the more technically advanced participants viewed the interactive example as a foundation for a more advanced planning tool. This creates a balancing act for the concept between providing enough parameters to the interactive tool to give the user more control over their data, while ensuring that the tool doesn't become so complex that it increases the time and effort required to complete a task. Selected quotes are compiled in Table 5.13.

Table 5.13: Quotes from the main theme *Interactive information*.

Participant ID	Quote
2	"*(Regarding visualization example General 2 in Figure 5.14)* I mean, it would be super interesting to be able to play around with stuff like that. I think many people would like that. At least I would have liked it."
5	"*(Regarding visualization example General 2 in Figure 5.14)* But that is the kind of thing that everyone [likes], you can basically play around a bit and see how much one thing or the other affects? No, but that's good; that way you can experiment and see what happens."
6	"*(Regarding visualization example General 2 in Figure 5.14)* Yeah, this was gorgeous. I would have wanted this on, like, Volvo's website or in the app, maybe? Super good. You understand the same thing there *(referring to visualization example General 1 in Figure 5.12b)*, but... The actual connection and what affects becomes very clear when you can sit and drag these things around."

I8 - Visual Information: This theme focuses on the opinions about the visual information, mostly derived from the three Visualization Examples shown during the interviews (see Section 5.3.2). In general, the more simple illustrations were more appreciated even by the technically advanced participants, but it was not unanimous. For the illustrations to be meaningful and intuitively understood, the core concepts they represent must be evident. The users also expressed the need for the visualizations to be connected to the consequences of their own actions. To be effective, these illustrations must be simplified so that the user can connect the visual data to specific, actionable measures they can take. In general, users preferred more common visualizations, for example bar graphs instead of circles. However, this can be contributed to the high technical competence among the participants. The correct use of colors in the illustrations is important, green is good and red is bad. In regards to the specific examples shown during the interviews, the battery illustration in Figure 5.11a was appreciated, but needed refinements. The choice of light blue to represent ice proved insufficient for many participants. The graph in Figure 5.11b was perceived as too complex while simultaneously lacking a clear real-world connection. This suggests that the visualization failed to bridge the gap between technical data and the user's actual driving experience. The visualization of speed in Figure 5.13 was very efficient and had impact on the users. Lastly, while the information behind the double graphs in Figure 5.13 was appreciated, the visualizations were too complicated and most participants failed to recognize the relationship between the two graphs.

Table 5.14: Quotes from the main theme *Visual information*.

Participant ID	Quote
9	"*(Regarding visualization example Locked Capacity 2 in Figure 5.11b)* I think the text is quite good here, but the graph is a bit confusing to me."
6	"*(Regarding visualization example Locked Capacity 1 in Figure 5.11a)* I think this one is good. Sufficient."
4	"*(Regarding visualization example HVAC 1 in Figure 5.12a)* Here it became very clear with the cabin temperature and range instead. There, I find out exactly how far I can go. It shows if it 'punishes' you or if it pays off to be stingy."
4	"*(Regarding the double graphs in visualization example HVAC 2, Figure 5.13)* I mean, I'm thinking that when I, who am an engineer and used to interpreting graphs, have to really look at it and ask: 'What is this actually saying?' Total use of energy, HVAC use of energy... yeah, it becomes a bit... no, it's a bit skewed."
1	"*(Regarding visualization example General 2 in Figure 5.14)* I think people are bad at estimating how much more area you get if you change the radius or the diameter of a circle. (...) Bars are easier to understand how you..."

I9 - Text: This theme is about how information is presented in text. Quotes can be found in Table 5.15. Participants expressed diverging preferences regarding information density, while some preferred things to be short and to the point, others didn't want any limit on the detail provided. The most common need was for information to be presented with shorter texts, alongside the possibility of finding more information, such as through 'Read more' links. This especially applies to the more complex information. Users emphasized that even when information is simplified, the presentation must signal a high level of expertise. As such, the concept can build the trust necessary for users to rely on it for more complicated topics.

Table 5.15: Quotes from the main theme *Text*.

Participant ID	Quote
7	"But for me, it might be appreciated that it's a bit longer. But I think to reach most people, you probably want to have it short and concise, if possible."
10	"*(Regarding visualization example HVAC 2) in Figure 5.13* I would probably want this more detailed information, but also for the range to be included somewhere."
12	"At the same time it's a really good phrasing, 'The locked up energy becomes available as the battery warms up to a more ideal temperature. 'That is really good..."

I10 - Data and Numbers: This theme is about the level of data the users wanted as well as how it should be represented. Representative quotes can be found in Table 5.16. Many users would like more, practical and comparative data. In general, they wanted more accessible data points to give insight into the specific conditions that actually affect driving. For example, several users expressed uncertainty about how long is necessary for preheating in certain conditions, and at what temperatures they would experience the greatest effect. However, the exact level of data that the users desired does either not exist or is too complex, which might be a contributing cause of range anxiety.

I11 - Units: This theme focuses on the units for presenting information. According to many participants, battery percentage appeared to not be practical in all cases. The context of is vital; a percentage only makes sense if the user knows what it is a percentage of. If the base value is not presented in close proximity to the percentage, users have to struggle to remember previous numbers to understand the scale of the impact. In contrast, range was perceived as the most practical and relatable unit for the majority of users. However, the unreliability of range remained a concern for the participants. While more experienced or more technically knowledgeable participants preferred the unit kWh for its precision and consistency, this unit was deemed inaccessible for new or less-technical BEV drivers. A selection of participant quotes is presented in Table 5.17.

Table 5.16: Quotes from the main theme *Data and Numbers*.

Participant ID	Quote
7	"But what I wish for is more reliable real-time data from the car, and that is not possible to receive."
3	"Okay, but what are we talking about? For how long do you need to preheat? Like, is it for ten minutes or an hour?"
4	"I haven't really familiarized myself with where the breakpoints are. I still don't know, as I said, because I don't have an infinite number of data points between my usual minus five and minus 18. So, yes, I understand, but no, I don't know anything in detail, so to speak. And I would have liked to have that in a simple and clear way."
2	"I don't really know how the car would do it, but somehow you should be able to get more precision in how far we can go with the conditions as they are now, and perhaps with background information and such."

Table 5.17: Quotes from the main theme *Units*.

Participant ID	Quote
4	"Like, the consumption doesn't tell me a lot because I don't really know to 100% what my battery capacity is. So it becomes a really abstract number."
8	"No, there is a number next to the battery where it says the amount of kilometers left that is completely unessential in my world. (...) I don't even know why it is shown there because it is never correct, especially not when it is cold outside."
9	"It would be much more clear too. Because in the end I care about how many kilometers more I can do than the specific percentage of energy benchmarks"
7	"Instead of talking about, like, how many kWh is used to keep the temperature, it is a part of the total energy consumption used to keep the cabin warm. I think that is better. It probably reaches more people that way."

5.3.3.5 Main Takeaways

The main takeaways can be organized around what participants expressed regarding where, when, and what information they want to receive. First, the information was well received and people genuinely wanted it, as both the visualizations and the interactive concept were highly appreciated. Participants highlighted connectivity to their own vehicle data was an attractive feature, and while some users wanted highly specific planning data, the project focuses on educating drivers rather than providing deep technical data. Lastly, simplicity was appreciated, as it kept the data readable and made the information relatable to them.

5.3.4 Target group and user personas

Two user personas were created based on the data from the previous studies to translate the findings into realistic drivers representing the target group. By defining their distinct backgrounds, needs, and levels of technical literacy, these personas served as a foundational tool for the design phase, aiming to address the specific challenges and expectations of the users.

5.3.4.1 Process

The results from the thematic analysis were used to create a definition of the target group and two user personas. This followed an inductive approach, using the collected data and observations to identify target group characteristics rather than starting with predetermined assumptions. All prior data collection served as a basis, with the thematic analysis of the interviews as the main contributor. Because the data revealed one user group seeking detailed data and another requesting educational data, the decision was made to focus on personas with lower technical experience to address this educational need. This mirrors the earlier decision to categorize deep trip-planning as a secondary focus, prioritizing instead vehicle transparency and user education.

The two user personas were created to align the project with the UCD approach [49], as such ensuring that the process captures the actual needs of the users. Two main types of BEV drivers could be identified from the data, and the two personas were given characteristics related to the use of their BEV based on the respective type to exemplify the difference between the target users. The two user personas were also assigned demographic information such as gender, age, and hobbies. This information was not derived from the observations and the collected data but instead completely fictional. It was intentionally added to make the personas feel like real, relatable people to help create empathy and to interpret the needs though a more holistic and human lens.

5.3.4.2 Results

Target group

The target group consists of BEV drivers who do not necessarily have a specialized interest in automotive technology or their car's functionality. Characterized by a low to moderate level of technical literacy, this group consists of individuals in two primary stages of ownership:

- New BEV drivers who are establishing their initial understanding of battery electric vehicle behavior who require a clear onboarding to the factors influencing range and performance to understand how to mitigate the effects.
- Individuals who have driven BEV before but do not maintain a constant focus on technical data. These users may need to re-align their expectations when a change in seasons impacts vehicle performance in a surprising way, even if it is not the first time it happens.

Regardless of their length of ownership, these drivers do not typically look up technical information about their BEV independently. Their engagement with vehicle data generally stems from immediate practical needs, such as ensuring a successful trip, or by notifications from the system. While their interest is primarily practical, they occasionally want more depth. In those cases, they value information that translates technical data into simple, relatable terms. Finally, they greatly value comfort while driving.

User Personas

Based on the target group and the collected data, two user personas were created. Each persona contains a picture and personal details for demographic information, and a short profile that describes their lifestyle and attitude towards their BEV and winter driving. Lastly, their frustrations and goals describe their attitude towards their BEV and winter driving.

The first persona, Karin, can be seen in figure 5.17. She is 51 years old and has just bought her first BEV. She is not very interested in technology, but is curious and would like to learn more about her BEV's functionality, but can't relate to the information she finds when she looks it up online. She easily gets overwhelmed by the information and wants a clear and simple onboarding process.

The second persona is named Peter and is 37 years old. His profile can be found in figure 5.18. He is a sales representative with two years experience of BEV driving, however he doesn't pay much attention to functions other than the ones that affect his comfort. He gets surprised by the lower range when winter comes, even though he has driven in cold temperatures before, and wants to be comfortable in the car while simultaneously not losing too much range.

5.3.5 List of user requirements

After the User Personas were created, a list of user requirements (UR) was created. The insights from the main themes were translated into ten specific user requirements to be used as a basis for design iterations and further data collection. The primary aim of these requirements was to establish a clear connection between the user data and the following design choices. The list of requirements is as follows:

UR1: As a user, I want to learn or deepen (my knowledge) about about

Figure 5.17: User persona 1. (Portrait image created with AI, Google Gemini May 2026)

Figure 5.18: User persona 2. (Portrait image created with AI, Google Gemini May 2026)

how speed, HVAC and locked capacity affect my available driving range in winter and what I can do to mitigate negative effects.

The first requirement is based on the main themes *When and Why* and *Insights and Themes*, with quotes found in Tables 5.7 and 5.11. It highlights that the target group of less advanced BEV drivers above all, but also more technical users, have a desire to learn about how specific factors affect their vehicles.

UR2: As a user, I want the concept to be integrated in the Volvo Cars app, so that I can decide for myself when to access the content.

This second user requirement is based on the main theme *Medium* and *Contents of the app*, where the users expressed that the Volvo Cars application was the preferable medium to receive information. It was seen as both simple and highly accessible, and it is important that they get to do it when they deem it necessary. Quotes from participants reflecting this can be found in Tables 5.8 and 5.9.

UR3: As a user, I want to be introduced to these ideas during onboarding, so I can start building my understanding of the car early on.

The third user requirement is based on the low technical interest of the target group and the main theme *Onboarding*. Quotes in Table 5.10 reflect how participants thought their own onboarding information was not sufficient. They felt more trust towards their vehicle when they were given more information about it, and expressed that they would like information about cold temperature factors introduced early on.

UR4: As a user, I want a clean, minimalist interface that matches the Volvo style, so I don't feel overwhelmed by unnecessary clutter.

The fourth user requirement is based on the main themes *Contents of the app* and *Amount of Information*, where participants expressed that a more minimalist interface with less notifications is preferable. Quotes from the interviews can be found in Tables 5.9 and 5.12.

UR5: As a user, I want to start with a more simple overview of the information and have the choice to dig deeper into the details only when I'm ready.

The fifth user requirement stems from the main themes *Amount of Information* and *Text*. The participants expressed that they wanted to be able to access more information-dense content, but not at first presentation, which quotes in Tables 5.12 and 5.15 reflect.

UR6: As a user, I want to be able to play around with different variables so I can actually see the cause and effect, rather than just reading static text.

The sixth user requirement is derived form the main theme *Interactive Information* (See Table 5.13. The users valued the ability to change parameters and see a direct result, both from an educational stand point and as a planning tool.

UR7: As a user, I want helpful illustrations and images to go along with the info, so that it becomes easier to grasp things at a glance.

The seventh user requirement is about the main theme *Visual Information*, where users (as seen in Table 5.14 appreciated the visualization examples independently of their technical level as a way of displaying information.

UR8: As a user, I want data visualizations that are easy to read, without overlapping lines or complex charts.

The eight user requirement is derived from the main themes *Visual Information.* They expressed that they preferred the more simple visualizations and graphs, independently of their technical level. Quotes can be found in Table 5.14.

UR9: As a user, I want technical data to be translated into units that actually make sense to me, and to see clear comparisons so I have the context I need to understand the impact.

The ninth user requirement is about the main themes *Data and Numbers* and *Units* (see Tables 5.16 and 5.17). The interview participants expressed that kilometers and percentage when in relation to an evident comparison was more relatable than kWh, and that they wanted data related to their own specific context.

UR10: As a user, I want the information and measures to be tied to real, practical driving, giving me tips and measures that I actually feel capable of doing myself.

Lastly, the tenth requirement is based on the main themes *Data and numbers* and *Visual information* (see Tables 5.16 and 5.14), where the interview participants expressed that the information presented to them was easier to understand when it was relatable and actionable.

5.4 Develop

Once the analysis of the interview data was complete and user personas and list of requirements had been created, the concept development phase began. Following initial rounds of ideation, low-fidelity prototypes were created in Figma, which were then used to gather user feedback through three co-design sessions. This feedback was subsequently collected, analyzed, and used as a basis for developing the final concept and establishing design recommendations.

5.4.1 Low-fidelity prototypes

The first part was an ideation process that lead into the creation of low fidelity concepts in Figma to be used in the following data collection. The aim of this phase was to explore a wide range of design solutions and translate them into initial visual prototypes that could be used as a concrete basis for gathering user feedback in the upcoming data collection.

5.4.1.1 Prototyping process

To ensure the process remained goal-oriented, the established list of requirements and user personas served as the foundation for ideation. The initial phase involved a first round of brainstorming to explore the main themes and create aligned concepts. Two subsequent rounds followed to iterate on these initial thoughts and develop new ideas for areas that proved lacking. After each session, the concepts were reviewed against the project scope, main themes, and user personas. Following these three rounds, a Dark Horse ideation session was conducted to gain a fresh perspective and promote innovation. Finally, two rounds of brainstorming were used to refine specific aspects, ultimately resulting in two final concepts. Both were built from the same core elements but were designed with variations in content and connections, leading to the names *Flow 1* and *Flow 2*. To conclude the ideation process, these final concepts were transformed into low-fidelity sketched wireframes.

Following the conclusion of the ideation process, the paper wireframes were translated into Figma as low-fidelity prototypes. However, Volvo uses a design system that is accessible as components in Figma. The utilization of this existing design system therefore resulted in a visual fidelity that appeared higher than the actual functional fidelity of the frames. The low fidelity prototype consisted only of static frames and could not be interacted with.

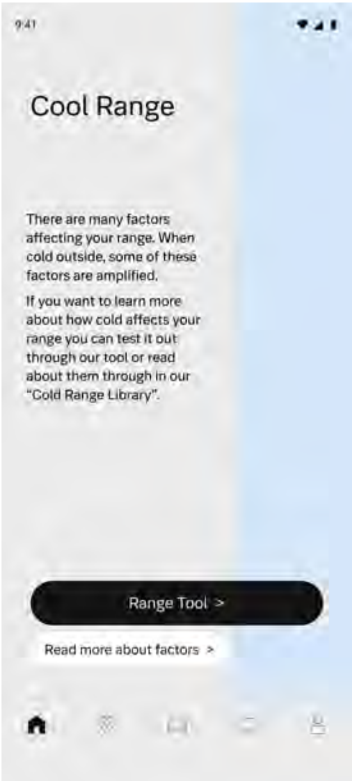
5.4.1.2 Created prototypes

The two flows are presented below. Both are placed within the Volvo Car's application according to [UR2] and consists of an interactive tool, a library with information about cold temperature factors and measures the user can take to not get as affected by the higher energy consumption. The visual design is minimalist, following [UR4], using Volvo's existing design system. For both flows, only the HVAC library page was developed to serve as a representative example. Though not created, the Locked Capacity and Speed chapters would match the design and detail of the HVAC example.

