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Promoting Energy Efficient Driving Through a Form of Eco Score

Master's Thesis in Interaction Design and Technologies

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Cover: A visualization of the final design emerged from the results of the project, a Driver Information Monitor of a Battery Electric Vehicle, with an inserted interface depicting an Eco Score as well as ambient lighting surrounding the monitor.

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Abstract

The increasing use of Battery Electric Vehicles (BEV) presents opportunities and challenges in promoting energy-efficient driving. This thesis explores how information about One Pedal Drive (OPD) and throttle usage can be visualized to help drivers better understand and manage their energy consumption. The study takes a user-centered design approach that involved conducting expert interviews and questionnaire study to understand the users. Prototypes displaying eco-driving feedback integrated into the Drivers Information Monitor (DIM) were developed, tested, and refined. The initial design concepts developed according to a defined requirements list, were tested in two focus groups. A semi-functional prototype were developed based on the feedback from the first iteration and tested with 20 participants in a Think-Aloud Protocol study. The findings highlight that dynamic real-time visualizations combined with post-drive visualizations can help user gain a better understanding of their energy consumption. Gamified elements such as an Eco Score, social comparisons, and ambient feedback were shown to motivate energy-efficient behaviour. The thesis presents a set of actionable design recommendations for in-car displays that aim to improve user experience, reduce cognitive load, and support sustainable driving habits. These insights contribute to the field of human-vehicle interaction and the development of intuitive interfaces for the next generation of BEVs.

Keywords: battery electric vehicle, energy-efficient driving, human-vehicle interaction, user experience, interaction design, user-centered design, gamification, information visualization

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Diana Boskovic & Linn Holmgren, Gothenburg, May 2025

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Abbreviations

BEV	Battery Electric Vehicles. v, xiv, 1–6, 8–10, 12, 13, 15, 18, 20, 21, 28, 38, 40–42, 44, 46, 47, 52, 59, 60, 69–75, 77, 78, 81, 85, 86, 90, 92–94, 96, 98, 101–103, 109–116
CoDev	Co Development. xiv, 6, 41, 42
CSD	Center Stack Display. xi, xiv, 3, 10, 11, 17, 38, 39, 46, 50, 58, 70, 71, 73, 75, 76, 91, 114
DIM	Drivers Information Monitor. v, xiv, 1, 3, 7, 10, 14, 17, 20, 38, 39, 46, 49, 50, 56–58, 61, 70, 71, 73, 75, 76, 80, 82, 84, 87–89, 92, 95, 96, 98–104, 106, 111, 113, 114
DVI	Driver-Vehicle Interface. xiv, 10
EDTE	Estimated Distance to Empty. xiv, 9, 10
EV	Electric Vehicle. xiv, 1, 3, 6–10, 12, 15, 17, 60, 71, 74, 92, 94, 102, 111
GDPR	General Data Protection Regulations. xiv, 1, 4, 113
HCI	Human-Computer Interaction. xiv, 19, 22, 23
HMI	Human-Machine Interaction. xiv, 24
HVI	Human-Vehicle Interaction. xiv, 24
ICEV	Internal Combustion Engine Vehicles. xiv, 1, 9, 12, 17, 94, 102, 115
MaaS	Mobility as a Service. xiv, 6

OPD	One Pedal Drive. v, xiv, 1, 2, 8, 38, 39, 44, 46, 47, 71, 73, 75, 77, 78, 81, 98–103, 110–112, 115, 116
RtD	Research through Design. xiv, 23, 24, 109, 115
SoE	State of Energy. xiv, 1, 9, 10, 39
UCD	User-Centred Design. xiv, 23, 109
UI	User Interface. xiv, 7
UX	User Experience. xi, xiv, 7, 21–23, 102, 109

1

Introduction

Battery Electric Vehicles (BEV) have become increasingly popular and are no longer considered an exclusive luxury but can be an affordable option since production has increased and the market of Electric Vehicle (EV)s has become diverse enough to cater to the general public. Hence, an increasing number of drivers switch from Internal Combustion Engine Vehicles (ICEV)s to EVs and there is a need of informing drivers en masse of how their previously favourable driving behaviour might not benefit their energy consumption. Energy efficient driving patterns could improve consumption patterns, and by that the range of the vehicle. Consumption has become increasingly important since the range of EVs, especially BEVs, is smaller than that of ICEVs, and the charging time of vehicles takes longer than filling a fuel tank of petrol. The infrastructure for charging EVs is another challenge, though it is prioritized by several countries and developments are ongoing, EV drivers depend on reliable and accessible charging infrastructure. The importance of driving styles is due to its effects on consumption and its consequences to the State of Energy (SoE) of the vehicle, deterioration of the battery and loss of range which could all result in otherwise avoidable emissions. EVs are considered an innovative solution to moving the transportation industry in a sustainable direction. Because of the global energy crisis and the concern of the impact of the emissions generated by the automotive industry, the development of EVs has rapidly become a global trend as the industry shifts to become electrified. With this, the cars status as a means of transportation has not changed, but the mental model of the cars attributes and affordances has evolved as the EV demands a change of behaviour by the driver. This poses the question if the knowledge of EVs and how to drive them energy efficiently has had a corresponding increase as the use of the vehicles themselves. To communicate how the driving task has changed with the EV, effective interfaces are required to successfully help drivers adapt to the new standard of vehicles.

1.1 Problem statement and Research Questions

The transition to BEVs presents a shift toward sustainable transportation, driven by the need to reduce environmental impact. As BEVs become more common, efficient energy management has emerged as a critical factor in enhancing their performance, range, and user satisfaction. However, many drivers need to be made aware of how their driving behaviour, specifically the use of features like One Pedal Drive OPD and the throttle, directly impacts energy consumption. While the awareness of vehicle energy consumption becomes more important, how to behave and manoeuvrer the vehicle in a manner that minimises energy usage might not be as easy to comprehend. This limits the potential efficiency gains of BEVs and the broader adoption of Eco-friendly driving practices. Understanding how to provide actionable feedback to drivers in a way that promotes energy-efficient behaviour while ensuring safety and an engaging user experience requires a multidisciplinary approach. The problem could be addressed by combining insights from behavioural research, user-centred design, and gamification techniques.

The research questions that will be investigated in the thesis are:

1. What information about One Pedal Drive (OPD) and throttle usage helps Battery Electric Vehicle (BEV) drivers understand their energy consumption?

2. What are the design recommendations for displaying information to promote energy-efficient driving?

1.1.1 Purpose

The purpose of the thesis is to investigate what information of energy consumption should and could be displayed to drivers whilst driving to provide either actionable or educational information. To gain understanding of this, the focus will lie on first understanding the user and their perspective, since usability and user experience is a central part of the research. Another focus is to understand the role that gamified feedback might play in information visualisation of energy consumption and if this could enhance the user's understanding of their driving behaviour affecting their energy consumption. To concretise the findings of the research, the aim is to develop several design recommendations for displaying actionable feedback to drivers about their BEV energy usage intuitively to reduce cognitive overload. With these intentions, the purpose is to develop low-fidelity and semi-functional prototypes with which the usefulness, usability and actionability of the proposed solutions can be tested with BEV users.