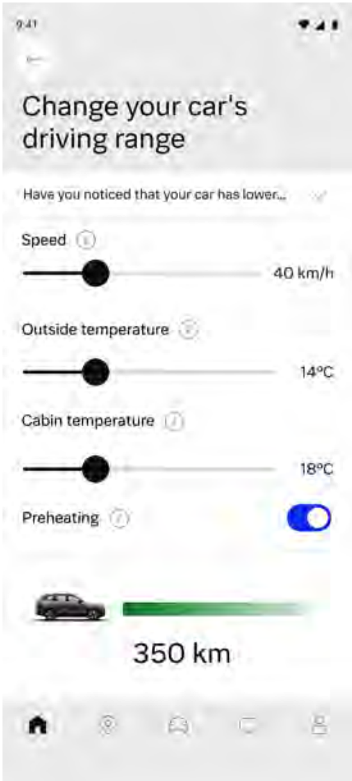
Flow 1

The first flow is the simpler concept, following user feedback about simplicity ([UR5]), and consists of only four frames: a start page, the tool, the library, and an HVAC chapter. The start page, shown in Figure 5.19a, contains an image placeholder, a title, a short description, and two action buttons for entering the tool and the library. The button for the tool is emphasized and placed hierarchically above the library button, as interview participants ([I7]) favored interactive content. The tool's interface is illustrated in Figure 5.19b. It features a collapsible description at the top, followed by four adjustable parameters: speed, outside temperature, cabin temperature, and preheating. Each parameter includes a small information icon. At the bottom of the page, an image of the user's car is displayed alongside the available driving rangevisualized in kilometers and a green bar graph to match the desire for visual content ([I8]). While this range is based on the capacity of the user's actual vehicle, the tool is strictly a simulation allowing users to manipulate factors and observe how the results change.

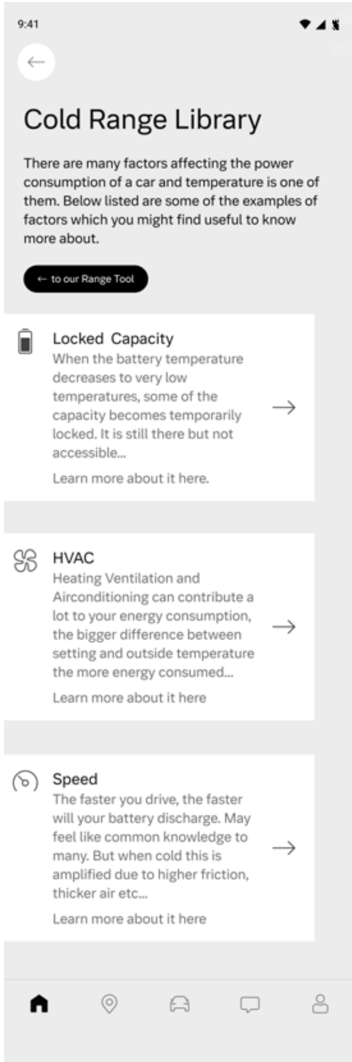
When clicking on the Read More About Factors button the user lands on the Cold Range Library (Figure 5.19c), where the three factors HVAC, Locked Capacity and Speed are introduced with an icon and a short text. The frame is scrollable to allow for short information about the three chapters, and at the top a text box with an introduction as well as a button leading the user to the tool is placed.



(a) Flow 1, start page.



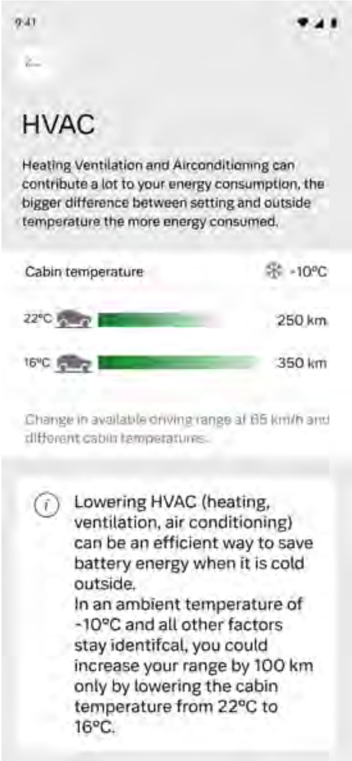
(b) Flow 1, interactive tool.



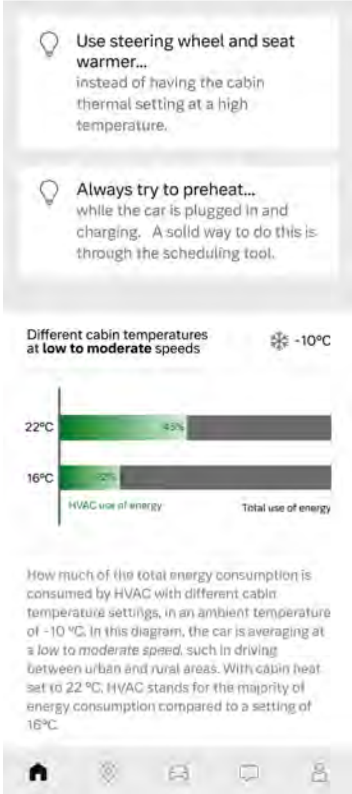
(c) Flow 1, cold range library

Figure 5.19: Three wireframes from Flow 1.

The chapters are also scrollable, as they contain more detailed information than what can be viewed in one frame. As Figure 5.20 shows, the chapter about HVAC contains descriptive graphs and texts mixed with actionable measures the user can take. Following [UR7] and [UR8] and based on user feedback from the interviews ([I8], [I9]), simple illustrations are used together with smaller blocks of text.



(a) Flow 1 HVAC first half.



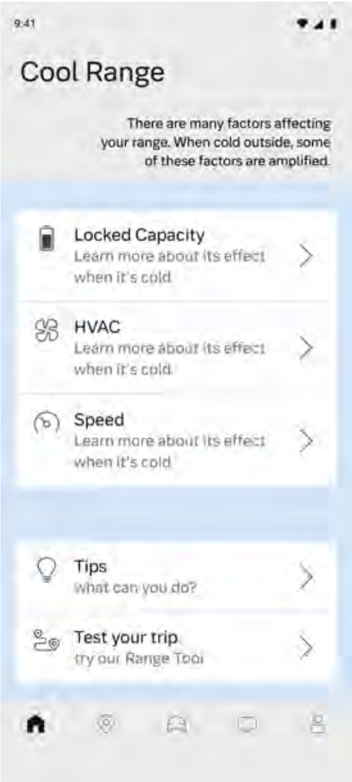
(b) Flow 1 HVAC second half.

Figure 5.20: HVAC chapter.

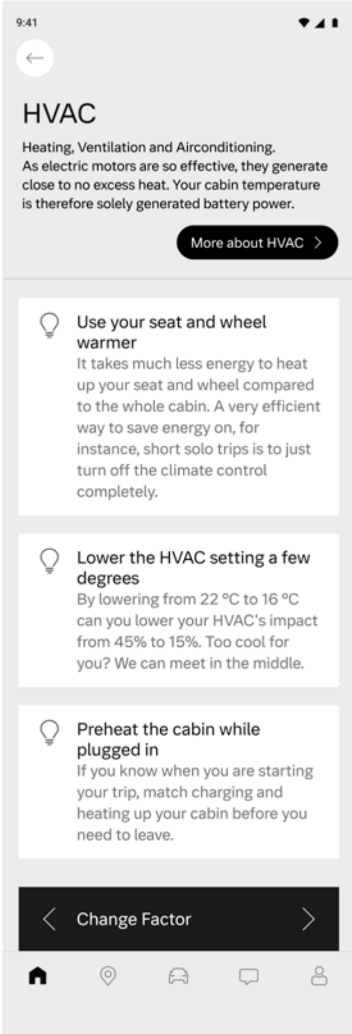
Flow 2

The second flow contains the same content but more detailed, with a clearer separation between the different parts of the concept. The start page (Figure 5.21a) contains a place holder for an image, and five buttons. At the top, the three topics are introduced directly to provide a quick overview of the available factors, matching [UR5], rather than requiring the user to enter a library first. The contents of the topics are the same as in Flow 1 for HVAC (Figure 5.20). Below the topics, buttons for the measures and the tool are placed. The measures are separated from the information in each chapter and placed in their own frame, seen in Figure 5.21b. This provided quick access to actionable measures without scrolling through information, addressing interview feedback on the importance of personally relatable information. ([I6], [I8], [I10], [UR10]). The measures are listed with a description and an icon, and at the bottom the user can change topic to view new measures by using the arrows in the Change Factor button.

The tool has its own start screen (Figure 5.21c) that gives a quick introduction to the topic and the tool itself. In contrast to the tool in Flow 1 that focuses on letting the user play around with the parameters without any real-world connection, the second tool lets the user pick an actual trip they have done or will do. This follows [UR9] and [UR10], that together with user feedback from the interviews ([I10]) state



(a) Flow 2, start page.



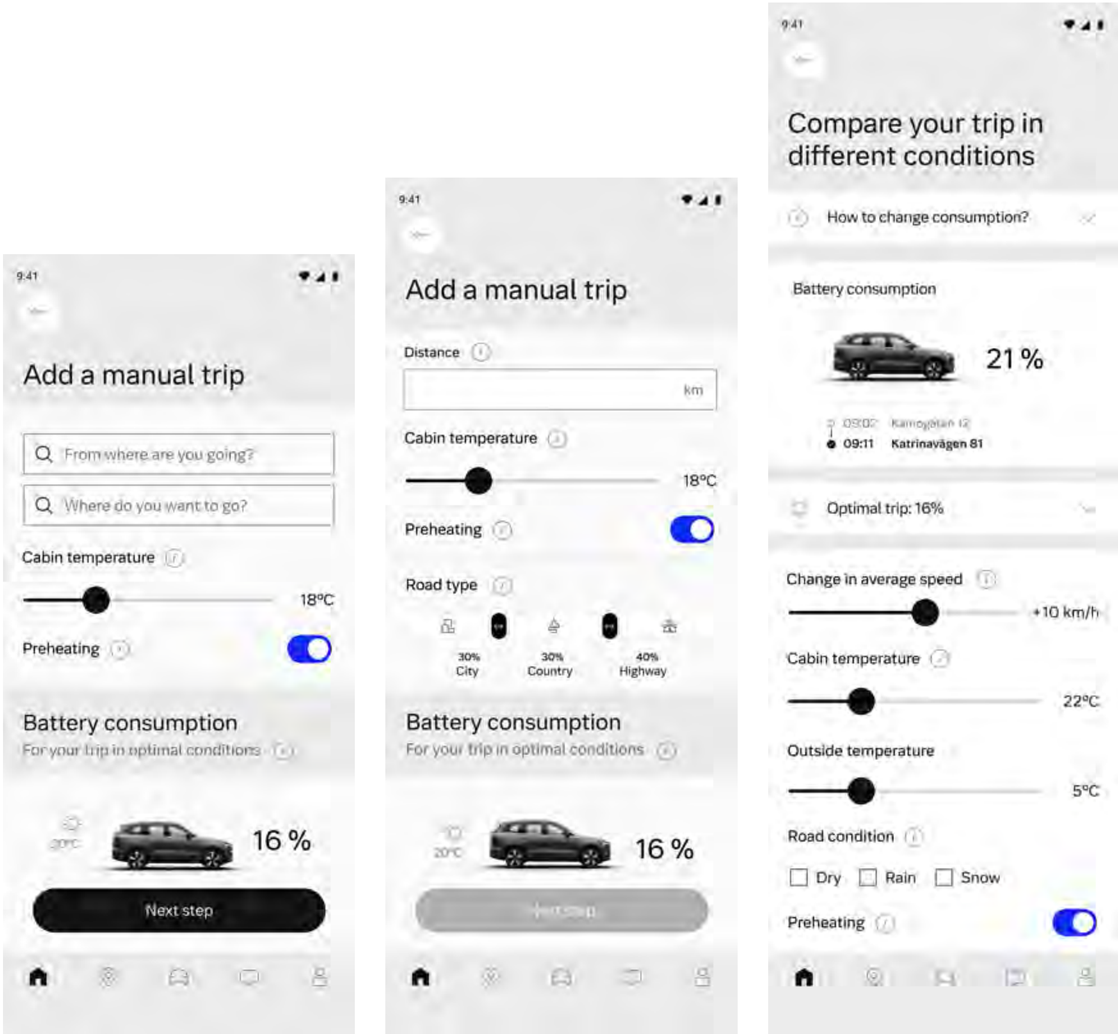
(b) Flow 2, list of measures.

(c) Flow 2, interactive tool start page: Test Your Trip!

Figure 5.21: Three wireframes from Flow 2.

that users want information that to have a real connection to real-life data. They have two options; either using logged data from trips registered in the Volvo Car's application, or to manually register a trip. By changing parameters they can see how much energy that trip would have taken in different driving conditions, such as cold temperatures and with or without preheating.

The first step in the tool is to choose the trip that will act as the *Optimal trip*, for which two options were created. The first option, as seen in Figure 5.22a, utilized the navigation tool from Google already incorporated in the Volvo Cars application to let the user input a trip, which then provides the trip details based on Google's own statistics (see Section 2.5.1 for more information). The second option, seen in Figure 5.22b instead allows the user to input the trip distance and adjust the road type with the parameter used in Volvo's Range Calculator (See Section 2.5.3) that categorized the trip into percentages of City, Country or Highway driving. From this, an average speed can be calculated. Both options contain parameter for cabin temperature and preheating, meant to symbolize the user's normal settings for the trip. At the bottom of the page, the battery consumption for the chosen trip is shown next to an image of the user's own vehicle.



(a) First step of Flow 2 tool: manual trip

(b) First step of Flow 2 tool: logged trip

(c) Second step of Flow 2 tool.

Figure 5.22: Flow 2 tool: steps and options.

Lastly, after entering their optimal trip, users move to the next frame of the tool, which is scrollable to accommodate additional parameters. This page features a collapsible information box at the top, followed by the current battery consumption displayed next to the vehicle image and the trip itinerary. Below this, a second collapsible box displays the optimal battery consumption to allow for quick comparisons. From here, users can adjust factors such as average speed, outside and cabin temperatures, road conditions, and whether preheating was used. More parameters are added compared to the tool in Flow 1, to emphasize the need for more data ([I10]). AAll factors are explained by clicking the small information icon next to them. As users manipulate these factors, the battery consumption display adjusts in real time, illustrating how cold temperatures and driving choices directly affect energy consumption and available driving range. The final screen in the tool can be found in Figure 5.22c.

5.4.2 Co-design sessions

After the two flows were defined in Figma, three co-design sessions were conducted with the aim of analyzing and gathering opinions on the low-fidelity concepts. Specifically, the sessions aimed to actively involve participants in the design process, allowing them to evaluate the two flows and suggest improvements. The aim of this process was to spot weak points in the early layouts and discover which visuals and functionality the participants preferred.

5.4.2.1 Study Design and Procedure

Prior to the co-design sessions, respondents from the second questionnaire who had expressed interest to take part in further data collections were contacted and offered to participate in the sessions. The request was also sent out to Volvo Car's internal co-development community (Co-Dev) of drivers who regularly take part in studies conducted at the company. This was done to get in contact with people with no prior experience of the project and further the inclusion of other demographics and technical levels. Both respondents from the questionnaire and the Co-Dev group were provided a Microsoft form with a schedule of available time slots, and when the time slots were filled participation was confirmed. Additionally, three Master's students in Interaction Design and Technologies at Chalmers University of Technologies were asked to participate with the intention of bringing an external design perspective to each respective session. The design students were each provided a description of the project's purpose and how BEV performance is affected by cold temperature driving to ensure a common baseline of understanding. The description can be found in Appendix D.

A semi-structured interview template was developed alongside a FigJam workspace containing the two proposed flows found in Section 5.4.1.2. The interview template is presented in Appendix E. The digital workspace was prepared with virtual post-it notes, while a physical version was printed out and arranged on-site together with physical post-it notes. One of the three sessions was conducted entirely on-site, and the remaining two followed a hybrid format with participants joining both on-site and via Microsoft Teams. During the sessions, one person acted as moderator and the other as note-taker, documenting the sessions in high detail.

The participants were asked to evaluate each flow separately and to write down their feedback on the post-it notes and place them next to the corresponding design elements, see Figure 5.23. This was done both in the digital FigJam workspace and with the post-it notes on site. After each flow had been discussed using the interview guide, the sessions concluded with collaborative flow mapping. The participants were asked to collectively create one single flow by selecting and combining the wireframes from the two initially proposed flow. This exercise was designed to identify which specific components and interaction patterns the users perceived as optimal. They were also encouraged to change details of the different wireframes to reflect their own preferences and needs. After each session was complete, participants were offered a gift card as a token of appreciation for their participation.

Figure 5.23: Co-Design Session.

5.4.2.2 Analysis

Once the co-design sessions were done, the physical post-it notes were collected and added to the FigJam workspace. The detailed notes taken during the sessions were refined and cleaned up, and the analysis process began. Once again a thematic approach was used with the KJ method to structure the data collected. The flow maps were analyzed alongside the notes by treating them as visual representations of the participants' arguments. Rather than evaluating the diagrams in isolation, the visual structures and design choices on the maps were cross-referenced with the corresponding participant quotes and observations to identify critique and conflicting preferences. The workspace is shown in Figure 5.24. First, both researchers independently reviewed the session to identify relevant quotes and annotations, without adding any interpretation. Afterwards the findings were compared and discussed. This independent and collaborative approach was done in an attempt to avoid subjective bias in the interpretation process, as touched upon in Section 5.1. Common findings were treated as confirmation that the idea was evidently present in the data, and additional findings were discussed to ensure it was actually grounded in the collected data and relevant for the analysis. This first step was done in order to minimize individual bias and improve the objectivity in the analysis. Once coded, the findings were collaboratively clustered into thematic affinity categories, generating initial insights. This iterative process was repeated for the second and third co-design sessions, adapting the categories to fit the growing dataset. Finally, the resulting themes (listed in 5.4.2.4) were reviewed and summarized into a definitive set of actionable insights.

Table 5.18: Co-design session Participants Demographics.

ID	Session	Recruitment sort	Technical Level	Gender	Age
1	1	Questionnaire	General	Man	45-54
2	1	Questionnaire	Informed	Man	55-64
3	1	Co-Dev	Informed	Man	55-64
4	1	IxD student	General	Woman	25-34
5	2	Co-Dev	Informed	Woman	45-54
6	2	Questionnaire	Expert	Man	35-44
7	2	Co-Dev	Informed	Man	55-64
8	2	IxD student	Novice	Woman	25-34
9	3	Questionnaire	Technical	Man	25-34
10	3	Questionnaire	General	Woman	45-54
11	3	IxD student	General	Woman	25-34
12	3	Questionnaire	Technical	Man	55-64
13	3	Questionnaire	Informed	Man	55-64

5.4.2.3 Participants

A total of 13 individuals participated in the three co-design sessions, of which seven were respondents from the questionnaire, three were part of the Volvo Cars internal Co-Dev group and three were Master's students in Interaction Design and Technologies at Chalmers University of Technology (IxD). Of the seven who had expressed interest to participate in the questionnaire, two had also participated in the interview data collections. Of the 13 participants, five were women and eight were men. The majority (five participants) were in the 55-64 years bracket. The majority of the participants categorized their technical level as Informed (five people) or General (four people). See the definitions of the categorization in Table 5.1. See Table 5.18 for demographic data.

5.4.2.4 Results

From the KJ-analysis (see Figure 5.24) 11 themes were identified. Three of the themes were deemed to not align with the project scope and the target group based on previous data collections. The three themes were *Preheating*, *Personal and real-time data* and *Advanced planning*, all three categories highlighting the high amount of detailed data desired by more advanced users as well as the lack of knowledge about how preheating in their vehicles work. Since similar themes had already being ruled out during the previous analysis of the interviews, it points to the topic being relevant to users even if it is not within this specific project scope. A discussion about level of data and different target groups can be found in Section 6.1.

This friction regarding data complexity and user preferences was further exposed during the collaborative flow mapping activity. The exercise revealed that participants did not share a unified perspective on how to structure the interface, resulting in contrasting outputs. Two of the groups created entirely different journeys; Group 1 mapped out a streamlined, minimalist flow with focus on connecting the tool di-

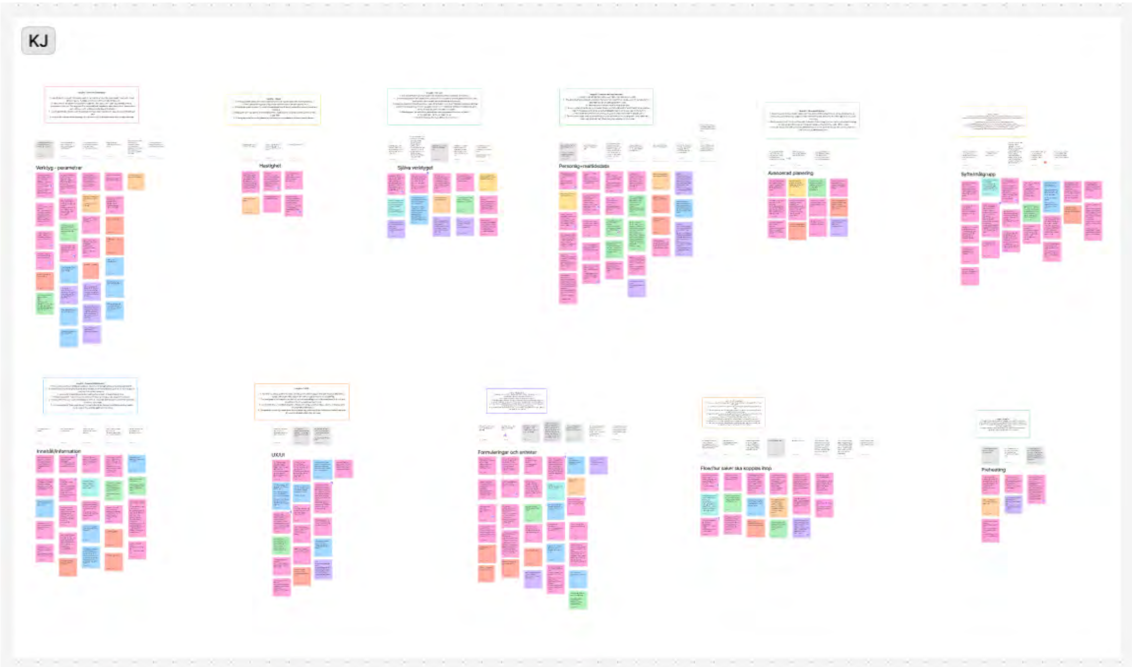
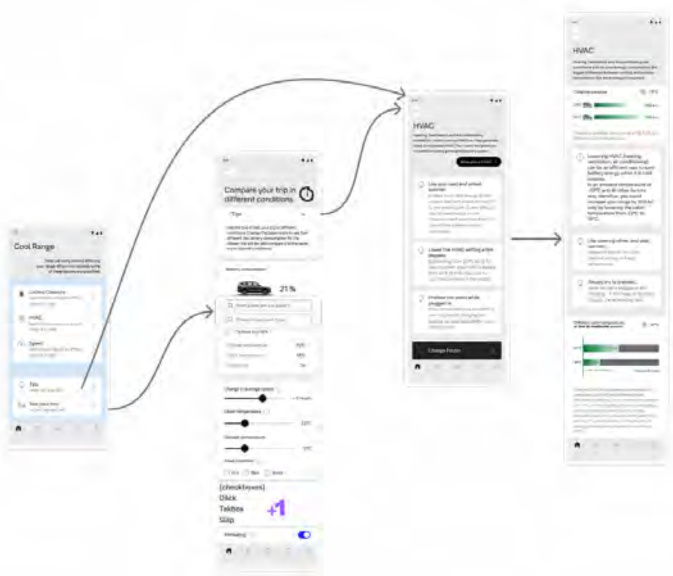


Figure 5.24: KJ-analysis of the Co-Design Sessions.

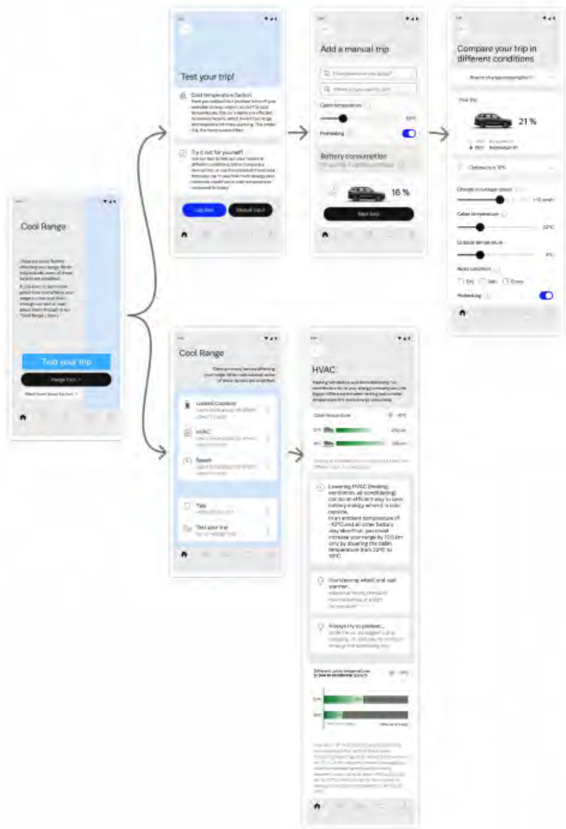
rectly to the rest of the content (see Figure 5.25a), while Group 2 designed a flow that divided the interactive tool and the static informative library into two separate sections (see Figure 5.25b). Meanwhile, the third group was unable to reach a consensus and could not complete a flow at all due to conflicting opinions on how much data should be displayed. This polarization highlights the ongoing presence of distinct user needs within the target audience.

Accounting for these insights from the flow mapping and the session notes, the final dataset was streamlined to capture the core themes of the interface. The remaining eight themes are *Purpose and target Group*, *Contents and Information*, *Flow and Connections*, *The Tool*, *Parameters*, *Speed*, *UX/UI* and *Phrasing and Units*. They are described below, together with quotes from the co-design sessions sorted into each respective theme.

CD1 - Purpose and Target Group: This theme contains insights about the perceived purpose of the concept and its intended target group, as preferences varied among the participants. See Table 5.19 for supporting quotes. In general, the tool was seen as the more significant part of the concept compared to the provided information. Although less experienced or novice users were difficult to recruit, those who participated in the co-design sessions, expressed that they saw significant value in relatable comparisons. Generally, less experienced participants saw more value in using the tool for educational purposes while more experienced participants wanted to consider more complex data. The findings suggest that if the tool is used purely for educational purposes, it will likely be dropped quickly by data-oriented users. As such, the perceived utility of the concept was considered to decrease as users' experience grew. Finally, it was deemed a good selling point for Volvo Cars to develop their own navigation tool as a as it meant saving time with settings in



(a) Group 1, a more minimalist flow suggestion with focus on reaching the tool quickly.



(b) Group 2, a flow suggestion where participants divided the contents between tool and information.

Figure 5.25: Two results from collaborative flow mappings

comparison with existing third party alternatives, considering the fact that Volvo already has access to the user's vehicle data.

Table 5.19: Quotes from the main theme *Purpose and target group*.

Participant ID	Session	Quote
6	2	"My thought is that it should be for another audience that are new to BEVs, so it should be quite simple."
7	2	"We have had a huge demand to have this and we really need it, but the question is how much will it be used in the coming generation?"
11	3	"This is just an educational tool so maybe you wouldn't need that (*Referencing a connection to the car's status*), but if it is a tool to also calculate your way then it would be useful."
5	2	"Because if you go outside the Volvo app and go to plan your trip there are heaps of different apps where you can plan and put in conditions."
3	1	"I feel that the most important thing for the end customer here is 'Test your trip'."

CD2 - Contents and Information: This main theme addresses insights regarding the contents and information in the concept. Quotes can be found in Table 5.20. Overall, the information presented in the two flows was well-received by the participants. The use of images and graphs was highly appreciated, and participants expressed a desire for more visual examples to be added with a greater emphasis throughout the interface. The overall content volume should be reduced to prioritize concise, high-impact information. As such, the information presented in the concept should be prioritized to first introduce simple and less information-dense content, while offering the possibility to read more details if the user so desires. Also, information should be presented step by step rather than all at once, allowing the users to navigate the information at their own pace. In regards to the first flow, participants considered the "Test your trip!" introduction screen to be too information-dense, and wanted it to be redesigned or excluded entirely from the flow. Similarly, for the second flow, they suggested that the information in the "Cold range library" should be reduced to minimize scrolling and allow for the possibility of adding more factors in the future. Finally, a specific piece of information that was appreciated by the participants was the measure about using seat and steering wheel warmer instead of the cabin heater to reduce energy consumption.

CD3 - Flow and Connections: This theme is about the flows and connections within the concept, with quotes found in Table 5.21. In general, the participants expressed that they wanted stronger integration between the concept's different frames and chapters. For instance, a direct connection from the tools in both the first and second flow to specific measures connected to the results of the input. Furthermore,

Table 5.20: Quotes from the main theme *Contents and information*.

Participant ID	Session	Quote
11	3	"Especially in the test your trip, I would not read all of this (see the frame in Figure 5.21c). I get the feeling that this is very serious."
3	1	"Yes, it is information overflow. How much do I need to know? How can you portion it out?"
8	2	"What about also adding a comparison graph for steering wheel and seat warmer, or preheat to show how much energy it will saved, compared with the situation not using seat warmer or preheat."
6	2	"I think this (Figure 5.20) is good but can be too much for one screen. So, it could be step by step, easy and you get more if you want it. If it is enough for you with short info and pics then you can stop there."
7	2	" But I think also a picture tells more than a lot of text. You can easily skip it because you don't need all of the information."

Table 5.21: Quotes from the main theme *Flows and connections*.

Participant ID	Session	Quote
11	3	"It depends on how you get here (*referencing the start page*). If you know where you are going to get to, then you don't need the first one. If you know then you don't need the explanations what it is."
3	1	"Absolutely, that I can agree with. Sometimes you might just want to look up tips and not do a simulation. But if you are in the simulation you might want tips without having to go back."
4	1	"It would have been great if you could add them to the tool somehow, maybe replace so that "Change consumption" to go to more tips instead, to have an info thing by the title instead.
5	2	"I think if it is possible to fit it in, if you have like Always do preheating for example, to have a link to the instructions for that."

the participants expressed that they wanted further connectivity between the concept, the rest of the Volvo Car's application and the user manual. Regarding the start page, many users appreciated entering a functional menu with options directly instead of a title page. Some participants also expressed that they preferred vertical hierarchy, prioritization the tool at the top of the start page and placing informational content at the bottom. Within the tool itself, participants suggested the possibility to pre-set conditions specific to the car, such as tire type, in advance to save time instead of manually changing the parameters every time. Finally, participants considered both flows to be unclear at times regarding layout and choice of words, and appreciated a lower number of clicks to enable more seamless exploration of the concept.

CD4 - The Tool: This main theme contains insights regarding the use of the different tools in the two flows, with quotes found in Table 5.22. The two different tools were preferred in different ways depending on how the participants perceived the context of use. A smaller number of participants favored the tool in the first flow, perceiving it primarily as a simple and educational resource. For them, the tool in the second flow was perceived as too complex and at times anxiety-inducing. Conversely, participants who preferred the tool in the second flow liked it because of the higher level of control and more data, and often related it to trip planning and/or navigation. The tool in the first flow was seen as something that would only be used a few times as one got to know the cold temperature factors, as participants felt it lacked practical application for real-life scenarios. Further insights were that both tools needed to be clarified further as participants experienced them as confusing at times. For example, the term "Optimal trip" in the tool in the second flow was difficult to understand. Finally, both the using the logged trips saved in the car and adding the trip manually were appreciated options for the tool in the second flow.

Table 5.22: Quotes from the main theme *The Tool*.

Participant ID	**Session**	**Quote**
13	3	"I prefer this (Figure 5.22b) because it's based on generic data."
11	3	"I feel there are too many options here (*Referencing the tool in Flow 2*, see Figure 5.22). Test your trip, manual or log, and then all the input. For me, I would maybe be a bit afraid to click something wrong."
12	3	"Great Function!" *(Regarding 'Add a manual trip' in Figure 5.22a.)*
4	1	"Same for me, I didn't understand that I was comparing an optimal trip with how it can be today. That way I think it is more valuable, but that was not what I understood."

CD5 - Parameters: This theme addresses the parameters included in the interactive tool. The participants in the co-design sessions expressed an interest in several additional parameters, with load calculation being the most sought after parameters to add. They wanted to know how their driving range is affected by, for example, a roof box, trailer or a fully loaded car. Other factors mentioned by users included headwind, driving with the Volvo Pilot Assist system, road type, regenerative braking, use of speakers and tire type. This suggests that users still feel they lack knowledge about how these factors affect performance, and desire further control over them. Furthermore, the participants did not appreciate having to estimate the road type themselves, as in the second option, in Flow 2 (see Figure 5.22b) due to the complexity and uncertainty of it. Instead, they preferred it to be automatically calculated using Google and the existing trip planner. Finally, using selection boxes for choosing road condition was considered sufficient and the participants did not deem it necessary to increase the complexity of that parameter. However, as more parameters are added, the tool inevitably becomes more complex. While simplicity was indicated as an important quality for both more technically advanced and novice users, a portion of the participants wanted more parameters in the tool, and as such more data. Nevertheless, an increased amount of data does not necessarily align with the intended informative purpose, as it can overwhelm the user. Quotes from the theme can be found in Table 5.23.

Table 5.23: Quotes from the main theme *Parameters*.

Participant ID	Session	Quote
12	3	"How much does a roof box affect? How much does that eat up of your charge? It's a mystery to people. I was also thinking of people that tow caravans, how much does that take from your range?"
12	3	"Pilot assist is a sort of computer heavy tool in the car, does that consume a lot of electricity? Is it good or bad to drive with it on? Sound system, the Bowers and Wilkins speakers might be heavy on the battery side."
3	1	"Add a selection box to choose if you have for example: roofbox, trailer, studless winter tires or studded tires. For example, if you have chosen winter tires it should be prechosen the next time you enter."
10	3	"I don't like the second alternative (see Figure 5.22b), the road types. For alternative two I know where I am living and I need to figure out how much is country road..."

CD6 - Speed: This smaller theme highlights the parameter speed, that is crucial to the tool as it has very big impact on energy consumption, but that appeared difficult for the participants to grasp. The term "Average Speed" was complicated to understand, both the parameter itself and the phrasing. Since driving speed changes over time during a trip, participants were confused which speed was meant as average, which lead to imprecision with manual input. When Google Navigator is used the average speed is automatically calculated, but then that needed to be made clear to the users. Additionally, changing the average speed might lead to numbers that are above the legal speed limit, even if the tool only simulates the results. Finally, an option to using average speed could be to use driving style instead, since it is already used by the car and therefore might be more relatable. Selected participant quotes can be found in Table 5.24.

Table 5.24: Quotes from the main theme *Speed*.