1.1.2 Delimitations

The information visualisation of in-car displays for BEVs is a relatively new area of research, because of this there is a limited amount of research on the subject. Because of the ongoing rapid development in the field, with new models of cars being brought out every year, the standard for interfaces in BEVs is evolving together with the market. This offers an opportunity for this research to bring fresh insights into the field. The goal is to understand what information should be displayed to users driving BEVs for them to understand the correlation between their own driving behaviours and the energy usage of the vehicle. Because of this and the limited previous research on the topic, the research will have a user-centred approach. Another aspect of the research is to investigate what gamified feedback could be used in in-car displays to display energy usage and how these could potentially effect energy usage. The field of gameful interfaces in cars is new and the information available is limited, adding an exploratory approach to understanding the value of gamified feedback in vehicles.

The research is limited to in-car displays, specifically the Drivers Information Monitor DIM. Other displays, such as the CSD or mobile applications will not be a part of the scope of this thesis. This is to narrow the scope and the interest of using information visualisation techniques in a limited amount of actionable space, such as in the DIM, which is regulated by law and corporate design language. The scope of the thesis will only include BEVs, an no other EVs will be taken into considerations even though they might share the same challenges and might benefit from the results of this research.

The participants in the studies will be BEV drivers employed by Volvo Cars. Adding consistency to our methodology, the participants are assured to be stakeholders. However, the findings of the study can not be guaranteed to apply to a broader range of BEV drivers without further investigation beyond the scope of this project. The participants will be recruited to represent a wide range of education, age, gender and area of work. This will offer insights from different perspectives. Because of their shared attribute of having the same employer, the findings might not reflect the general public. The study is conducted in Gothenburg, Sweden, with the participants living in the same area. This makes the findings based on a limited demographic, which might not be representative for the global populations because of cultural differences, climate and social factors.

1.1.3 Expected Contributions

The research is expected to contribute to the field of research of BEVs, as well as information visualization in in-car displays and of gameful design in cars.

The findings of the research will be represented in several design recommendations according to the scope of the project. These are expected to answer the research questions and guide future iterations of in-car displays in design challenges.

1.2 Ethical Considerations

The nature of the environment which will be investigated immediately offers ethical concerns which need to be taken into account. Because of the focus on user experience whilst actively driving, and the scope including actionable feedback, the safety of the user is a priority. When addressing information visualisation in in-car displays, the designs need to be made to avoid information overload and potentially distracting the user. Since the research has a user-centred approach, decisions of the design will me made so to not overwhelm or distract the user, as well as not demanding their attention whilst driving.

Whilst aiming to understand the user and the impact of energy consumption displayed to them, knowledge of the correlation between driving behaviour and energy consumption should not lead to stress or anxiety. The research is meant to empower users driving BEVs by informing them of how they can actively have an impact on energy consumption by their daily choices.

The proposed solutions will be developed to include aspects of accessibility, and the designs will be constructed as to not exclude colour-blind individuals. All research will be conducted according to the General Data Protection Regulations (GDPR), implying that data privacy and security is prioritised. All data will be handled to assure privacy, no sensitive information will be asked of the participants of the questionnaires, interviews, focus groups or think aloud protocol studies and all data will be made anonymous after processing.

2

Background

The context needed to understand the research questions and the problem statement introduced in Chapter 1 will be presented in this chapter. The stakeholders will be introduced, together with the topics of BEVs and their vehicle specific attributes, as well as data visualisation in the context of BEVs. Sustainability, energy-efficient driving, and gameful design will be addressed to shed light on the context specific areas of interest for the thesis. Regulations regarding in-car displays will be put into context to provide information necessary to understand the scope of development for the design recommendations proposed.

2.1 Stakeholders

The expected outcomes of this research is of relevance to three main groups of stakeholders. Volvo Cars, which are expected to benefit from the design recommendations which might be further implemented in future developments of information visualisation of energy consumption, will provide vital input, expertise and resources to aid the process of the project. The drivers play a central role in the discovery and development phase of the project, and user insights gathered during the evaluations will further drive the development of the final prototype and the design recommendations.

1. **Drivers**: drivers of BEV will participate in the different stages of the process. The final proposed design solutions will aim to help drivers drive more energy-efficient, which they can benefit from economically whilst positively impacting the environment.

2. **Environment:** the global transport industry has had a negative impact on the environment, not only by adding to rising CO_2 levels. By electrifying vehicles and choosing a future sustainable way of transportation that could minimise those emissions.

3. **Automotive industry**: the industry has drastically shifted into prioritising the development of BEVs to face current and foreseeable challenges, implementation of new innovative technology is happening continuously and having informative interfaces to guide drivers into changing their driving habits would help setting a new standard of driving energy efficient vehicles. This would affect manufacturers, designers and the industry as a whole.

4. **Bystanders**: if the design recommendations were to be implemented and influence future versions of BEV interfaces, there might be a long-term impact on bystanders perspective of BEVs and perhaps their future driving style and demands on BEVs.

2.2 Volvo Cars

Volvo Cars is a multinational company based in their hometown of Gothenburg, Sweden. Their core values are safety, quality and care for the environment. With this, they aim to be leading in the automotive industry in safety technology, electrification and autonomous driving [1]. Their long-term plan for the production of cars align with their values, as Volvo Cars' goal is to become a fully electrified company, with the aim of reaching 65-70% CO_2 reduction per vehicle by 2030 [2]. To add to this expansion into the manufacturing of fully electrified vehicles, they aim to release an EV annually. Due the substantial international recognition of the brand Volvo Cars, their commitment to adapt sustainability policies and their open concern for the future of the environment, their progress in developing BEVs is noticed and has already had an impact on vehicles in use by cross-national customers.

2.2.1 Vehicle Subscriptions

With the rising awareness of negative social, environmental and economical factors of private vehicle travel and ownership, the demand for alternative solutions has been identified [3]. In countries with poorly developed public transportation systems, residents depend on having access to a private vehicle. The dependency contributes to climate changes and environmental damage, it affects infrastructure and pollution. An alternative ownership is Mobility as a Service (MaaS). The automotive industry has managed to shift the way consumers view mobility by introducing user-ship instead of ownership, in line with the concept of MaaS which includes alternatives such as car subscriptions and sharing [4]. These solutions offer flexibility, adaptability, and convenience to the consumer, compared with leasing or private ownership. As for environmental impacts, car subscription solutions could increase resource efficiency since the car is with the customer for a shorter period of time, and is returned at the end of the contract. The owner can then keep the car on the market if the customer chooses to end their subscription or change models, resulting in a decrease in the need to manufacture or acquire new vehicles [5]. Consequently, the rising trend of car subscriptions has lead to encouragement of responsible resource utilization.

Volvo Cars has their own car subscription services, one of which is an exclusive offer to employees. A part of the service is to offer participation in their Co Development (CoDev) fleet, which means choosing a car with test equipment and commitments made by the driver. This offer is beneficial both for the employee and the company, as the contract is an opportunity for Volvo to gain valuable insights of their products, which can be used for improvements. The commitments includes active participation by the drivers in surveys and interviews, making CoDev BEV drivers ideal candidates for the research conducted in this project. CoDev drivers will be asked to participate in the different evaluative methods used in the research. By offering the use of their own resources within the company, Volvo Cars have been of great help in finding participants of relevance for our user studies.

2.2.2 Working Towards Emission Free Vehicles

Volvo Cars has adopted a sustainability plan meant to have their sales consist of 90-100% EVs, with a reservation of a limited number of hybrid vehicles. With five fully electric cars already on the market, and another five in development, the car company has already established their presence on the EV market. The company had an increase in sales of EV of 70% in 2023, equivalent to 16% of their global sales [6]. Of the five fully electric models EX40, EC40, EX30, EM90 and EX90, the EX30 was during the last quarter of 2024 ranked third of the best selling EV in Europe [7]. Whilst still producing hybrid vehicles, the whole electrification of the company stands as the long-term goal, the current EVs on the market and those in development being meant to pave the way for the future of the company's manufacturing and investment plan. Together with their own fleet of EV, Volvo Cars collaborates with Polestar, a Swedish EV brand founded by Volvo which now operates separately. The two companies are partners across manufacturing, research and development [8], collaborating intimately because of their history. This partnership acts as a valuable asset for the development of future EVs.

2.2.3 Design Principles

Volvo Cars has internal design guidelines used by User Experience (UX) and User Interface (UI) designers to ensure that all interfaces share the same design language. To further anchor this vision into all vehicles and updates in Volvo Cars' systems, design values are set to guide the designers. As thesis workers, we have been given access to these principles together with wireframes and modules used in the interfaces of cars today compiled in Figma files [9]. Files containing up-to date DIM interfaces were used to create low and high-fidelity prototypes, to create realistic artefacts to use in the process of the project. The intention with adopting the already used design language of the corporation is to utilise recognisable as well as established standards of orientation with which proposed design solutions will blend into, within the restraints of existing regulatory frameworks.

Summary of principles relevant to our design process:

- Information should be displayed in a safe way which does not distract users from their immediate surroundings whilst driving
- Access to information should be predictable, users should not experience confusion
- The design should be accessible and inclusive
- Incentives to resort into phone usage should be eliminated
- Layouts should be simple and glanceable

- Colour is a mean used to communicate, and should be discrete unless the value of the information demands otherwise

- Affordances should be indicated clearly, size and colour contrasting should be utilised accordingly

2.3 Battery Electric Vehicles

A BEV is an EV with an electric engine and system solely consuming energy from rechargeable battery packs for propulsion BEV which need to be plugged into an energy outlet to charge [10]. Compared to the more general term EV, which also includes hybrid electric vehicles utilising fossil fuels such as gasoline or diesel, BEV have power as their exclusive source of energy. The idea of the BEV has long been around, and has become an increasingly popular alternative in the midst of the global climate crisis together with expanding fuel costs. Advancements in battery technology to battle battery degradation and infrastructure for charging are making BEV a viable option for drivers worldwide. Lithium-ion batteries have further opened up opportunities for development because of their force capacity generating longer range, advancements in the field are essential for making BEVs more sustainable [11].

2.3.1 Features

A feature unique to BEVs is the ability to harness energy by charging the battery whilst the brakes are applied, resulting in regenerative breaking. This is integrated in most BEVs and works by converting energy during deceleration manoeuvres. Energy that would otherwise have gone to waste can by this be renewed and saved in the battery, making BEVs energy efficient. With this attribute, drivers have significant influence over the vehicles use of energy, as inefficient use of generative breaking can result in a loss of 30% in the energy efficiency of the vehicle [12]. Although this feature is of importance to increase the energy efficiency and by that the range of the vehicle, recuperated energy could be limited by additional friction braking whilst already decelerating. To counter this and offer a comfortable solution to drivers, OPD has been implemented and is now a feature found in most BEVs. Applying the feature allows for acceleration and deceleration with the throttle alone, reserving the brake pedal for emergency breaking. OPD could lead to more energy efficient driving since the algorithm is designed to utilise regenerative breaking to a certain level [13]. However, with easier access to control the acceleration and braking of the vehicle with one pedal, this mechanism could result in easier practice of non-efficient driving because of the easy access to implementing non-smooth driving behaviour because of the use of a single pedal. Releasing the pedal will instantly result in braking, which might not always be beneficial. Most drivers quickly adapt to using OPD, increasing trust into regenerative breaking systems [14]. The affordance diminishes the need to frequently shift between pedals, resulting in increased speed control flexibility.

2.3.2 Environmental Impact

Increasing climate challenges has notified the public of the emissions generated by the global transportation sector, as the industry accounted for 24% of global greenhouse gas emissions stemming from fuel combustion in 2017, of these emissions 74% are due to road transport [15]. To manage this, numerous cities and countries are committing to eliminating ICEVs in favour of BEVs. With increasing global sales, 14 million cars being 18% of all cars sold in 2023, it is projected that one in two cars sold in 2035 will be an EV [16]. This is in part due to increased support for energy, climate and industrial policies. Another incitement for scaling up production of EVs are zero-emission zones implemented in many European cities, where restricted or no access is granted for ICEVs [17]. Along with decreasing green house gas emissions, EVs could have an impact on air and noise pollution. In the pursuits of pivoting the global transportation system into a more sustainable counterpart, electrification of passenger vehicles is regarded as a key strategy.

2.3.3 Information Visualisation in Battery Electric Vehicles

Even though sales of EVs have been significantly increasing for years, the concepts displayed through in-car displays may not be considered familiar to the general population. In a study conducted by Chalmers University [18], participants were deemed to have problems understanding information specific to EVs whilst expecting the vehicle they were operating to behave like an ICEV when faced with a traditional interface and experienced insecurities handling innovative interfaces. The results indicated that drivers were unsure of what information is relevant to them as EV drivers, they also did not show full understanding of aspects of importance, indicating a need for better information display. The reason for the confusion might be lack of knowledge concerning electricity and batteries, having useful mental models of these was deemed of critical importance to understand the vehicle and its behaviour. BEVs introduce new and sometimes unfamiliar technologies to users, such as regenerative breaking, one pedal driving, limited range, charging optimisation, battery degradation and driving style consequences to range. Other research of BEV drivers has revealed the user need of improved information display, stressing the importance of additional information particularly for energy consumption and efficiency [19] [20].

2.3.3.1 Driver Information Monitor and Center Stack Display

Since they rely solely on power, the information visualization of BEV in-car displays needs to contain the SoE, the amount of energy stored, as well as the Estimated Distance to Empty (EDTE), the approximate calculation of possible mileage you can drive until charging is required, in the vehicles. A study conducted by Volvo Cars found that the participants, employees leasing EVs, did not actively feel concern of the SoE or caring for it [21]. Despite the relaxed attitude to the meaning of SoE, the participants stated an interest of having more information of possible battery protection and preventative actions to preserve SoE. Another finding of the study was the preference of having the State of Health displayed together with other car status notifications. An example of SoE and EDTE status and their location in the DIM of a BEV can be seen in figure 2.1.