Participant ID	**Session**	**Quote**
12	3	"In the calculator, you choose speed. Maybe you should have driving style instead of speed. Because there is sort of a range tool already in the car, where we don't talk about speed but about driving style."
7	2	"Since you know we have Google and Gemini, I think we should in some way emphasize that because it is not obvious for everyone that the average speed is calculated by Google."
12	3	"Because I am not sure, this could be a bit sensitive as a security brand and all. In a Volvo car you can set the cruise control faster than the legal speed, you can't in a Tesla."

CD7 - UX/UI: This theme is about the UX/UI design of the interface of the two flows introduced during the co-design sessions. Quotes can be found in Table 5.25. Four main topics were pointed out during the co-design sessions. First, the participants thought that the start page should focus on emphasizing the tool. They suggested the visual design should be engaging enough to catch customer interest, and as such act as a main selling point to the users. Second, comparisons are of high importance for understanding, and need to be further emphasized and clear for users in all areas where they are used. Third, the participants preferred a simple overview of parameters in the tool as a first step, followed by an option to access more detailed information if so desired. Lastly, scrolling is not necessarily disliked by users. However, they preferred it in contexts that demand higher levels of information density. When possible, information load should be reduced in order to avoid scrolling.

CD8 - Phrasing and Units: This theme contains insights about phrasing of terms and the use of units in the concepts. Supporting quotes from the participants can be found in Table 5.26. Regarding the language used, participants agreed that the concept should avoid abbreviations, overly complicated or corporate terms for topics. For example, they suggested that 'HVAC' and 'Locked Capacity' should be renamed

Table 5.25: Quotes from the main theme *UX/UI*.

Participant ID	Session	Quote
6	2	"I would prefer less parameters per picture and then go to the next slide with new parameters."
3	1	"I don't have anything against scrolling, it is more the possibility that I want to do a basic or an advanced thing. It is a relevant choice to make."
7	2	"Maybe you should show SoC level in normal case, normal temperature etc, and then this one when it's calculated. You don't have any reference here."
6	2	"I think the first page is important because that is how you get the customers to use it."
11	3	"If I clicked on tips and ended up on HVAC, I would be like What, I clicked on tips. I would be like "Oh no I mis-clicked and then go back, and not change the factors that you can do below."

Table 5.26: Quotes from the main theme *Phrasing and Units*.

Participant ID	Session	Quote
13	3	"HVAC, it seems like some technical humbug I don't know."
12	3	"I think this is a maturity thing, if you wait 5 years people will be much more in tune and then you can add it. Going from ICE to BEV, customers, at least the average ones, are not there mentally, they have problem talking of kWh."
2	1	"If you want to simulate, it's better to know how much will be consumed, but if it's momentary you want to know how much you have left. I went wrong right away, I thought 16% and then 21%, do you have more battery left if you raise cabin temperature?"
7	2	"For me to see 16% reduced SoC, I try to understand how I can use that in my driving."
5	2	"Either you have I want to go right now from here to there, this is the condition, that means that I should see the current status. But of course, if I were to plan for next week I wouldn't know what my car would have, so on that one it would be better to say what the car would use."

to be more intuitive. Regarding units, the findings suggest that the unit used should be adapted after the purpose of the tool. Although the participants had different preferences, kilometers was deemed to be the most relatable unit for the majority of users. However, participants with higher technical knowledge and experience with kW and kWh seemed to prefer the unit in some cases. Interestingly, participants noted that, while kW and kWh might be confusing to many user now, users will likely grow accustomed to using them as BEV adoption and general increase of electrification in society continues to grow. Finally, it was highlighted that numbers and units are less meaningful to users if they aren't in relation to another number, as comparison is essential to make the data relatable.

5.4.3 Design Specifications and Synthesis

Based on the data collected from the three co-design workshops, a list of main take-aways was formed to summarize the most essential findings. The primary aim of this phase was to bridge the gap between user research and final concept implementation. By grouping these insights together, this process created a clear basis for ideation to turn user needs into direct design changes, ensuring the final concept was fully based on user feedback.

5.4.3.1 Design Synthesis

Before commencing the final ideation phase, the qualitative feedback and main insights were summarized into a single set of design specifications. This list serves as a framework and a direct baseline for the following brainstorming and prototyping sessions, outlining the direction, functional and visual updates, and terminology adjustments required for the final concept:

Target group and purpose: The concept is primarily meant for less experienced users, like new BEV drivers or those who are less interested or technical. However, to prevent limiting its long-term lifespan, it must incorporate advanced topics that extend beyond this core group. At the same time, a high demand for real-time data is unavoidable because BEV drivers as a whole are a relatively technical and interested group. Since there are already planning tools on the market filling advanced navigational wishes, that specific need is already met elsewhere. Therefore, future research is needed to look into how more accurate personal data can be used for navigation directly in the Volvo Cars application, which could then be used as a unique selling point.

Flow and connections: Cross-functional connections must be introduced between different frames and chapters, including direct links to the digital user manual for pre-heating.

Information content: The concept must remain simple and less information-dense at first impact, but allow users to access deeper data and graphs if they choose to look for it. To avoid unnecessary scrolling, frames should be minimized to fit onto a single view frame when possible. Some specific changes include:

- The contents of the library in Figure 5.19c needs to be minimized to introduce the topics in one frame without need for scrolling.
- The introduction of the tool in Flow 2 (Figure 5.21c) is too information-dense, and adds an unnecessary step.
- Chapters for Locked Capacity and Speed need to be created.

Visual design: The overall depth of information was well-received, but the delivery needs a stronger visual focus. This includes replacing text blocks with more images and graphs, updating illustrations, and utilizing a cold-representative color palette. Comparisons should be used when possible.

The tool: The tool should be the main focus of the concept, and will be structurally modeled after the second flow concept (see Figure 5.22) while maintaining a simple layout resembling the first slow. Some specific changes required include:

- The tool should be based on trips the user can add using data from Google Maps, or on previously logged trips.
- The unit used in the tool should be updated to better reflect real-life conditions that the users can easily relate to.
- Parameters should be categorized into standard settings and advanced, optional features to avoid overwhelming the user.
- Clear reference points and indicators should be added on each slider to show exactly where the reference condition sits.
- The illustration showing the result of manipulating the tool needs to be updated to be more relatable and to more transparently reflect the usage of the tool.
- Several topics in the tool need to be clearly defined, for example, explicitly explaining how data from Google is utilized.

The start page: The start page needs to act as a selling point by giving an overview of the contents and prioritizing its content according to feedback, with the tool being placed at the top in a vertical hierarchy.

Phrasing and terminology: To ensure a relatable, real-life connection rather than an overly technical tone, the following labeling updates must be implemented across the interface:

- Rename HVAC to *Climate Control* and Locked Capacity to *Energy Limited by Cold*.
- Change the overall concept title to *Winter Range Lab* and the tool's title from Test Your Trip to *Test Your Consumption*.
- Change the term Optimal Trip to *Reference Trip*.
- Change Average Speed to *Change in trip average speed* and add a descriptive tool-tip box for added context.

5.4.4 Main Takeaways, Co-design sessions

It became evident that the connectivity to the own vehicle was a valuable aspect and even at times referred to as a selling point of the concept. Regarding simplicity, this was still considered an important quality as well as using less technical terms. While some users advocated for the more advanced parameters, as well as bringing up examples of parameters which they wished to see, they acknowledged there being a conflict with keeping the tool and the information short and less overwhelming. Similarly to after the interviews, findings during the Co-design sessions were categorized and summarized into a total of eight themes.

5.5 Final Concept

After the Co-Design Sessions and the following analysis were done, the design synthesis were used to iterate the low fidelity design concepts. The aim was to iterate the initial designs so that they better matched how users actually want to see information about driving in cold temperatures. This process aimed to ensure that the final concept was directly shaped by the insights gathered during the co-design sessions.

5.5.1 Prototyping Process

The feedback from the Co-Design Sessions were used together with the user personas to iterate the two flows. Two rounds of brainstorming focused on the functionality of the concept were conducted where the two flows were combined to one, as seen in Figure 5.26. Subsequently, the ideas were evaluated based on the established list of user requirements (see Section 5.3.5 and the design synthesis. This was followed by a session of brainstorming conducted for each core element in the concept, for example the tool, and after final decisions about functionality and design had been made paper wireframes were created.

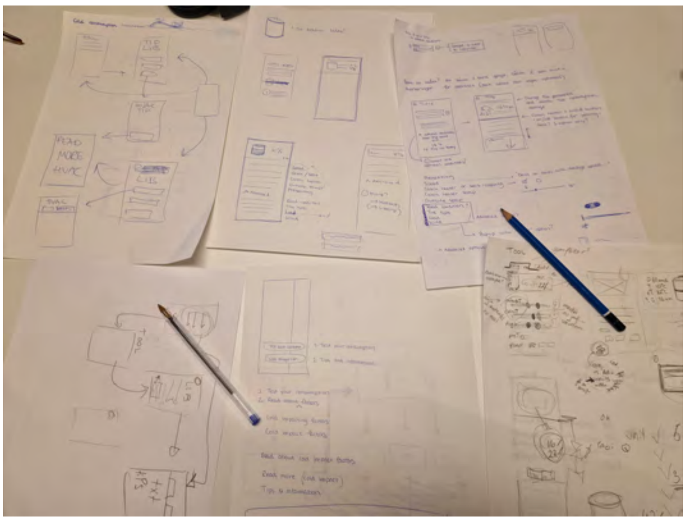
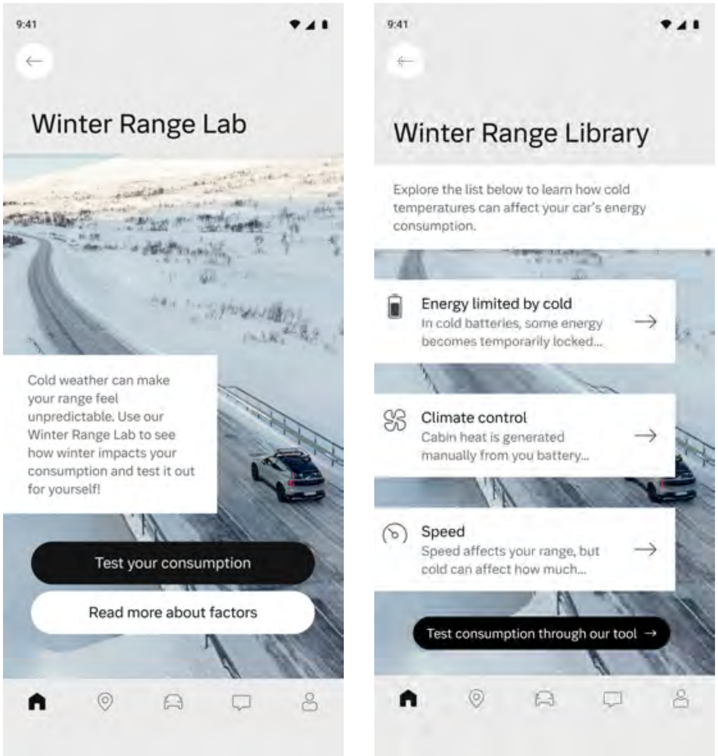


Figure 5.26: Photograph of ideation for the final concept.

After the brainstorming had concluded, the paper wireframes were build in Figma using the same existing design system as the two original flows. The frames were still non-interactive, but this time build with a higher level of fidelity, utilizing pictures, color schemes and more detailing. The core elements created were the same as the flows shown in Section 5.4.1, but chapters in the library for the two remaining topics (Climate Control and Speed) were also created.

5.5.2 Created Concept

The final concept was named *Winter Range Lab*, and just as *Flow 1* and *Flow 2* it consisted of a start page, a library titled *Winter Range Library* and a tool. The UI design of the concept adopts Volvo Cars minimalist aesthetic, directly reflecting user feedback regarding visual design from both Interviews and Co-Design Sessions, while meeting user requirement [**UR4**].

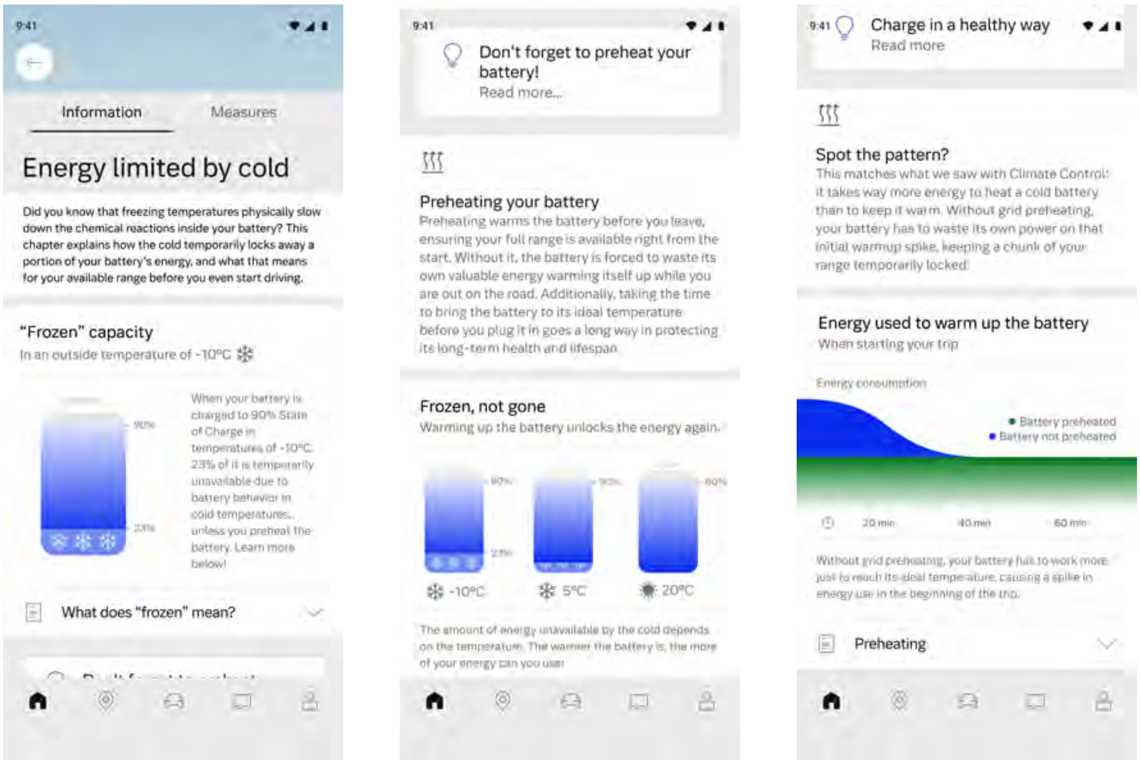


(a) Final prototype of the start page

(b) Final prototype of the library

Figure 5.27: Final prototype interface screens. Background photograph courtesy of Volvo Cars [111], used with permission.

The start page, Figure 5.27a, has the new title *Winter Range Lab*. It stems from the start page in Flow 1 (see Figure 5.19a), but contains a box with shorter information and two buttons called "Test Your Consumption" and "Read More About Factors". As established by the main themes of *UX/UI* ([CD7]) and *Flow and Connections* ([CD3]), the start page was redesigned by integrating a background hero photograph and emphasizing the interactive tool to better optimize user engagement (see quote



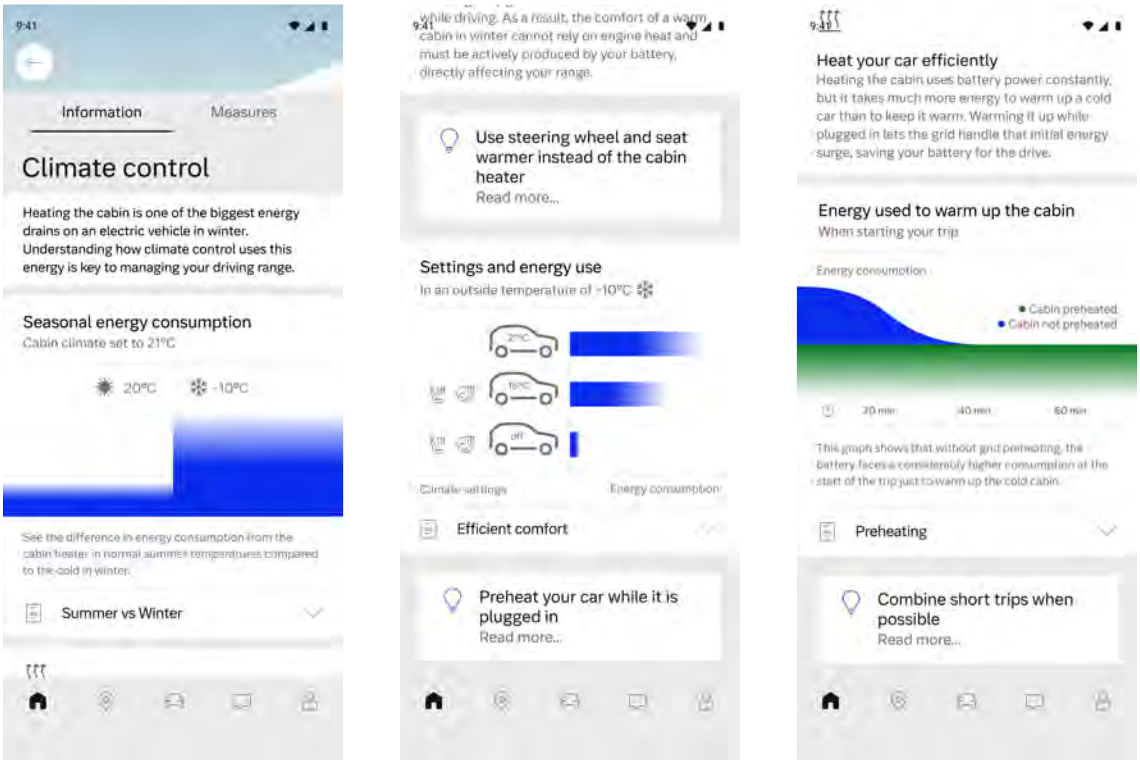
(a) First scroll section. (b) Second scroll section. (c) Third scroll section.