BEVs, like other automotive vehicles, are built with indicators and instruments in the instrument cluster behind the steering wheel, referenced to as the DIM in this thesis, as well as in the console centred in the build, referenced to as the CSD. Examples of these are portrayed in figure 2.1 and figure 2.3 respectively. These are the Driver-Vehicle Interface (DVI) available to the driver during the activity of driving, whilst it is becoming increasingly usual to have mobile apps available on separate personal appliances to access real-time updated information of the vehicle.

Figure 2.1: DIM during driving of a Volvo EX90

Although the cluster of information displayed in the DVI is not limited to what amount of information is allowed to be displayed, a cluttered display filled with unnecessary information or non-beneficial visualisations could lead to confusion in finding and categorising information and might cause a strain on attention, causing the driver to cast long glances on the DIM or CSD [22]. Distractions from the driving task could cause errors in reading comprehension. Hence, specific indicators or instruments should not be too complex in their construction for the user to grasp the content, the visualisations should not be changing too fast and size and contrast need to be considered [23]. The time needed of the driver to divert their attention from their task of driving to read and comprehend the information should be minimal.

In figure 2.2, part of the DIM is visible. The image depicts the SoE of the battery in the vehicle at 29%, the EDTE at 120 km and the power meter, a vertical bar showing an orange limitation of the BEV's power capacity at the instant, in this case possibly because of climate conditions, and a green bar in the lower halve, notifying the driver of an ongoing regeneration of energy. The power meter is associated with EVs, and can be visualized in different ways, often being in the form of a bar or in the more recognizable classic speedometer aesthetic. The power meter gives real-time feedback of power used and occurring regeneration whilst accelerating or practising deceleration or harsh breaking manoeuvres. Some interfaces display the limit of recouperation.

Seen in Figure 2.3 is an image of the Range and Trip information in a CSD. The content of the information regarding energy consumption differs between manufacturers

Figure 2.2: DIM displaying regeneration through the power meter in a Volvo EX90

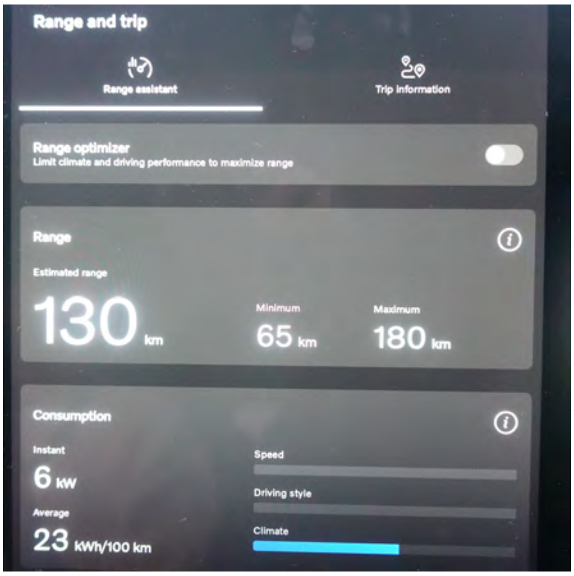


Figure 2.3: Range assistant application in the CSD of a Volvo EX90

and generations of vehicles, some of which only have the general trip information such as in the trip computer, where information of fuel or energy usage and total distances are displayed. The range and trip information acts as a complement to this information. In this example, the driver sees their energy consumption visualised with visual elements indicating energy usage to see what activity affected their consumption most, with the opportunity of comparing the specific drive to historic data.

2.3.4 Range Anxiety

Estimations of limitations to energy or battery capacity is something encountered by most individuals daily in phones or computers, and our following actions are dependent on the information displayed. Estimations of battery life is indicated by miles or kilometres in cars, often higher than it should be, this creates unrealistic user expectations [19]. As it is difficult to display power accurately, especially for a remaining drive which is a dynamic activity where the power used is not entirely predictable, users being signalled accuracy of those metrics has consequences. Uncertainty of the state of charge during a drive can bring an element of surprise when the user comes to the realisation that the range of the vehicles current battery power might not be enough for them, either because of time or accessibility of charging infrastructure. This can cause distress, which could lead to increased risk taking and careless driving behaviour. This phenomenon relating to limited range is called range anxiety.

Drivers have been shown to create strategies to handle range anxiety, adapting to the behaviour of their EV and by this decrease the amount of incidents with critical range [24]. To give perspective a sense of awareness of the situation, estimation of range, state of charge, the power meter and informing of charging opportunities are useful tools that might give the driver knowledge on how to act in relation to the range, and could have a positive effect on range anxiety. A field study made with EV drivers about interaction with limited mobility resources showed that drivers comfortably used up to 80% of available range of energy without issues of anxiousness [25]. Traits such as low impulsivity and beliefs of control correlated positively to range values and utilisation, suggesting that drivers utilise range preserving strategies and personal traits and competence have a role in specific user-cases of range utilisation.

2.4 Regulations and Policies

This section will touch on regulations concerning EVs, however they share the same demands on uniformity and clarity as ICEVs on identification of indicators, hand-controls and tell-tale signs [26] as well as for devices allowing indirect vision, such as mirrors and cameras, and their installation [27]. The European Union are aiming to decrease emission caused by the transportation sector by 90% by the year 2050 compared to 1990 [28]. They declare that it is essential for this change that transportation vehicles makes a shift towards using low-carbon fuels, including electricity as the most efficient power source. To enable this dramatic change of fuel use, infrastructure for charging needs to be improved and made accessible to EV drivers, the objective of the policy is to have EV charging be as accessible, quick and simple as that of a fuel tank.

2.5 Recommendations

Battery Electric Vehicles (BEV) introduce new information demands that differ from those of conventional Internal Combustion Engine Vehicles (ICEV) . Neumann and Krems [29] examined how specific BEV displays affect driver understanding and vehicle interaction. The study showed that although drivers initially found displays moderately helpful for estimating energy-related metrics, their perceived usefulness declined over time. One issue was the difficulty in interpreting electrical units such as kWh, range, and consumption rates, which are unfamiliar to many drivers. These findings suggest that traditional approaches to in-vehicle information design are insufficient for BEVs. To effectively support energy-efficient driving, interfaces should both present accurate data and translate complex electrical information into intuitive, understandable formats. The recommendations includes adopting clear, user-centered design principles and introducing additional assistive cues that help drivers relate their actions such as acceleration or regenerative braking to real-time energy consequences. Improving display clarity and relevance is therefore crucial for promoting energy efficient driving behaviour in BEVs.

3

Related Work

This chapter will introduce and assess works related to this project. Since the scope concern driving behaviour and its effects on energy consumption, how information should be displayed and visualised to drivers for them to fully comprehend their effect on their BEV and how gamified elements could be used enhance understanding, several fields of science and design will be introduced.