Figure 5.28: Final prototype of the chapter about Energy Limited by the Cold.

[6:2] in Table 5.25).

The library, visualized in Figure 5.27b, follows the same design language as the start page and uses the same background hero photograph. While it is based on the library from Flow 1 (see Figure 5.19c), it has been compressed to fit onto a single screen to eliminate the need for scrolling. This layout choice was made to satisfy user requirement **[UR5]** and is directly based on user feedback from the *Content and Information* ([CD2]) and *UX/UI* ([CD7]) themes in Section 5.4.2.4. In those sessions, participants noted that scrolling should be saved for contexts that actually demand higher levels of information density (see representative quote [3:1] in Table 5.25). The topics HVAC and Locked Capacity have been renamed *Climate Control* and *Energy Limited by Cold* to avoid overly technical language and better reflect the real-life connection that users desire. This change is directly based on the main theme *Phrasing and Units* ([CD8]) from the Co-Design Sessions (see Table 5.26 for representative quotes), where participants expressed a preference for more intuitive terms. A button to the tool is added for a better flow between the different sections of the concept.

The first of the three topics introduced in the final concept is *Energy limited by cold*, former Locked Capacity, and is presented in Figure 5.28. The chapters are all scrollable, following the feedback from [CD7] where participants stated scrolling should be used for content with higher information density.

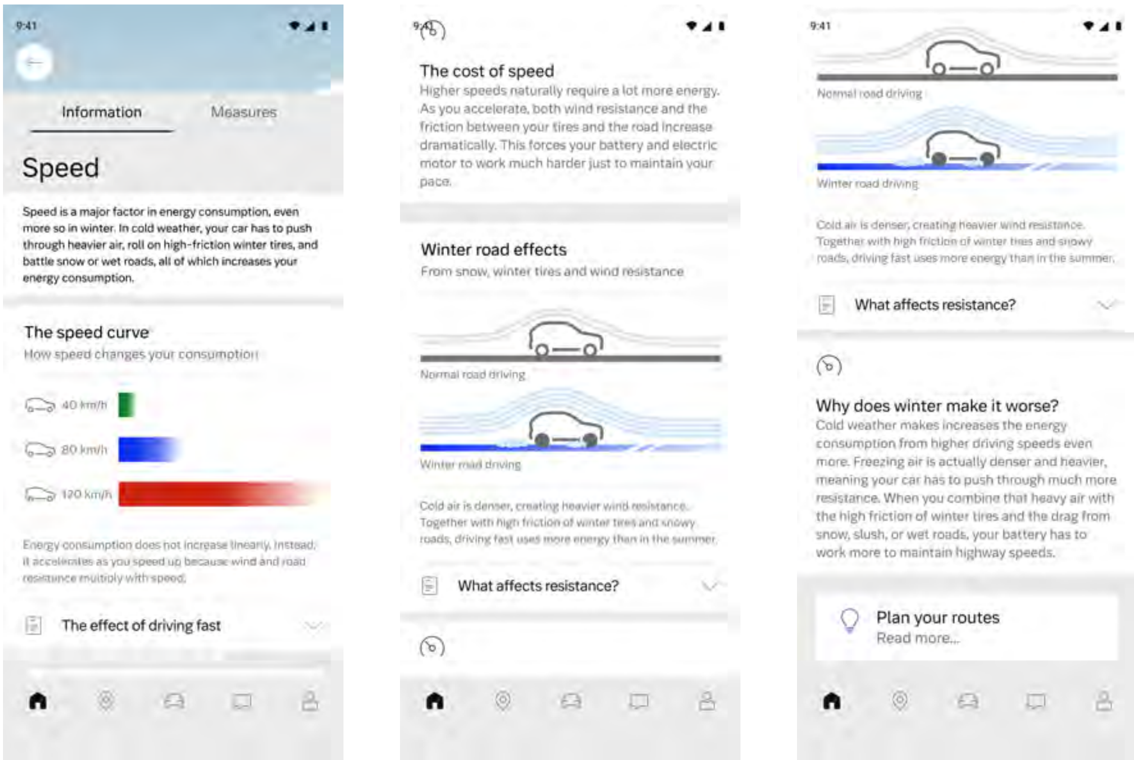


(a) First scroll section. (b) Second scroll section. (c) Third scroll section.

Figure 5.29: Final prototype of the chapter about Climate Control.

All chapters have been divided into an introductory text, illustrations, blocks of texts and measures, to structure and simplify the layout. As [UR5] states, users want to be introduced to the topics easily at first, with the possibility of reading more. Therefore, each illustration is explained with a collapsable textbox, and each measure is clickable with more information. Following [CD3], from the measure about preheating the user can reach the user manual to read more about how preheating works.

The next chapter is *Climate Control*, formerly HVAC. This chapter can be seen in Figure 5.29. The three chapters share a consistent design framework based on the same underlying principles. A primary design choice across all chapters directly addresses [UR7] and [UR8], which emphasize prioritizing simple illustrations over dense blocks of text. Consequently, minimalist illustrations were created using Volvo's Figma design library to visually communicate topics within each chapter. While based on commonly known graphs, the illustrations have been simplified by removing all numbers and units apart from the setting parameters. In accordance with [CD7] and [CD8], this design choice makes the data more relatable by allowing users to focus on conceptual comparisons rather than absolute numbers. However, all illustrations are directly based on the conducted literature review to make sure the provided information is accurate and trustworthy. For the graphs requiring relative scaling, numerical values are used from [31] for the Speed chapter, [32] and [112] for the Energy Limited by Cold chapter, and [66] and [113] for the Climate Control chapter.



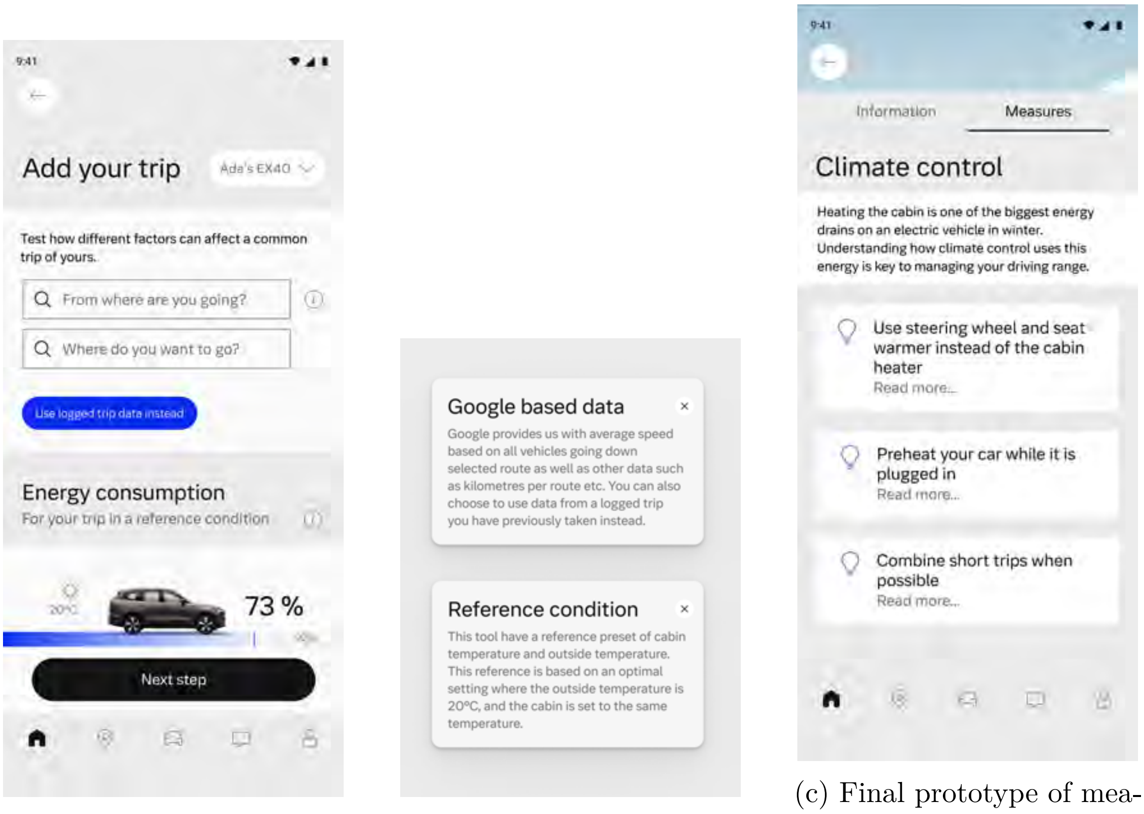
(a) First scroll section. (b) Second scroll section. (c) Third scroll section.

Figure 5.30: Final prototype of the chapter about Speed.

Finally, the third chapter introduces the topic of *Speed* (see Figure 5.30). Following the same design principles as the first two chapters, it contains illustrations, smaller blocks of texts, and actionable measures. The illustrations across all chapters have been designed using the preexisting colors in the Volvo design library, utilizing a bright blue as the main color to represent cold temperatures. As mentioned in [I8], the use of color is important, and therefore secondary colors of green and red have been added to specific illustrations to symbolize positive and negative effects.

Lastly, users can at the top of each chapter change to only show the actionable measures of that specific chapter, see Figure 5.31c. This is to give them quick access to actionable measures instead of having to scroll through the informational content in each chapter.

The tool is the core element of the concept, and has been designed to meet user requirements [UR6], [UR8], [UR9] and [UR10]. In order to give the tool a real-life connecting while simultaneously focusing on the primary education purpose, it is based on the tool from Flow 2 (see Figure 5.22). The interface is split into two steps to keep the layout simple and avoid overcomplicating the user experience, as participants pointed out in the Co-Design Sessions (see quotes in Table 5.25) The first step, Figure 5.31a, lets the user add a manual trip using Google, or use their logged trip data. This function was appreciated by participants in the Co-Design Sessions, as reflected in the main themes *Parameters* ([CD5]) and *The Tool* ([CD4]) in Section 5.4.2.4, as it provided a real-life connection and automatically calculated trip data. Based on the latter main theme, the phrase Optimal Condition has been changed to *Reference Condition* (see representative quote [4:1] in Table 5.22). The need for clarification has been met by adding two tooltips explaining the use of Google data and the meaning of a reference condition, as seen in Figure 5.31b.



(a) First step of the final tool.

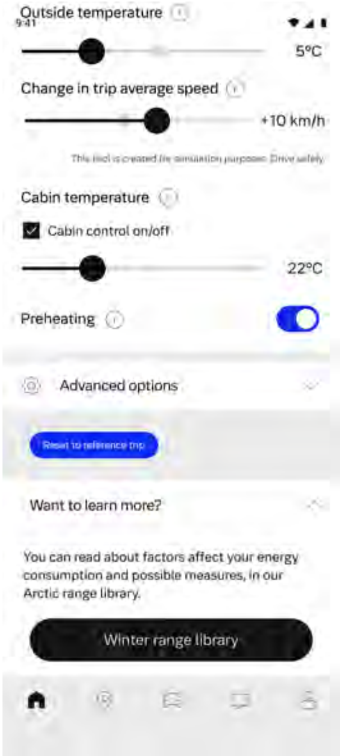
(b) Interactive tooltips for the first step of the tool.

(c) Final prototype of measures for the Climate Control chapter.

Figure 5.31: Final prototype of the tool, first step.

The second step of the tool, Figure 5.32, contains the parameters the user can manipulate to watch the energy consumption change. The tool displays the remaining charge left in the battery after the chosen trip, using a visualization based on the existing Volvo design system. This visualization, as seen in Figure 5.32a, updates dynamically as the user manipulates the parameters, indicating the remaining SoC compared to the reference condition indicated in the first step. The illustration shows the remaining SoC instead of the consumption for the specific trip, as the tools in Flow 1 and 2 did, in order to meet the user feedback specified in the main theme *Phrasing and Units* ([CD8]) of adapting the unit to the purpose of the tool. As the available driving range depends heavily on the user's specific vehicle and very recent driving data, the percentage of remaining SoC was chosen instead. This was done because it reflects a relatable, real-life condition without providing a specific range number that the user might rely on too heavily. Especially since that data may not always be completely accurate or trustworthy. In the first step of the tool, shown in Figure 5.31a, a miniature version of this illustration is placed at the bottom of the screen to show the user the result of the reference condition before they move on to the next step.

(a) Upper section of the interface.



(b) Lower section of the interface.

(c) Tool advanced options.

Figure 5.32: Final prototype of the tool, second step.

The step is divided into two sections, one of which isolates advanced, optional settings to keep them out of the primary view (see Figure 5.32c). This layout choice captures the needs of more technically advanced users, which was pointed out in the main themes *Purpose and Target Group* ([CD1]) and *The Tool* ([CD4]) (see representative quotes [6:2] in Table 5.19, [11:3] in Table 5.22 and [3:1] in Table 5.25), while still maintaining the primary focus on the general target group. Several parameters have been added to this advanced section, based on feedback in the main theme *Parameters* ([CD5]). As stated in [UR9] and [UR10], comparisons were of utmost importance to the user. Therefore, indicators have been placed on each slider to show exactly where the reference condition sits. At the bottom of the page, a button to reset all parameters to the reference condition has been added, to give the user a quick reset to the starting point.

Based on feedback summarized in the main theme *Speed* ([CD6]) in Section 5.4.2.4, Average speed was renamed to *Change in trip average speed* to emphasize the average speed of the entire trip. While the parameter was kept in the tool due to the large effect higher speeds have on consumption, a small warning text explicitly advising the user to drive safely was added. This safety aspect is further emphasized in the parameter's tooltip, where the variable is also explained in greater detail. Each parameter has an added tooltip next to the title to provide information to the user as well as further connections between the different sections of the concept. See

Figure 5.33 for all tooltips added in the second step of the tool. This was done to meet the user feedback stated in the main theme *Flow and Connections* ([CD3]) in Section 5.4.2.4. By adding the connections, the user who wants to know more about the topic of a specific tool can go directly to the library to find more information. A connection leading directly to the library is also added at the bottom of the tool, so that the user can connect the results of manipulating the tool to the background information.

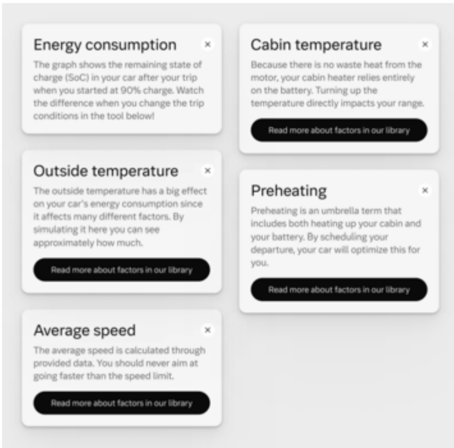


Figure 5.33: Interactive tooltips for the second step of the tool.

5.6 Design Recommendations

The insights gathered up to this point, consisting of findings from literature and the results and user feedback from the Exploratory Pre-Study, the Communication Survey, the Interviews and the Co-Design Sessions, have been summarized into eight design recommendations presented in this section. The recommendations are suggestions for the design of a mobile educational concept for BEV drivers, with the aim of translate the empirical findings into actionable guidelines. The list is presented in Table 5.27 together with an overview of each recommendation and the sources from which it was derived.

Table 5.27: Design Recommendations.

ID	Design Recommendation	Description	Source
1	Duality of beginner and advanced utility	Core features should target the needs of novice drivers while incorporating more advanced attributes for long-term utility. This ensures the concept serves beginners immediately without becoming obsolete as their user knowledge deepens.	[UR1], [I1], [I4], [CD1], [50]

Table 5.27: Design Recommendations (Continued).

ID	Design Recommendation	Description	Source
2	Mobile integration and vehicle connectivity	Deploy the content within a smartphone application instead of a webpage to ensure effortless access at any time, as well as facilitate a direct connection to the vehicle.	[UR2], Fig. 5.9, [I1], [I2], [I3], [CD1], [45], [48]
3	Contextual and early onboarding	Allow the users to access the information from the very beginning of the onboarding process when buying a BEV.	[UR3], Fig. 5.6, [I4], [CD1], [59], [76]
4	Multi-layered information architecture	Provide less information-dense content at first glance, while allowing users to click through to advanced data and parameters for deeper technical insight.	[UR4], [UR5], [I6], [I9], [CD2], [CD7], [45]
5	Actionable and relatable guidance	Frame all content and information around the user's daily driving context, prioritizing practical measures and clear insights they can easily apply to their own trips.	[UR6], [UR9], [UR10], [I5], [I7], [I10], [CD1], [CD2], [CD4], [CD8], [45], [48]
6	Emphasize visual communication over text	Dense text should be limited and information should be communicated with intuitive illustrations and other visual indicators when possible.	[UR7], [UR8], Fig. 5.7, [I8], [CD2], [CD7], [48]

Table 5.27: Design Recommendations (Continued).