In line with the second research question of this project, developing design recommendations for display of information with the purpose of promoting energy-efficient driving is the goal. Pongchancha et al. [30] similarly did a user-centred study on user needs regarding information display in BEV to enhance understanding of battery State of Energy, with recommendations of efficiently communicating BEV-specific energy to drivers. This study adds to the scarce research on user-perspectives of Sate of Health and other BEV topics which are now becoming increasingly important due to global initiatives, thereby expanding the market, prominence and private use of EVs.

3.1 Gamification

Gameful design, commonly known as gamification, is applied in the automotive industry. Diewald et al. [31] reviewed existing and future use of game design, and discussed challenges with integration of game mechanics into automotive contexts. There is a distinction between external and in-vehicle applications of gameful design. Externally, gamification is used in marketing strategies to enhance brand engagement and customer loyalty. Automotive companies have utilised game mechanics in campaigns, mobile apps, and reward systems to motivate customer interaction [31]. Within vehicles, gameful design is primarily focused on promoting safer and more efficient driving behaviours. However, one main application is Eco-driving where drivers receive real-time feedback, points, or rewards for maintaining fuel-efficient and environmentally friendly driving styles. Navigation systems and driver-assistance technologies also integrate game elements, such as challenge-based route optimisation or rewards for maintaining good driving patterns. There are still significant challenges in applying gamification to driving. The main concern is driver distraction since poorly designed game elements could compromise safety by drawing attention away from the road. Additionally, the effectiveness of gameful interventions varies depending on user motivation, cultural differences, and driving habits. It is important to design balanced and non-intrusive game mechanics that enhance driving experiences without introducing new risks [31].

Wee and Choong [32]further explored how different gamification elements could motivate drivers to engage in energy efficient behaviours. Their research was grounded in Self-Determination Theory, which suggests that motivation is driven by three psychological needs namely *autonomy, competence, relatedness, and intrinsic motivation.* Nine core game design elements were identified as effective in satisfying psychological needs and fostering engagement. The suggested elements for gamified energy-saving were as follow:

- Personal Profile
- Non-fixed Structure
- Challenge
- Feedback
- Theme
- Short Cycle Time
- Competition
- Cooperation
- Chat-based Social Networking

These elements provided users with a sense of control, opportunities to develop skills and track progress, and social connections through challenges and shared goals [32].

Implementation of gamified elements into in-car displays need to not distract the driver by attention-seeking visualisations and too dynamic visual changes of the interface. Interfaces should be simple and promote natural interactions to avoid distraction. In an attempt to achieve this, Rodríguez et al. [33] proposed a gamified ambient in-car display solution, where drivers are challenged to drive safely by competing with their social network. The proposed technology would provide ambient feedback to drivers when following or breaking traffic laws, with a connected mobile application where scores can be compared to others and rewards can be collected in an attempt to motivate and modify driving behaviours.

3.1.1 Social Networks and Collective Data Sharing

Driving in traffic is an inherently social activity, Riener and Reder [34] explored how collaborative data sharing can improve driving efficiency and road safety. Experienced drivers can support less experienced drivers by sharing driving data and creating a collective intelligence network that benefits all drivers. They developed a social driving application that provides drivers with real-time recommendations for navigating a specific route. This system uses data from multiple vehicles for analysing driving patterns, traffic conditions, and environmental factors to generate personalised suggestions that promote safer driving. The application aimed to reduce traffic congestion, optimise fuel consumption, and minimise accident risks through collaboration. Data-driven feedback systems could be used to change individual driving habits while contributing to broader traffic improvements. However, there are challenges regarding data privacy and user acceptance to support data sharing at scale [34].

Meeco [35] is another digital platform that was designed to promote environmentally friendly behaviours through gamification and social networking. According to Macias et al. [35], sustainable habits can be more effective when integrated into an engaging and interactive digital environment. The platform used location-based services and web technologies to allow users to log their ecological actions and share them within a social network. It motivated users to adopt greener behaviours while fostering a sense of community by incorporating game mechanics such as rewards, challenges, and leader boards. The social aspect reinforces participation as users can track each others progress and compete in sustainability challenges. Gamification can therefore act as a tool to drive behavioural change by making sustainability an enjoyable and socially rewarding experience. Still, the implementation proposed challenges such as maintaining user engagement, ensuring the credibility of logged activities, and addressing privacy concerns in location-based tracking [35]. In our research, we aim to explore collective data sharing as a way to motivate users as a form of feedback to change their driving style based how well they drive compared to other drivers of the same vehicle.

3.2 Energy efficient driving behaviours

What effects environmentally friendly behaviours is complex factors that conflict with each other and influence our daily decision making, which also applies to environmentally friendly behaviours [36]. What could be considered contributing to environmentally friendly behaviour is environmental knowledge, attitudes, and values. These are shaped by internal and external elements, where social and cultural factors can be included. A contributor to not embracing environmentally friendly behaviour in daily life is old habits, which can act as a barrier to adopting new behavioural patterns. Sympathy and a sense of personal control has ben shown to correlate with environmentally friendly behaviour patterns, where individuals feeling personal control in solving environmental issues could improve environmental ethics [37]. This implies that a focus on the individual and internal factors might affect their sense of environmental responsibilities.

The driving styles of ICEVs and EVs are not interchangeable, studying the first months of driving EVs compared with ICEVs show that drivers new to the technology have stronger acceleration and deceleration patterns, possibly due to EVs allowing high acceleration indifferent to the engines revolution per minute [38]. The distinct technological features of an EV make for a unique experience which is likely reflected in driving behaviour. Aggressive driving styles such as harsh brakage, frequent acceleration and high speeds could result in 30% higher energy consumption [39]. Nudging tactics used in car interfaces to improve driving behaviour is becoming more prevalent, settings labelled with the words *Eco*, *green*, *sustainable*, or *efficient* modify driver settings such as climate control and power usage. Whilst these tactics prove useful for a while, that effect fades over time, failing in creating lasting driving habits.

Additionally, in a study by Günther et al. [40], Eco-driving behaviours in the context of BEVs were examined to identify strategies that optimise energy consumption and range while maintaining safe and efficient driving practices. Both objective driving performance metrics and subjective driver perceptions were analysed by integrating multiple data sources. Eco-driving behaviours such as acceleration and braking, anticipation of traffic flow, and efficient use of regenerative braking were central. The findings were that drivers can influence the energy efficiency of BEVs through their driving style. However, individual differences in user behaviour, motivation, and experience affect the adoption of Eco-driving strategies [40].

3.3 Eco Score

There are several studies of Eco Score implementation aiming to explore ways to change driving behaviours to be more energy efficient. Stillwater and Kurani [41] explores how in-vehicle feedback influences drivers to adopt more energy-efficient driving behaviours and investigates whether goal setting, framing, and anchoring within feedback systems could motivate do so. Findings from their study indicated that roughly 75% of drivers modified their driving behaviour in response to the feedback. The study also found that different types of feedback influenced behaviour in different ways. Real-time feedback was especially useful for experimentation since it allow drivers to test and refine new driving strategies while historical performance feedback was more effective for setting goals and maintaining motivation. Participants were more likely to adopt new Eco-driving techniques when they had a clear efficiency goal, and framing the feedback in a game-like manner made it more engaging. When drivers were provided with a baseline comparison or anchoring, such as the average fuel efficiency of other drivers, they gained a better understanding of their performance and adjusted their behaviour to align with that standard [41].

Franke et al. [42] further explored the possibilities of improving energy efficiency and driver experience in BEV. Effective energy interfaces need to integrate technical and psychological perspectives to support drivers in optimising energy consumption while reduce concerns such as range anxiety [42] [24]. Factors influencing energy interface design include the dynamics of vehicle energy use, driver cognition, and behavioural strategies. Current energy feedback systems in electric vehicles often fail to provide intuitive, actionable feedback that could lead to inefficient driving behaviours and increased range anxiety. To address these challenges, Franke et al. [42] propose a conceptual framework that considers three main aspects *technical energy dynamics, driver perception and decision-making,* and *system usability.* They suggest that energy interfaces should offer predictive, and context aware information that helps drivers anticipate and manage energy use effectively.

Another study conducted by Hibberd et al. [43] also investigated the effectiveness of in-vehicle interfaces to promote environmentally friendly driving. It was conducted using a high-fidelity driving simulator to evaluate potential Eco-driving interfaces, including visual dashboard displays, multimodal combinations of visual and auditory feedback, and haptic feedback through the accelerator pedal. The goal was to determine which of the interface modalities most effectively guided drivers toward optimal accelerator pedal use and consequently improve fuel efficiency. Interfaces providing real-time and intuitive feedback can significantly improve Eco-driving performance. The feedback combining visual and auditory cues were particularly effective. Haptic feedback through the accelerator pedal also showed potential through subjective impressions [43]. These insights are valuable for the development of in-vehicle systems and interfaces aiming to support environmentally friendly driving.

3.4 Cognitive Aspects

The concept of nudging suggest that it is possible to leverage the knowledge about cognitive biases to influence behaviour in a positive way. Researchers have adopted the idea of nudging to promote healthy behaviours in the field of Human-Computer Interaction (HCI). Caraban et al. [44] created "The Nudge Deck" to assist designers in creating effective technology-mediated nudging. They develop the cards as a tool to navigate the unstructured theoretical knowledge about nudging and make the information more actionable during the design process.

The deck of cards consisted of 32 cards categorized into three types: *Trigger Cards, Mechanism Cards, and Category Cards.* Trigger Cards help identifying the appropriate moments to implement a nudge, Mechanism Cards feature 23 different nudging mechanisms that provide insights into strategies that can influence user behaviour, Category Cards assist in organising and selecting nudges based on specific behavioural objectives. Examples of nudging mechanisms for social influences includes leveraging social commitment, raising the visibility of users' actions, and enabling social comparison. The mechanisms for reinforcement includes just-in-time prompts, ambient feedback, and subliminal priming. Mechanisms to facilitate includes default options and opt-out policies while mechanisms to confront includes throttling mindless activity and providing multiple view points. The findings of the evaluation indicated that the Nudge Deck significantly enhances designers̓efficiency. It help to bridge the gap between complex theoretical concepts and practical applications [44].

A second cognitive phenomenon, flow, has been researched in a variety of fields, such as gaming, productivity, and creativity. It is defined as the ideal psychological state of profound immersion and enjoyment in an activity. Blanchard et al. [45] presented the "Flow Engine Framework" that describes the dynamic relationships between flow-related elements and cognitive processes. The Input-Process-Output model is the foundation of the framework and is similar to an engine in which flow is produced and maintained by key components. The terms *inputs* refer to the prerequisites for flow, which include objectives, immediate feedback, and a balance between skill level and challenge. Processes describe the cognitive mechanisms that regulate and sustain flow, including attentional focus, motivation, and the combination of action and awareness. Outputs represent the outcomes of flow, such as enjoyment, improved performance, and productivity. The framework are suggested to be applied in various fields, including game design where fostering engagement and productivity is essential [45].

To the best of our knowledge, previous research on BEVs did not addressed how gameful and real-time feedback systems, designed with a user-centred and cognitive aware approach, can be integrated into the DIM to support energy-efficient driving. While studies have explored Eco-driving behaviours, energy interfaces, and gamification individually, few have combined these domains in the context of in-vehicle feedback related to BEV-specific characteristics such as regenerative braking and throttle sensitivity. Moreover, most existing solutions overlook the interactions between behavioural motivation and long-term habits related to interface design. This gap has motivated us to investigate how gamified feedback grounded in cognitive principles and supported by real user input can be used to enhance driver understanding and promote sustainable driving practices in BEVs.

4

Theory

This chapter provides the theoretical foundation for the research by presenting significant frameworks and concepts relevant to the study. It covers topics such as Wicked Problems, User Experience Design, Interaction Design Approaches, Human-Vehicle Interaction, and Information Visualisation, as well as gameful design and cognitive theories. These perspectives inform the planning and design strategies used to address the challenges in this project.

4.1 Wicked Problems

Complex problems in social settings are often referred to as picked problems. These issues are recognised because they evolve and change as attempts are made to solve them, resulting in no clear initial definition. The understanding of these problems shifts as solutions are suggested and tested. This makes addressing wicked problems a non-linear process as problem-solving and understanding occurs simultaneously [46]. Rittel & Webber also state that solutions to wicked problems are not right or wrong. Instead, they are evaluated as better or worse, or sufficient or insufficient [46]. Richard Buchanan further highlights that design thinking plays a crucial role in structuring and framing wicked problems allowing innovative approaches that integrate multiple perspectives and evolving conditions [47].

In this research, our goal is to provide a set of recommendations for a new design concept of an interface solution in BEVs to promote energy-efficient driving through a form of Eco Score. Due to its complexity, this challenge is considered a wicked problem with no straightforward solution. Various factors can influence the issue such as user behaviour, location, environmental responsibility and evolving technology of interfaces and computer models. The problem may have multiple solutions, and the aim of the research is to identify a feasible and optimal solution. Additionally, the iterative nature of wicked problems is particularly relevant as each stage of the process maybe leads to new insights. The solution will be assessed based on the clarity and usability it provides to the user.

4.2 User Experience Design

UX entail all aspects of the end-usert́s interaction with a company, services, and products. It is a dynamic and context-dependent subjective account of human-technology interaction. The field of Human-Computer Interaction HCI has evolved to include an experiential perspective that focuses on the emotional and affective aspects of technology use [48]. Mirnig et al. [49] provides a formal analysis of the International Organization for Standardization (ISO) 9241-210 definition of UX. The official ISO 9241-210 standard defines UX as "A persons perceptions and responses that result from the use and/or anticipated use of a product, system, or service".

The Interaction Design Foundation [50] outlines seven factors that influence UX design to help designers understand what shapes a user's perception and interaction with a product or system. According to the Interaction Design Foundation [50], the factors that influence UX and what it should facilitate are:

- **Useful:** The product or system must meet user needs and provide value. Users will not engage with a product if it does not solve a problem or improve a situation.
- **Usable:** The the product or system should be easy to learn, efficient to use, and be error-resistant. A usable product reduces frustration and increases satisfaction.
- **Findable:** Users should be able to easily locate information or navigate the interface without confusion.
- **Credible:** Users must trust the product. Credibility is built through reliability and transparency.
- **Desirable:** A product should create emotional engagement through appealing visuals and interactions.
- **Accessible:** The design should be inclusive and usable by people with different abilities. This includes considerations like contrast and alternative input methods.
- **Valuable:** The product must provide value to both users and businesses. It should align with user goals while meeting business objectives.