ID	Design Recommendation	Description	Source
7	Incorporate interactive elements	Provide the users with interactive features to allow them to create a stronger connection to how their driving impacts vehicle performance.	[UR6], [I7], [CD1], [CD4], [CD5], [CD6], [CD7]
8	Clear, non-technical terminology	Utilize clear, non-technical phrasing and parameters to make the content highly intuitive for everyday drivers.	[UR9], [I5], [CD6], [CD8], [45], [48], [72]

R1: Duality of beginner and advanced utility.
[UR1] highlights the target group as less experienced drivers, for which the content should be adapted by providing educational content early on in the ownership process ([I1], [I4]). In order to engage more novice BEV drivers, an educational concept must be simple enough for absolute beginners or non-technical drivers, but not be oversimplified to the point of becoming boring over time ([CD1]). If the content is limited, users will stop using it over time. As such, the system should to support layered content, accommodating both immediate, high-level summaries for new drivers and more advanced options for more technical users. This can help the interface match the user's growing experience, keeping data-oriented users interested over time while still being easy for beginners to understand, including a broader spectrum of primary and possibly secondary stakeholders [50].

R2: Mobile integration and vehicle connectivity.
To maximize easy access and relevance, both relevant factors within interaction and user design [45], [48], the educational content should be located within a mobile application. This approach aligns with [UR2], which emphasizes the importance of delivering cold-weather performance insights directly through the vehicle's dedicated app. Utilizing the app connected to the car is preferred over other media, such as a website (Figure 5.9), because the application serves as the most convenient medium for accessing information on demand and the threshold of accessing an external website is too high ([I2]). The content must be seamlessly integrated into the existing application structure to provide immediate value ([I3]). The application also provides a direct connection to the user's own vehicle, which creates the possibility of accessing relatable, personal data to help users better understand the information provided ([I1], [CD1]).

R3: Contextual and early onboarding.
Information regarding cold weather performance should be available from the very beginning of the user's experience, starting right at the vehicle purchase or onboarding phase (Figure 5.6). Users felt more trust towards their vehicle when they were given more information about it, and wanted it in relation to or before accessing their BEV ([I4]). Inexperienced drivers want to know how their vehicle is affected by cold temperatures and what they can do themselves to mitigate it ([CD1]), which is reflected in [UR3]. Concerns about BEV behavior and funcionality, and its implications on range lead to more range anxiety in BEV adoption [59]. Early access to this information helps drivers create more accurate mental models of how winter conditions impact their vehicle, which have a positive effect on performance [76]. By understanding these effects from the start, users can make better driving decisions and optimize overall vehicle performance.

R4: Multi-layered information architecture.
To prevent the interface from becoming overwhelming, the information presented should be structured to first introduce simple and less information-dense content, while offering the possibility to read more details if the user so desires ([CD2]), as desirability is also mentioned as an important factor [45]. This approach balances the split mindset between users who want as much information as possible and those who prefer a minimalist layout ([I6]). Specifically, dense texts must be phrased short and concise to meet the needs of novice users, avoiding an overwhelming initial experience. To balance this with the needs of more experienced drivers, the architecture should allow for deeper insights to be accessed by the users who want them ([I9]), which is mentioned in [UR5]. The visual design should meet this recommendation by following a minimalist aesthetic ([I6]) and provide divisions between fundamental and advanced options ([CD7], which is reflected in [UR4].

R5: Actionable and relatable guidance.
To ensure the concept provides clear value, [45], all content and information should be framed with practical connection to real world driving ([I5]). The interface should prioritize practical measures and clear insights that drivers can easily apply to their own trips. This also aligns to one of Nielsen's heuristic points, "User control and freedom" [48]. Specific everyday measures, such as using the seat and steering wheel warmer instead of the cabin heater to reduce energy consumption, were highly appreciated by participants and should be highlighted ([CD2]). Drivers reported comparisons and practical connections being important for them to understand the information provided. Access to more data points and relatable comparisons give context to the actual impact on their driving performance, and provide a stronger sense of control ([I10], [CD1], [CD8]). Interactive parameters demonstrate a clear demonstrate clear cause-and-effect relationships and provide a stronger sense of control that give context to the actual impact on their driving performance ([I7], [CD4]). This design recommendation is related to [UR10] mentioning that measures need to be tied to real-world driving, as well as in [UR6] and [UR9].

R6: Emphasize visual communication over text.
The use of images and graphs is highly appreciated by users, and visual examples should be emphasized throughout the concept ([CD2], Figure 5.7). As such, the

interface should minimize text-heavy descriptions to improve information retention, as mentioned in [UR7]. By replacing long blocks of explanation with direct visual data, the tool makes it easier for users to quickly grasp key insights at a glance without feeling overwhelmed. Both technically knowledgeable and novice drivers prefer simple visualizations ([I8]), and as such complex data and vehicle states should be communicated when possible through intuitive illustrations, graphs, icons, and dynamic visual indicators ([UR8]). Furthermore, integrating these visual elements alongside specific parameters helps drivers instantly make comparisons between different factors, facilitating understanding of their actions ([CD7]), as well as aligning the system with real-world imagery [48].

R7: Incorporate interactive elements.
Instead of relying entirely on static reading material, it is recommended to incorporate interactive features into the design, which is mentioned in [UR6]. Allowing users to manipulate parameters on their own terms gives them a sense of control ([I7]) and makes comparisons and relationships clearer. An interactive tool was seen as the significant part of an educative concept, with information in text being complementary ([CD1], [CD7]). By adding more parameters into an interactive tool, the learning experience becomes much more engaging, as users can playfully experiment with different factors. Through this active exploration, users can gain more knowledge of how these factors affect performance and learn how to act to mitigate them. However, the tool should not be overly complicated. Clarity and focus on providing educational content should be emphasized to avoid overwhelming the users ([CD4],[CD5], [CD6]).

R8: Clear, non-technical terminology.
As [UR9] summarizes, an educational concepts need to translate the technical data into units that makes sense to a non-technical BEV driver, both connecting system to real-world [48] as well as making the information more accessible [45]. Overly technical terms have no practical real-life connection for the users and should be avoided ([I5]). Additionally, abbreviations, overly complicated or corporate terms for topics also adds confusion, and more intuitive terminology for novice users should be implemented ([CD8]). It is more effective to use data explaining the reasons behind consumption ([72]). This applies both to text information and an interactive tool, where users need to understand the factors that they are manipulating ([CD6]). One example is that "Average Speed" was difficult to interpret, which ultimately decreased the users' motivation to engage with the tool. The same thinking applies to the numerical units used, where relatable units should be prioritized ([CD8]).

6
Discussion

Following chapter will discuss different aspects regarding the thesis, starting with findings regarding the final results in relation to the research questions. The execution of the research with connected theories is covered, followed by a discussion about ethical considerations regarding the thesis. Finally, the chapter ends with identified future work and limitations related to the project.

6.1 Result

The aim of this master's thesis was to identify the factors affecting BEV driving in cold temperatures, focusing on how to educate drivers about their effects and what they can do to mitigate them. In addition, the research investigated through which digital medium this information could be delivered most efficiently and trustworthily. While previous research has heavily focused on how to mitigate range anxiety itself, this study shifts the focus toward the educational aspect of directly informing drivers about cold temperature variables. By addressing both the necessary content and the delivery method, the study aims to make teach drivers how they can efficiently manage their vehicle in cold temperatures with lower rates of range anxiety. The final results informed the development of a mobile interface concept and eight design recommendations, which together aim to answer the initial research questions and provide a framework for future driver education tools. The research questions are:

RQ1: *What specific knowledge do BEV drivers require to make informed decisions regarding both pre-trip planning and real-time energy management in cold temperatures?*

and

RQ2: *Through what interaction medium can this information be communicated as trustworthy and actionable advice to drivers with varying technical literacy in cold temperatures?*

Findings in relation to the research questions
RQ1 was adressed through the development of both the final concept and the accompanying design recommendations, which focused on identifying what level of knowledge is necessary for BEV drivers to make more informed decisions in cold temperatures. As the project progressed, the focus shifted from BEV drivers in general towards more novice drivers specifically. The findings suggested that BEV

drivers do not necessarily require a deep technical understanding of battery systems, but rather accessible explanations of key phenomena affecting winter range, such as HVAC demands, speed-related consumption and temporarily limited capacity in cold batteries. The concept therefore prioritized foundational understanding and actionable guidance over detailed technical information.

While the topic itself can be explored at significantly greater depth, the project identified a need to balance informational depth and access for for drivers with varying technical levels. The research question itself asked what knowledge drivers "require", which could be interpreted from multiple perspectives. During interviews and workshops, several participants expressed interest in having access to more detailed vehicle data and parameters. However, when presented with the educational content, some participants instead expressed that the content would have been valuable for them when they first started driving BEV. This suggests a distinction between information users desire over time and information that is required to establish an initial understanding of winter-related range and behavior.

Another aspect which evolved throughout the project was the role of the concept in relation to trip-planning. At later stages of the project, the project group decided to move away from the planning aspect as several existing solutions already fulfill that purpose effectively. Although participants expressed that more advanced planning functionality could be appreciated within the vehicle's application, this was increasingly viewed as a separate tool from the educational purpose explored. The final concept's tool and informational chapters may support drivers in making informed decisions before and during their trips, but it is not intended to actively plan the trip for them. Instead, the concept aims to increase awareness of additional considerations related to cold temperatures, which may in turn help users to adapt their behavior independently. Either by planning an additional charging stop along the way or making use of existing, advanced route-planning tools.

RQ2 was addressed by exploring how this information could be communicated in a way perceived as both trustworthy and intuitive. From an early stage of the project, the vehicles mobile application was considered a suitable medium due to its close relation to the vehicle while still allowing users to engage with the information outside of driving. Throughout the design process, the project group therefore explored how educational content, visualizations and practical recommendations could be presented in an interface that supports understanding without overwhelming the user. The resulting concept emphasizes simplified, visual communication, contextual explanations and actionable measures intended to support drivers.

As the mobile application was pointed out by users early in the process, alternative mediums were not explored beyond discussions at the interview stage. No comparative prototypes were developed, as participants generally did not perceive this a suitable option. Arguments in favor of placing the concept externally from the vehicle's application were primarily connected to comparative purposes, between different cars, rather than educational support intended to help drivers understand and manage their own car, in cold temperatures. Consequently, the suitability of the medium became closely tied to the intended purpose of the concept. For the educational purpose explored, the vehicle's mobile application was considered the most intuitive and trustworthy option, particularly as it has access to the driver's own vehicle data, aligning with design recommendation [R5].

Design recommendations in relation to User Experience
The final result consists of a list of Design recommendations and a wireframe concept designed based on user feedback and requirements. The eight Design recommendations address several of the aspects of UX-design [45] to enhance driver's experiences of BEV winter driving. Since the Design recommendations are based on user feedback from the four data collections, it has aided in the fulfillment of several of these factors. The purpose of the Design recommendations is to create a product that is Useful for the users, as it is supposed to mitigate the problem of anxiety-inducing winter driving by providing drivers with clear, actionable advice. By offering this information when the user desires, the concept can provide value when the driver needs it. The wireframe concept and Design recommendations are based on the gathered participant feedback, aiming to support usability by shaping the proposed layout with expressed user preferences. Finally, an effort was made to support the perceived credibility of the concept by prioritizing relatable and actionable content, aiming to minimize complex technical language that may be difficult for novice users to interpret, according to design recommendations [R5] and [R8].

However, since the project lacks investigation in the specific architecture required to incorporate the concept in the Volvo Cars application, it's Findability is difficult to determine. In order to further fulfill that aspect, the concept needs to be integrated within an application and further user testing needs to be conducted. While the final concept and design recommendations are based on user feedback, no formal evaluation of the final wireframes has been conducted. Therefore, the product's internal Findability as well as whether it is Accessible and Desirable cannot be fully determined and further, interactive testing needs to be done. Intents have been made to ensure its Desirablity by utilizing Volvo's design language, however its true appeal can be validated through an interactive visual design with even higher fidelity, and interactive user testing. Finally, the product's Valuability for the user is answered by the Design recommendations, but further investigation into how this brings value to Volvo needs to be conducted.

It should be noted, however, that the Design recommendations do not prescribe a singular method for constructing the user experience. The wireframes of the final concept illustrate only one potential implementation of these guidelines. Consequently, numerous design variations could successfully meet the proposed recommendations and satisfy the factors of UX design in different ways.

Critical aspect and Designing for Reduced Dependency
An additional aspect reflected upon during the project was that the concept was not intended to become permanently relied upon as a tool, but rather a form of transitional support for drivers who are unfamiliar with how cold temperatures affect BEV behavior. In this sense, the concept became designed with the intention of gradually becoming less necessary over time, as users develop their own understanding and experience. Rather than continuously providing increasingly advanced information,

the concept's purpose is to support the development of foundational mental models that drivers can later apply independently in everyday situations. This perspective also relates to a broader transition towards BEV adoption, as they move along diffusion of innovation curve [1]. Several of the behaviors and considerations currently perceived as unfamiliar or uncertain may become increasingly normalized as public understanding matures. Similar to how certain behaviors related to ICE vehicles are often understood through general driving experience rather than active learning, aspects of winter-related BEV behavior may eventually become part of common driving knowledge. From this perspective, the concept can not only be presented as an informational interface but also as a transitional educational support during only a period of time, where BEV-related knowledge is more unevenly distributed among drivers.

6.2 Processes and Procedures

The study procedure
The overall process was primarily structured around answering the research questions through successive data collection activities, with principles related to user-centered and interaction design in mind. The project was initiated with an exploratory pre-study aimed at supporting the investigation of RQ1 by establishing an understanding of users existing knowledge regarding the main subject. In order to identify what information users may need, it was first necessary to understand what knowledge they already possessed. As mentioned in Section 5.2.1, previous work regarding user knowledge within this area was found to be relatively limited.

The following questionnaire, described in Section 5.3.1, was more directly aimed towards answering RQ2 by investigating how information should be presented. Rather than solely focusing on preferred media platforms, most questions were designed to investigate how, when, and what type of information respondents preferred to receive. Although a broad range of alternatives was included, it can be argued that certain approaches to information presentation and learning were not sufficiently represented within the questionnaire design. This may have influenced the response distributions, which is why the subject was explored further during the interview phase described in Section 5.3.3.

The interview stage contributed to both research questions by enabling more open-ended discussions regarding users informational needs, as well as their perceptions of different communication formats and concept directions. While the questionnaires primarily identified broader tendencies and preferences, the interviews allowed participants to elaborate on their reasoning, experiences, and expectations in greater detail.

The execution in relation to theory
All user-oriented data collection activities involved BEV users, which aligns well with User-Centered design (UCD) theory [49]. The analytical stages relied on established methods within the field for interpretation and synthesis of the collected material. Although the project process was not strictly structured around a singular

formal framework, several decisions and activities aligned with principles related to User-Centered Design (UCD) and Interaction Design (IxD). Users were not only treated as participants providing opinions and experiences, but were also actively involved during interviews and co-design workshops, where they were encouraged to discuss, reflect upon, and contribute their own ideas and perspectives. This approach aligns with the broader field of HumanComputer Interaction, which focuses on how humans interact with and communicate through computer-based systems and interfaces [12]. User feedback was iteratively incorporated into the process and continuously influenced both the direction and refinement of the developing concepts.

Several design decisions throughout the project were influenced by established usability heuristics [48]. Rather than attempting to introduce entirely new interaction patterns, the design process generally aimed to build upon structures and behaviors that users were likely already familiar with through existing automotive and mobile interfaces. Existing visual assets and interaction principles were therefore used as references during concept development in order to support intuitive interpretation and interaction, which aligns with multiple of Nielsen's usability heuristics, listed in Section 3.2.

Another recurring aspect of the process was the interpretation and translation of user opinions, experiences, and preferences into design requirements and concept directions. Participants rarely described concrete solutions directly, meaning that the project team continuously needed to interpret underlying needs, motivations, and frustrations from the collected material. This reflects a common challenge within user-centered and interaction design processes, where user feedback often requires further abstraction and synthesis before it can be translated into functional design decisions.

The concept of mental models also became increasingly relevant throughout the project, particularly regarding how drivers interpret BEV behavior in cold temperatures. Since Internal Combustion Engine (ICE) vehicles still dominate large parts of existing driving culture and driver experience, many expectations related to vehicle behavior may originate from previous experiences with ICE vehicles rather than BEVs, aligning to the metaphor models brought up by Carroll et. al [73]. As a result, certain characteristics specific to BEVs, such as temporarily reduced available battery capacity during cold conditions, may appear not intuitive or problematic if interpreted through pre-existing mental models developed around ICE vehicles.

User sample and recruitment

Participant recruitment during the interview and workshop stages was deliberately approached with the intention of including a broader range of perspectives and balancing dominant user groups through a quota-oriented sampling strategy. Despite these efforts, certain participant groups proved significantly more difficult to recruit than others. A majority of participants across the data collection activities were men and reported relatively high self-estimated technical levels. Across the four completed data collections, the representation of female participants ranged from 17% to 38%, with the lowest proportion occurring during the interviews and the highest during the co-design sessions. Interestingly, an identical distribution was observed regarding the participants' technical backgrounds. Users who identified with the two lowest technical competencies ("Novice" and "General"; see Table 5.1 for detailed descriptions) constituted between 17% to 38% of the total participants. Exactly mirroring the gender metrics, this cohort saw its lowest representation in the interview phase and its peak during the co-design sessions. One possible explanation for high-level distribution is the industrial context of Volvo Cars, where participants may generally possess a stronger technical interest in vehicles and technology-related topics. However, similar distributions regarding technical level and knowledge could also be observed in the externally distributed exploratory pre-study questionnaire. This may indicate that participation itself was influenced by existing interest in BEVs and related technologies, particularly as external recruitment largely occurred through BEV-focused forums and online communities. Users with lower technical interest or engagement in the subject may therefore have been less likely to participate throughout the study. Novice users were especially difficult to recruit across multiple stages of the project, despite being considered an important user group in relation to the projects educational focus. This higher participation of women and individuals with lower technical competencies in the final data collection phase can likely be attributed to the inclusion of the internal Volvo Cars Co-Dev group. By actively reaching out to employees outside of the technical and BEV-focused departments, this channel could allow for more demographically and technically diverse participants. Despite their limited representation within the collected material, it was decided to direct the concept towards new BEV drivers, as the informational need was considered more significant for this group. If continuing the project further, it would be relevant to evaluate the final concept in settings where novice users represent a larger proportion of participants.