These seven factors interact to create a holistic UX. Designers should aim for a balance among these elements to optimise user satisfaction [50].

UX is a broad term for several design disciplines that is used to create useful, usable, and desirable designs. Cooper et al. [51] emphasises the interconnection of three overlapping areas of concern in UX *form, behaviour, and content* as seen in figure 4.1.

4.3 Interaction Design Approaches

Interaction design is an area that focus on discovering requirements for the product, designing to meet requirements, and producing prototypes to evaluate. The field refers to designing interactive products to support the way humans communicate in their everyday life, and the users and their goals should be consistently considered. It is about creating user experiences that enhance the way people work, communicate,

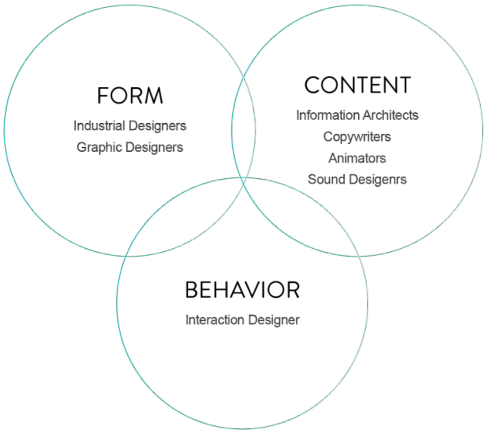


Figure 4.1: UX designs overlapping areas of concern [51].

and interact. Typically, interaction design refers to the field that includes a variety of different theories, frameworks, approaches, methods, and guidelines that designers can apply to deliver appropriate UX [48].

4.3.1 User-Centred Design

One fundamental approach in interaction design is User-Centred Design (UCD) that prioritise the needs, expectations, and limitation of the user during the design process [48]. It is an iterative methodology that relies on user involvement to ensure that the final product is both functional and user-friendly. Active participation of users in the design and development stages is essential. This mean that designers engage with users through methods such as interviews and usability testing to understand their behaviours, preferences, and challenges. It ensures that the design is informed by users actual needs rather than assumptions. In addition, UCD follows an iterative design cycle where prototypes are developed, tested, and refined multiple times based on user feedback. This helps to identify and address usability issues early in the process. The design process begins with in-depth user research to explore their goals. UCD also considers the emotional and experiential aspects of interaction ensuring that products are engaging and satisfying to use. Usability testing and evaluations are conducted at various stages to assess how well the design supports user tasks and whether it meets accessibility and efficiency standards. Compared to traditional functionality driven design approaches, UCD reduce the risk of creating products that are too difficult to use [48].

4.3.2 Research Through Design

Research through Design (RtD) is a method for interaction design research within HCI [52]. The design itself can serve as a probe to generate new knowledge by creating and evaluating interactive products. This method differs from traditional scientific and engineering approaches that rely on controlled environments and hypothesis testing. Instead, RtD focus on exploring possibilities and producing insights throughout the design process. Researchers can uncover new theoretical perspectives and frameworks that might not emerge through conventional methods by producing and iterating on design artifacts. The value of RtD lies in addressing complex, open-ended problems where traditional approaches might not be applicable [52].

4.4 Human-Vehicle Interaction

Human-Vehicle Interaction (HVI) is an important field of modern transportation since vehicles become increasingly automated and intelligent. It refers to the way drivers and passengers interact with a vehicles systems, interfaces, and features. Advancements in automotive technology continue to evolve and the role of HVI start to extend beyond traditional Human-Machine Interaction (HMI) where intelligent systems and automation play a more active role in driving and decision-making processes [53]. However, designing effective human-vehicle interactions requires addressing challenges such as cognitive workload, system transparency, and user trust.

Intelligent in-vehicle interaction technologies is changing the way of transportation where user-centred design aim for automation to assists rather than replace human decision-making. Haptic feedback and adaptive displays provide drivers with information to focus on minimising distractions and enhancing situational awareness. These technologies are important to ensure that human-vehicle interactions remain safe, efficient, and user-friendly [54]. The design of human-vehicle interaction must balance technological advancements with human cognitive and perceptual capabilities.

4.4.1 Cognitive Overload

Mental Workload refers to how humans process information and manage cognitive workload in complex environments such as driving and multitasking scenarios. According to Wickens [55], cognitive resources are divided across four different dimensions. The first dimension relates to the stages of processing that include perception, cognition, and response. Tasks that rely on the same processing stage, such as two demanding activities, are more likely to interfere with each other than those that engage different stages of processing. The second dimension is the modalities of input and output. Since humans process information primarily through visual and auditory channels, tasks that depend on the same modality can create interference and increase cognitive load. The third dimension focuses on processing codes where there is a difference between spatial and verbal tasks. Spatial tasks, such as interpreting a map, and verbal tasks, like reading written instructions, rely on different cognitive systems. Interference is more likely to occur when two tasks are processed in the same code. Finally, the fourth dimension involves response mechanisms. They can can be manual or verbal, such as steering a car or speaking to a co-driver. Performing two tasks that require the same response mechanism leads to greater cognitive load and diminished performance [55].

Wickens model has significant implications for human-vehicle interaction and driving safety [55]. Multitasking while driving becomes particularly problematic when two visual tasks compete for attention. Keeping eyes on the road while reading instructions about the energy consumption on a display is one example of competing tasks. However, presenting some information audibly rather than visually distributes the cognitive load across different modalities resulting in reduced interference. This principle supports the effectiveness of heads-up displays in vehicles, as they allow drivers to keep their eyes on the road while accessing critical information. Understanding how drivers distribute attention and cognitive resources is essential to prevent overload or disengagement from the driving task.

Furthermore, Young and Stanton [56] argue that automation in vehicles does not lead to a linear reduction in mental workload. Instead, it redistributes cognitive demands. Highly automated systems may reduce the need for continuous manual control but increase the demand for monitoring and decision-making in complex situations. This shift can lead to cognitive underload which is a state in where drivers become disengaged and less prepared to take over control when necessary. However, if automation is poorly designed or requires frequent interventions, it can create overload that increase cognitive strain rather than reducing it. Drivers may lose the ability to perform certain tasks effectively, particularly in emergency situations where manual control is suddenly required as automation takeover more driving functions. System design must consider ways to keep drivers engaged and ensure that they retain essential driving skills. Automation can create confusion where drivers misunderstand the current level of automation or overestimate the systems capabilities. This can lead to delayed reactions in critical moments. Young and Stanton [56] highlights the need for intuitive and transparent automation interfaces that clearly communicate the systems status and limitations. Automation should enhance safety without diminishing driver engagement or essential skills.