6.3 Ethical Considerations

Accessible design

When developing the concept, Volvo Cars existing design language was kept in mind. The project team had access to an existing Figma library containing assets and colors already used within Volvo-related user interfaces and, in order to maintain a coherent visual expression and probe Familiarity, these were used throughout the concept development process. The project team did not prioritize conducting a detailed analysis of color contrast and visual accessibility at the time, when designing the informational figures included in the concept. Although multiple colors were available within the design library, some alternatives were associated with semantic meanings such as warnings or critical system states, and were therefore not considered appropriate for visualizations intended to communicate neutral informational content, such as curves illustrating changes in energy consumption under different conditions. It could therefore be relevant to further evaluate the figures from an accessibility perspective, particularly regarding color differentiation and contrast within the informational figures.

Similarly, as the concepts primary purpose is to communicate information, it became relatively information-dense in terms of textual content. During the development process, time was spent rephrasing terminology and expressions that participants identified as difficult to understand for users without technical background knowledge. However, as the project team became increasingly familiar with the technical subject throughout the process, there is a possibility that certain concepts or terminology may still have been perceived as more understandable internally than they would be for less experienced users.

Due to the amount of information that needed to be communicated, visual figures and graphical elements were prioritized, where possible, in order to reduce textual load. Despite this, explanatory text was still required to provide sufficient context and clarity. Within the tool-oriented parts of the final concept, there was also a continuous balancing between keeping interaction flows concise while simultaneously including all parameters considered necessary for understanding and usability, resulting in sections that remained relatively information-dense.

One possible consideration for future development could therefore be the inclusion of accessibility-supporting features such as text-to-speech functionality, although this was not explored within the scope of the project.

Volvo Cars employees

The majority of the data collections have been conducted by recruiting BEV drivers internally at Volvo Cars. The very first pre-study questionnaire, see section 5.2.1, being the exception in this regard by also being shared externally. Although this was done due to a representative similarity between the internal and external respondents' answers regarding knowledge about cold temperature factors, it does not ensure a complete range of demographic perspectives. Therefore, the project may not include all possible or valuable perspectives relating to the subject. *Inclusive Design* [114] is about creating products for people of all backgrounds and abilities, and when interpreting these findings, it is important to consider that participants from the automotive context of Volvo Cars naturally possess a level of domain-specific knowledge, influencing how they responded to questions. There is therefore a risk that some BEV drivers' perspectives never came to light as many participants had similar background. This is especially relevant in regard to the self-perceived technical level. By primarily involving people inside the industry, there is an inherent risk of missing out on truly norm-creative perspectives. During the process of recruitment, attempts were made to reach participants outside of the main interested demographic, including women, lower ages and lower technical levels to capture a greater variety of viewpoints. However, this outreach was not as successful as anticipated, highlighting the need for more targeted inclusive design efforts in the future. Future work with a broader demographic user group needs to be conducted in order to ensure a more inclusive and innovative point of view that works for society as a whole.

6.4 Limitations and Future Work

Accordingly to Design Recommendation [R2], users expressed that the final concept should be placed within the existing application. This project has not handled the actual integration but it has been considered as an upcoming step by the project group. During data collection, users expressed a clear desire for easy access to information on their own terms, instead of being forced to see the content. Along with this, several users mentioned that the concept should be placed somewhere highly visible, but in a way that doesn't get in the way of the application's other core features. Further work would therefore need to explore the existing interface of the application and conduct user testing in order to identify where the final concept should be placed, balancing visibility and non-disruption of the overall user experience.

In addition to spatial placement within the interface, future work should also consider the Onboarding process, as user feedback from the data collections resulted in design recommendation [R3] that states that the concept should be available from the beginning of the user journey. However, details in how this process looks today is lacking from the project, as participants reported their onboarding process isn't representative for the general new BEV owner (see feedback in [I4]). Therefore, a more detailed investigation into the onboarding process could be valuable in understanding when and how the concept should be introduced. Whether it should be introduced by the car dealer, first time connecting to the mobile application or if it should introduce itself at a later stage.

Other aspects that would require further investigation concern the amount of data included in the concept, as well as how this information is represented. Throughout the project, participants expressed interest in having access to more detailed data and explanations while simultaneously emphasizing the importance of avoiding information overload. As a result, the project group aimed to prioritize information that communicated foundational knowledge in a simplified manner rather than attempting to visualize all different factors. The selection and scope were therefore not only influenced by perceived relevance, but also by considerations related to readability and overall length. Further work could therefore explore the informational depth further, if it should be expanded and if this would not negatively affect the usability or overall perception of the interface.

Regarding the units used in the final concept, the project identified a tension between reliability and understandability. During the data collections, many participants expressed a preference for range represented in kilometers, as this was perceived as the most intuitive and relatable unit. However, as the project progressed, the concept instead moved towards visualizing energy consumption and battery impact more generally. This decision was largely connected to concerns regarding reliability and interpretation as remaining range is complicated to to translate to. The variability regarding range estimations was considered possible to contribute to additional range anxiety and was therefore avoided. At the same time, units such as kW and kWh were avoided to be presented in the educational content due to being perceived as overly technical by participants. Instead the final concept's tool communicated impact through remaining battery percentage while the library relied on visualizations of proportions and simplified comparisons rather than numerical values. Further development would allow to investigate how to present range further, as this is the most perceptible unit among users.

The data used throughout the Winter Range Library would also need further refinement before a fully implemented version of the concept. The visualizations developed were intentionally simplified, based on approximate relationships and values identified through literature and publicly available content online. However, one strong user request concerned a closer connection to the driver's own vehicle's driving data. The original intention was therefore for the content to be adapted to the specific car owned by the user. While cold temperatures affect all BEVs, the extent of these effects vary depending on factors such as battery type and vehicle size. Consequently, the current visualizations and information would benefit from integrating Volvo-specific vehicle data in order to deliver trustable and relatable advice according to design recommendation [R5].

Limitations throughout the project
One limitation encountered throughout the project concerned the communication of the project scope itself, particularly during the earlier questionnaire-based data collections. From the beginning of the project, the concept was intentionally delimited to exist outside the vehicles built-in interface. However, despite repeated clarification within the questionnaires, several participants still suggested solutions integrated directly into the vehicle. This may indicate that the distinction between in-vehicle and external interfaces was more difficult to communicate through questionnaires alone compared to later interviews and workshops, where the context could be clarified verbally and through discussion. While this occasionally complicated the interpretation of certain responses, it also became a finding in itself, as participants consistently associated vehicle-related support with in-car systems.

Another limitation concerns the use of multiple languages. While all questionnaires were presented in English, participants were allowed to respond in Swedish or other Scandinavian language in open-ended questions. Additionally, the majority of interviews and workshops were conducted in Swedish, as this was the primary language of both researchers and participants, or if it in any other way expressed as preferred by participant. This likely supported more natural discussions and reduced the risk of participants struggling to express themselves due to language limitations. At the same time, the project also included data collection sessions in English. Although researchers were proficient in English, it was not the native language of either them or most of the participants. As discussed by van Nes et al. [115], language and translation can influence interpretation and communication, particularly in discussions involving experiences, attitudes, and reflections. Consequently, some nuance or contextual meaning could have been affected through the translation or interpretation process.

The project was also delimited to the Nordic context and Sweden, partly due to convenience and access during recruitment. While cold-weather BEV-usage is highly relevant within this context, winter related challenges are not unique to Nordic countries. Furthermore, a large portion of participants were located in or near Gothenburg, with only limited geographical variation outside earlier questionnaires. Future work could therefore explore how perspectives and informational needs may differ across regions with different infrastructure and climates.

7 Conclusion

This thesis aimed to bridge the gap between complex battery electric vehicle (BEV) functionality in cold temperatures and driver behavior by designing an intuitive information concept within Volvos design ecosystem. Cold weather heavily reduces a BEV's driving range due to factors like increased HVAC consumption, increased effects from higher speeds, and unavailable battery capacity. This sharp decrease in range often leads to severe range anxiety, heavily affecting the driving experience for BEV owners. To address this challenge, this project investigated two core research questions:

RQ1: *What specific knowledge do BEV drivers require to make informed decisions regarding both pre-trip planning and real-time energy management in cold temperatures?*

RQ2: *Through what interaction medium can this information be communicated as trustworthy and actionable advice to drivers with varying technical literacy in cold temperatures?*

To answer these questions, a user-centered and iterative approach was applied following the British Design Council's Double Diamond process. The problem space was refined across four data collection phases: an exploratory study, a survey, interviews, and co-design sessions. To align with this UCD methodology, the initial insights were translated into user personas and a defined list of user requirements. These assets guided the development of two initial design concepts, which were ultimately synthesized into a single, cohesive solution based on the final co-design feedback.

The empirical findings directly address both research questions by defining the knowledge BEV drivers require and the format for its delivery. The research demonstrates that while drivers need to comprehend how environmental and driving variables impact range, this technical data must be translated into a more intuitive format. To ensure the advice is perceived as both trustworthy and actionable, the concept must bridge the gap between theoretical concepts and the driver's practical experience. Additionally, the optimal placement for this information is within a mobile application framework. A list of eight design recommendations (full version can be read in Table 5.27) were created, which details the functional and visual requirements of the user interface and answers the research questions:

R1: Duality of beginner and advanced utility

R2: Mobile integration and vehicle connectivity

R3: Contextual and early onboarding

R4: Multi-layered information architecture

R5: Actionable and relatable guidance

R6: Emphasize visual communication over text

R7: Incorporate interactive elements

R8: Clear, non-technical terminology

Given the rapid increase in BEV adoption, these design recommendations offer a valuable framework for researchers and designers focused on creating intuitive digital coaching experiences. While this thesis establishes the core conceptual foundation, future work must explore the technical integration of this system into the Volvo Cars app, specifically determining how to seamlessly introduce the modules during the initial vehicle onboarding process for new owners. Ultimately, it is hoped that these recommendations will advance the understanding of how cross-device driver education can be effectively implemented, prompting further research into motivating energy-efficient driving habits.

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A

Appendix: Questions for the Exploratory Pre-Study

Pilot Study; Driving experience with BEV in winter conditions

May 26, 2026

This is a pilot study regarding Battery Electric Vehicle (BEV) drivers and their experiences when driving, especially in winter in the Nordic region of Europe.

You may answer this form in English or Swedish/similar Scandinavian language.

* Required

Consent form

Link to consent information:
https://intranet.volvocars.net/:b:/s/ExjobbDeepRange/IQAqK3f9j7gsQIYk7uSlu8lmAYQG1Y1IT4YunR1S7BaaNp0?e=7tN4jD

1. **Do you agree to the terms in above linked document?** *

By entering "yes" you confirm that you:
- have read and understood the information linked in this section
- understand that your participation is voluntary and you may withdraw your data
- understand that the collected data will be used for academic research
and will be published in anonymised, aggregated form
- consent to the use of your responses for the purposes described in document

◯ Yes

◯ No

Do you drive or have access to a BEV (Battery Electric Vehicle)?

This *does not include* HEV (Hybrid Electric Vehicles), PHEV (Plug-in Hybrid Electric Vehicles) or any other vehicles that use another source of energy apart from an electric battery.

2. **Do you drive or have access to a BEV?** *

◯ Yes

◯ No

Geographic location

3. **In what country do you primarily use a BEV (Battery Electric Vehicle)?**
*

- ◯ Sweden
- ◯ Norway
- ◯ Finland
- ◯ Iceland
- ◯ Denmark
- ◯ Another country/region *within* the Nordics
- ◯ Another country/region *outside* the Nordics

Information about you and your BEV

4. **How old are you?** *

- ◯ 18-24
- ◯ 25-34
- ◯ 35-44
- ◯ 45-54
- ◯ 55-64
- ◯ 65-74
- ◯ 75+

5. **Which gender would you say you identify with?** *

- ◯ Woman
- ◯ Man
- ◯ Non-binary
- ◯ Prefer not to say
- ◯ Other

6. **What is your highest completed degree of education?** *

- ◯ Compulsory school
- ◯ Secondary education
- ◯ Post-secondary education
- ◯ Bachelor's degree
- ◯ Master's degree
- ◯ Doctorate degree
- ◯ Other

7. **Which of the following best describes your level of technical knowledge regarding BEV batteries?** *

- ◯ Novice: I know how to operate the car and charge it.
- ◯ General: I understand the common factors that affect driving.
- ◯ Informed: I pay attention to the car's data and am interested in how different factors affect performance.
- ◯ Technical: I have a strong grasp of how battery systems in my BEV work.
- ◯ Expert: I have a deep technical understanding of battery technology and electronics.

8. **What option best describes your access to a BEV (Battery Electric Vehicle)?** *

- ◯ I own a BEV
- ◯ I lease a BEV
- ◯ I do not personally own/lease a BEV but we have one within the household
- ◯ I drive a BEV through work
- ◯ I borrow a BEV from family member/friend
- ◯ I often rent a BEV for e.g. trips
- ◯ Other

9. **What brand/-s of BEV (Battery Electric Vehicle) do you use on a regular basis?** *

- [ ] Tesla
- [ ] Volkswagen
- [ ] BMW
- [ ] Audi
- [ ] Hyundai/Kia
- [ ] Volvo
- [ ] Renault
- [ ] Mercedes-Benz
- [ ] Skoda
- [ ] Polestar
- [ ] Toyota
- [ ] Nissan
- [ ] Ford
- [ ] Other

10. **How often do you take long range trips, longer than 300 km, with BEV?** *

- ○ Never/ Insignificant
- ○ At least once a year
- ○ At least once every 6 months
- ○ At least once every 3 months
- ○ At least once a month
- ○ At least once a week or more
- ○ I don't know

Factors affecting the range of an BEV

11. **Based on your own understanding and experience, how much do you think the following factors affect the driving range of your battery electric vehicle (BEV)?** *

	No or neglible impact	Small impact	Moderate impact	Large impact	Very lar impac
HVAC: Heating, Ventilation, Air-condition	○	○	○	○	○
Faster driving speeds	○	○	○	○	○
Battery state of health (SOH)	○	○	○	○	○
Significant elevation changes	○	○	○	○	○
Aerodynamics/ wind resistance	○	○	○	○	○
Cold temperatures	○	○	○	○	○
Hot temperatures	○	○	○	○	○
Rolling resistance	○	○	○	○	○
Driving style: acceleration and deceleration	○	○	○	○	○
Driving style: Frequent start and stops	○	○	○	○	○
Use of media screen, speakers and/or bluetooth	○	○	○	○	○

12. **Which of these factors were new to you?** *

- [ ] HVAC: Heating, Ventilation, Air-condition
- [ ] Faster driving speeds
- [ ] Battery state of health (SOH)
- [ ] Significant elevation changes
- [ ] Aerodynamics/Wind resistance
- [ ] Cold temperatures
- [ ] Hot temperatures
- [ ] Rolling resistance
- [ ] Driving style: acceleration and deceleration
- [ ] Driving style: Frequent start and stops
- [ ] Use of media screen, speakers and/or bluetooth
- [ ] None
- [ ] All of them

13. **Based on your own understanding and experience, how much do you think the following factors affect the driving range of your BEV on a day when *the temperature is below 0 °C?*** *

	No or neglible impact	Small impact	Moderate impact	Large impact
HVAC: Heating, Ventilation, Air-condition	◯	◯	◯	◯
Less usable energy/capacity in battery	◯	◯	◯	◯
Reduced regenerative breaking	◯	◯	◯	◯
Faster driving speeds	◯	◯	◯	◯
Increased rolling resistance from winter tires	◯	◯	◯	◯
Increase rolling resistance from winter road conditions	◯	◯	◯	◯
Driving style: acceleration and deceleration	◯	◯	◯	◯
Driving style: frequent start and stops	◯	◯	◯	◯
Using seat and/or steering wheel warmer	◯	◯	◯	◯
Lower energy efficiency (more energy wasted inside the battery)	◯	◯	◯	◯

14. **Which of the following do you think contributes the most to reduced driving range *in cold temperatures (below 0 °C)?***
(Select up to three) *

Please select at most 2 options.

- ☐ HVAC: Heating, Ventilation, Air-condition
- ☐ Less usable energy/capacity in battery
- ☐ Reduced regenerative breaking
- ☐ Faster driving speeds
- ☐ Increased rolling resistance from winter tires
- ☐ Increased rolling resistance from winter road conditions
- ☐ Driving style: acceleration and deceleration
- ☐ Driving style: frequent start & stops
- ☐ Using seat and/or steering wheel warmer
- ☐ Lower energy efficiency (more energy waster inside the battery)

15. **Which of these factors *in cold temperatures (below 0 ℃)* were new to you?** *

- [ ] HVAC: Heating, Ventilation, Air-condition
- [ ] Less usable energy/capacity in battery
- [ ] Reduced generative breaking
- [ ] Faster driving speeds
- [ ] Increased rolling resistance from winter tires
- [ ] Increased rolling resistance from winter road conditions
- [ ] Driving style: Acceleration and deceleration
- [ ] Driving style: Frequent start and stops
- [ ] Using seat and/or steering wheel warmer
- [ ] Lower energy efficiency (more energy wasted inside the battery)
- [ ] None
- [ ] All of them

16. **In your experience or understanding, to what extent does *cold weather (below 0°C)* increase the following?** *

	No increase/no effect	Small increase	Moderate increase	Large increase
Total time required for a DC Fast Charge (e.g., at a highway station)	○	○	○	○
Total time required for a Slow AC Charge (e.g., at home or work)	○	○	○	○
Risk of permanent damage from a DC Charge event in the cold	○	○	○	○
Risk of permanent damage from charging to 100%	○	○	○	○
Risk of permanent damage from leaving the car plugged in (at max 80%)	○	○	○	○

Measures to take in cold temperature

17. **What measures do you take while driving *in cold temperatures?*** *

- [ ] I lower my use of cabin heating
- [ ] I warm the steering wheel and/or the seat instead of the cabin
- [ ] I precondition the battery while plugged in
- [ ] I precondition the battery from the car's own energy
- [ ] Slower driving speeds
- [ ] More careful acceleration
- [ ] I dedicate more time to charging
- [ ] I avoid charging to 100%
- [ ] I use my car's eco-driving option
- [ ] I avoid parking outdoors if possible
- [ ] I plan my routes more thoroughly
- [ ] I don't take measures
- [ ] I avoid using the BEV
- [ ] Other

18. **To what extent do you believe 'Preconditioning' (preheating the battery/cabin while plugged in) can recover driving range lost to cold temperatures?** *

- 0% (no impact)
- Up to 10%
- Up to 20%
- Up to 30%
- Up to 40%
- Up to 50%
- More than 50%

Scenarios and issues while driving

19. Have you ever experienced any of these following scenarios when driving your BEV during *winter times?* *

- [ ] The car started with a lower battery percentage than when I parked it.
- [ ] The car was unable to start even though I know it had energy left when I parked it
- [ ] When it is cold the battery's state of charge decreases fast, especially when it gone below a certain percentage.
- [ ] The battery state of charge percentage has gone up and down in front of my eyes while driving.
- [ ] The car's range estimation is significantly lower during winter
- [ ] My battery has charged slower
- [ ] None of these have affected me
- [ ] I have avoided/do actively avoid using the BEV in winter times
- [ ] Other

20. Have you ever experienced any of these following scenarios when driving your BEV, regardless what season it is? *

- [ ] I have felt unsure whether I will reach the next charging station in time
- [ ] My route planner's and car's range estimation has shown different values
- [ ] Problems when charging stations have not worked as anticipated
- [ ] I have struggled planning longer trips
- [ ] I have run out of battery on route
- [ ] Other

B

Appendix: Questions for the Communication Survey

Communicating cold temperature factors to drivers of Battery Electric Vehicles (BEV)

May 26, 2026

This survey will focus on how to communicate information to drivers about how factors in cold temperature affects available driving range, and measures that you can take while driving to limit the range loss from cold temperatures. You may answer this survey in Swedish, any other Scandinavian language or English. Thank you so much!

* Required

Consent form

Link to consent form:
https://intranet.volvocars.net/:b:/s/ExjobbDeepRange/IQDIRbKhvPYwTYxeSAoaFYw0Ae6FtTIFsBZaEBGuYTGxiww?e=9q2zWl

1. Do you agree to the above linked document? *

By entering "yes" you confirm that you:
- have read and understood the information above
- understand that your participation is voluntary and that you may request withdrawal of your answers at any given time without explanation.
- understand that the collected data will be used for academic research and will be published in anonymised, aggregated form
- consent to the use of your responses for the purposes described above

◯ Yes

◯ No

Do you drive or have access* to a BEV (Battery Electric Vehicle)?

This *does not include* HEV (Hybrid Electric Vehicles), PHEV (Plug-in Hybrid Electric Vehicles) or any other vehicles that use another source of energy apart from an electric battery.

* Access to us could be; "Owning", "Leasing", "Borrowing", "Through work", "Through family/friend" or another way.
Regardless of what your access look like, we seek you who does have access to drive a BEV on a somewhat regular basis.

2. Do you have access to a BEV?

◯ Yes

◯ No

General background questions

3. In what country do you primarily use a BEV (Battery Electric Vehicle)? *

- ◯ Sweden
- ◯ Norway
- ◯ Finland
- ◯ Iceland
- ◯ Denmark
- ◯ Another country/region *within* the Nordics
- ◯ Another country/region *outside* the Nordics

4. How old are you? *

- ◯ 18-24
- ◯ 25-34
- ◯ 35-44
- ◯ 45-54
- ◯ 55-64
- ◯ 65-74
- ◯ 75+

5. Which gender would you say you identify with? *

- ◯ Woman
- ◯ Man
- ◯ Non-binary
- ◯ Prefer not to say
- ◯ Other

6. Which of the following best describes your level of technical knowledge regarding BEV batteries? *

- ◯ Novice: I know how to operate the car and charge it.
- ◯ General: I understand the common factors that affect driving.
- ◯ Informed: I pay attention to the car's data and am interested in how different factors affect performance.
- ◯ Technical: I have a strong grasp of how battery systems in my BEV work.
- ◯ Expert: I have a deep technical understanding of battery technology and electronics.

7. What brand/-s of BEV (Battery Electric Vehicle) do you use on a regular basis? *

- [ ] Volvo
- [ ] Polestar
- [ ] Tesla
- [ ] Volkswagen
- [ ] BMW
- [ ] Audi
- [ ] Hyundai/Kia
- [ ] Renault
- [ ] Mercedes-Benz
- [ ] Skoda
- [ ] Toyota
- [ ] Ford
- [ ] Cupra
- [ ] Seat
- [ ] MG
- [ ] Mitsubishi
- [ ] Mini
- [ ] Nissan
- [ ] Opel
- [ ] Fiat
- [ ] Porsche
- [ ] Jaguar
- [ ] Other

Communicating information about driving in cold temperatures

This section will focus on how to communicate information to drivers about how factors in cold temperature affects available driving range. We want to understand how you prefer this information being phrased, when and how you want to access it. So, when answering all of these questions, imagine ***cold weather driving scenarios*** where you get information about factors that affect your vehicle.

8. Where do you today get information about how driving in cold temperatures can affect available range? *

- ☐ I read articles, webpages, blogs or similar
- ☐ I participate in discussion forums or similar
- ☐ Youtube or video content
- ☐ I learn from practical driving experience
- ☐ Information shown in my car, for example dashboard
- ☐ My car's external tools, for example an app or a webpage
- ☐ Other external tools, for example route planners
- ☐ Social sources (friends, family, colleagues etc.)
- ☐ Car professionals, for example mechanics or dealers
- ☐ I don't actively look up information
- ☐ Other

9. Do you lack information that would make driving and/or trip planning in cold temperatures easier for you? If yes, please specify what type of information. *

10. When would you prefer to receive information or tips about winter driving and battery use? *

- [ ] Before I receive/buy my car
- [ ] When I first get the car
- [ ] When planning a trip
- [ ] During the drive
- [ ] Occasionally as tips or reminders
- [ ] When I look it up or have questions needing to be answered
- [ ] I don't feel like I need more information
- [ ] Other

11. Which format would you find most helpful for winter driving information? *

- [ ] Short practical tips or advice
- [ ] Explanatory texts
- [ ] Visual indicators (icons, illustrations, animations)
- [ ] Numerical data (kWh, km, percentage etc.)
- [ ] Video format
- [ ] Games
- [ ] Interactive elements, such as quizzes or small exercises
- [ ] AI agent
- [ ] Auditory information (sounds, voices)
- [ ] Other

12. How do you *most often* prefer information about winter driving and battery use to be presented? *

- ○ Exact values (e.g. "This would change range about 10%)
- ○ Estimated intervals (e.g. "This would change range about 10-20%")
- ○ General guidance without numbers ("By lowering your cabin temperature could change your range")
- ○ A mix of values/intervals and general guidance
- ○ I would prefer not to receive this type of information

13. Which of your car's tools do you think is most intuitive to look up or receive information about how cold temperatures affect your driving and battery usage? *

- ◯ The app
- ◯ The webpage
- ◯ The user manual
- ◯ None, I use/would use external sources
- ◯ None
- ◯ Other

Interview

We would love to be able to talk more regarding BEVs, information sharing and range for our project. Would you be interested in taking part in this study at a later stage as well? Either in an interview in near future or evaluation of concepts (at latest in May 2026). It can take place online or in Gothenburg.

Answering yes means that you give us permission to contact you regarding a possible interview, but does not guarantee that you will be contacted due to limitations in data collection.

If yes, we will ask you for your contact information to potentially reach out to you in the future. The information entered will *not* be disclosed to anybody other than the responsible for this project and will be stored accordingly with GDPR, as mentioned in the consent form in the beginning of this essay. You may at any given point revoke this extended consent and *we will delete the collected personal information* towards with the end of our thesis (July 2026 at latest), regardless of your request.

14. Would you be interested in taking part in an interview within our project? *

- Your answer is not binding, you are able to opt out of an interview at any point.
- As a thank you for you extra time, we will give out a gift voucher upon conducted interview.

◯ Yes

◯ Yes, but only in the upcoming weeks

◯ Yes, but only later in spring

◯ No

15. If yes, please enter your email address here:

C

Appendix: Interview tempate

Introduction

Hi! Our names are Britta Christensson and Ebba Lindholm. We are two students at Chalmers University of Technology with a master of Interaction Design and Technologies. We are writing our master thesis here at Volvo Cars at the Vehicle Energy Management department, with Michaela Nilsson as supervisor. Our thesis is about how to communicate to drivers of battery electric vehicles (BEV) how the battery usage and available driving range in their vehicles is affected by cold weather.

The purpose of this interview is to collect data to create a prototype of a concept that can teach drivers about how their BEV is affected by the cold temperatures. The aim is to help drivers understand the effects of weather and their own actions before they get into the vehicle, to facilitate trip planning and driving. This means that the concept will be located outside of the cars own interface. We estimate that the interview will be around 45-60 minutes long, and you are very welcome to ask questions during the interview.

Consent form and GDPR

Show them the separate document, ask them to sign.

Initial questions:

1. How old are you?
2. Which gender would you say you identify as?
3. What would you consider your technical level to be?

Main Questions:

1. How do you today plan a trip in cold temperatures?
    (a) Do you ever check weather or temperature specifically to estimate how it might affect your range?
    (b) When planning a longer trip in winter, what tools or resources do you use?
    (c) Have you ever used a route planner or range calculator? Which?
    (d) How do you look up information?

2. Is there any point within this process where you feel like your knowledge is lacking?
3. Are there situations where you prefer to get information during the drive contra when planning it? What information and why?
   (a) As we mentioned in the beginning, this concept will not be placed inside the car. Could you think of some way we could give you information before the drive, that would mitigate your need for this information? (try to hint of reminders etc.)
4. What is your experience with the numbers shown on the dashboard? Do you understand them? Do you feel comfortable interpreting them? (try to discuss locked capacity)
   (a) When the temperature drops, what do you think is happening in the car that affects range?
   (b) Have you heard about locked capacity in batteries in cold temperatures? Do you know what it is?
5. Look back to when you were new to your BEV. Did something about driving in cold temperatures surprise you? Did you have to change your behavior for something special regarding cold temperatures?
   (a) What was your experience with onboarding? From the dealer, from Volvo?
   (b) Did you understand cold weather driving when you got your BEV? Or what information did you have to look up afterwards?
6. How would you present numeric data? Ask them to sketch.
7. We will show some rough examples of how one could display information/data. We would like you to share your thoughts regarding how they are presented and then the level of data presented.
   (a) How do you feel about the way they are presented? (Illustrations, numbers etc...)
   (b) How do you feel about the technical level? Please relate to it personally, which one would you prefer?
   (c) Which seems more reliable?
8. Would you expect this type of information to come from Volvo directly?
   (a) Would it make sense as part of a Volvo app or service?
   (b) Would you ever use a third-party tool for this?
9. As a final question, do you want to add anything?
   (a) Is it something that is bothering you that you would like to bring up?

   (b) Of the things/themes we have discussed, what would be of most/least use for you?

10. Would you consider participating in an evaluation session later this spring?

D

Appendix: Co-Design task description

Hello!

Thank you for taking part in our co-design session! You will be in a group of 4-5 people, where your task is to bring a designer perspective to the concepts. Here follows a description of the subject and the background, so that you can prepare for the session.

This master thesis work is about how Battery Electric Vehicles (BEVs, electric cars) are affected by cold weather conditions. BEVs only include pure electric cars, not any type of hybrids, which means they only run on the car battery. Because of that, their performance is very affected by the cold. There are a lot of factors that cause a higher battery usage and as such a lower available driving range, but in this thesis we have chosen to focus on the following three:

- *HVAC* = Heating, ventilation and air conditioning. A very large part of the battery is needed to heat up the cabin, since there is no waste heat from the motor as is the case in internal combustion engine cars.
- *Speed*. The faster you drive, the higher the consumption. For example, one study showed an instantaneous power demand of 2.9 kW at 40 km/h, but 32.7 kW at 120 km/h.
- *Locked capacity*. In cold temperatures, the battery's internal chemical reactions slow down. This means that a portion of the energy becomes unavailable, which can be visualized as a part of the battery is "frozen". As the battery becomes warm, the energy becomes available again. This can cause problems if the car starts with a low battery percentage in the cold, since not all of that charge then is available. Therefore, the available driving range when starting the car is less than what it said when the car was parked with a warm battery.

Our job is to create a concept on how to inform drivers of BEV of these factors, and what they themselves can do to mitigate the effects. It can for example be to preheat the car to always start with a warm battery, to use the steering wheel and seat warmer instead of the cabin heater, and to drive slower. The goal is to make them understand this before they get behind the wheel, and one main point is therefore that the concept is supposed to be outside of the car's own interface.

Based on previous data collections, a concept has been created that is introduced at the onboarding (when the drivers get their new cars) and is located in the Volvo app. The app is mainly used for trip planning and vehicle status, and has a minimalist interface design.

This is the topic, and we will present the exact tasks at the co-design session. Thank you again for helping us!

E

Appendix: Co-Design Session template

Introduction:

Hi! Our names are Britta Christensson and Ebba Lindholm. We are two students at Chalmers University of Technology with a master of Interaction Design and Technologies. We are writing our master thesis here at Volvo Cars at the Vehicle Energy Management department, with Michaela Nilsson as supervisor. Our thesis is about how to communicate to drivers of battery electric vehicles (BEV) how the battery usage and available driving range in their vehicles is affected by cold weather.

The purpose of this co-design session is to collect data and opinions on two concepts, to later create a final prototype of a concept that can teach drivers about how their BEV is affected by the cold temperatures. Our job is to create a concept about this, and to teach drivers what they themselves can do to mitigate the effects. It can, for example, be to preheat the car to always start with a warm battery, to use the steering wheel and seat warmer instead of the cabin heater, and to drive slower.

The goal is to make them understand this before they get behind the wheel, and one main point is therefore that the concept is supposed to be outside of the car's own interface. Based on previous data collections, a concept has been created that is introduced at the onboarding (when the drivers get their new cars) and is located in the Volvo app. The app is mainly used for trip planning and vehicle status and has a minimalist interface design.

We estimate that the co-design session will be around 90 minutes long, and you are very welcome to ask questions during it. We will also ask you to sketch out your thoughts and use post-it notes to write your opinions down. Both in FigJam and physically here in the meeting room.

Consent form and GDPR:

Show them the separate document, ask them to sign.

Initial questions:

1. How old are you?
2. What gender do you identify as?

3. How would you describe your technical level?

Flow 1:

1. First, we would like your spontaneous thoughts. What do you think? What is your first impression?
2. What do you think about the tool?
   (a) What setting do you miss?
   (b) What setting is redundant for you?
   (c) How do you feel about the level of data?
3. What do you think about the way the topics are presented?
4. What do you think about the ways the measures are presented? (together in one place, or only in each topic)

Flow 2:

1. First, we would like your spontaneous thoughts. What do you think? What is your first impression?
2. What do you think about the tool?
   (a) What setting do you miss?
   (b) What setting is redundant for you?
   (c) How do you feel about the level of data?
   (d) How do you want to add your trip? Do you want to add distance manually? With google maps/nav? With the road type tool from the web page? Is that not interesting at all as soon as you start logging trips?
   (e) How do you want to change the road condition?
3. What do you think about the way the topics are presented?
4. What do you think about the ways the measures are presented? (together in one place, or only in each topic)

General questions:

1. When do you want this concept? Onboarding? How do you feel about notifications? The idea is that it is always present in the app so that you can read when necessary, and that it reminds you closer to the winter season.
2. What do you feel about the names of the topics? HVAC/Locked Capacity? Do you understand them? Would you call them something else?

The tool (general):

1. What do you feel about the unit? Do you like the range in km vs the battery usage in %?

2. How do you feel about the unit of km (for range) vs kW(h) (for energy consumption). What makes more sense to you? Both generally and in regard to these tools.
3. Do you prepare momantaneous consumption or a larger picture?

Create their own flow:

1. Now that you have seen both concepts, we want you to combine the parts you liked the most into one flow that feels intuitive and useful for you. You can use the wireframes we have created, or add post-it notes with things you want to add.