4.5 Gameful Design

Gamification is not only about adding points, badges, or leaderboards but also about crafting meaningful, engaging experiences by incorporating game design elements into non-game contexts. There is a difference between gameful and playful experiences, where gameful design is structured and goal-oriented, while playful design allows for exploration and creativity [57]. It is important for designers to consider user motivation and the context of use as well as the psychological mechanisms that drive engagement. Effective gamification requires an understanding of motivation relating to that systems should be designed to promote competence, autonomy, and relatedness rather than relying rewards [57].

4.6 Information Visualisation

Information visualisation is an aspect of interaction design that helps users interpret and engage with complex data effectively [51]. By transforming raw data into meaningful graphical representations, information visualisation reduces cognitive load and enables users to recognise patterns and make informed decisions quickly. Clarity should always take priority over decoration. Effective visualisations use hierarchy, contrast, and grouping to guide users toward the most important insights without overwhelming them. The choice of visualisation should align with user needs and the specific tasks they aim to accomplish. Interactivity is also important to consider, allowing users to filter, zoom, and manipulate data enhance their ability to explore information and understand the data [51].

Furthermore, Tufte [58] highlights the importance of presenting complex data in a way that is both precise and efficient. The primary goal of any visualisation should be to convey data clearly without unnecessary distractions. The data-ink ratio is concept that encourages minimising non-essential elements in a graph. Every element should directly contribute to the representation of the data, and irrelevant features, such as unnecessary 3D effects or decorations, should be eliminated to focus on the data itself. Tufte critiques "chartjunk" which is the use of redundant design elements in visualisations that can distort the data. A Good visualisation should be straightforward and unambiguous. The integrity of the data must always be preserved, and any distortion risks reducing the credibility of the visualisation [58].

5

Methods

This chapter introduce the applied process of interaction design used in the thesis and present the chosen methods for each phase of the Double Diamond framework.

5.1 Interaction Design Process

There are multiple design processes in the field of interaction design, but the processes have aspects in common that typically cover multiple stages taken in design along with the methods and tools used. One established interaction design process is the Design Councils design methodology, the Double Diamond, which consists of four phases represented by two diamonds [59]. The first half of a diamond represents the process of investigating a problem in a comprehensive way (divergence), while the second half of the diamond describes the process of deciding and acting, (convergence). The Double Diamond consists of four key phases : *Discover, Define, Develop,* and *Deliver* [59] [48]. The design process is presented in figure 5.1.

Discover is the first phase that focuses on researching the issues and gathering insights from the stakeholders who are affected by the problems. The Define phase is for understanding the insights and shaping the problems in different areas to focus on. The result of this phase is a clear problem definition. After the challenges have been identified, the development phase is to brainstorm possible solutions to design and develop potential designs including testing and iterating on the generated ideas. Lastly, the Deliver phase involves testing the potential solutions and choosing one for further refinement and delivering the most promising solution [59] [48]

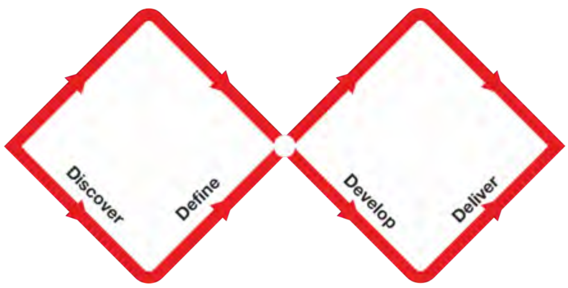


Figure 5.1: Double Diamond design process [59]

5.2 Methods for Discover

In this section, methods considered suitable for the Discover phase are presented. This includes benchmarking, expert interviews, and questionnaires, aimed at gathering insights from users and identifying and addressing challenges.

5.2.1 Benchmarking

Benchmarking is a structured methodology used to evaluate and improve business processes, performance, and best practices by comparing them against industry standards or leading organisations. According to Stapenhurst [60], benchmarking serves as a tool for organisations wanting to enhance efficiency, competitiveness, and innovation. The method of benchmarking involves identifying performance gaps and best practices by studying organisations within the same industry [60].

Benchmarking was used in our research as a method to identify best practices and performance standards within the automotive domain. According to Stapenhurst [60], benchmarking is a effective tool for improving processes and innovation by evaluating your approach against industry competitors. Comparison of existing solutions and user interface strategies used by leading automotive manufacturers enables identification of areas for improvement regarding the display of energy consumption and ensures that the developed solutions are in accordance with current industry standards.

5.2.2 Expert Interview

Expert interviews are a form of qualitative interviews in which the subjects have specialised knowledge or expertise in a particular field, professional or academic [61]. This method can be applied when researchers need to understand specific phenomena that are difficult to investigate using other data sources or when the knowledge required is highly specialized. These types interviews are used to gain insights into complex topics or to gather informed opinions and analysis from individuals who are experts on specific issues [61]. The primary purpose of expert interviews is to gather insights from experts with significant experience and knowledge in driver behaviour and BEVs that are both technically complex and rapidly evolving areas. Conducting expert interviews directly with professionals who have experience and contextual understanding of the challenges in this domain provide in-depth information not available from public sources.

5.2.3 Questionnaire

User research refers to the data collection and analysis needed to understand the users and the context of use before the product development begins [48]. Questionnaires are a technique used to collect users opinions using closed or open questions, where open questions allow participants to give free-form text answers and closed questions restrict participants to one of a limited set of possible answers. They can be distributed to a large number of participants and therefore more data can be collected than with an interview study [48].

Questionnaires is a method to gather input from a broad group of drivers to understand the users aimed to design for. This is particularly valuable in the early stages of the research when gaining an overview of user needs and behaviours was essential for guiding design decisions. The scalability of questionnaires make possible to reach diverse participants which strengthened the reliability and relevance of the findings.

5.3 Methods for Define

The Define phase centres on analysing insights gathered during the Discover stage. The methods presented for the Discover phase in this section are thematic analysis, affinity diagramming, personas, scenarios, and requirement list.

5.3.1 Thematic Analysis

Thematic analysis is a qualitative research method to identify, analyse, and interpret patterns of meaning within the data. Braun and Clarke [62] define it as a flexible and accessible approach that allows researchers to make sense of complex qualitative datasets. The method of analysis consists of six phases. Researchers must first familiarised themselves with the data through repeated reading to begin recognizing potential patterns and gain an in-depth understanding of the dataset. Once familiar with the data, the next phase is coding involving systematically identification of relevant features in the data and assigning codes to meaningful segments [62]. The process of coding can be data driven (inductive) or guided by existing theories (deductive). It can be at a semantic level, focusing on explicit meanings in the data, or a latent level which explores underlying concepts, assumptions, or ideologies. The third phase focus on searching for themes where codes are grouped into patterns that capture significant aspects of the research questions. These themes serve as the foundation for the analysis and should reflect the insights emerging from the data [62].

Following, the fourth phase involves reviewing, refining, and combining themes to ensure they accurately represent the data. The fifth phase is defining and labelling the themes to articulate the essence of each theme. Lastly, the sixth phase is producing the result by weaving together the identified themes into a coherent narrative. The final analysis should offer meaningful interpretations of the themes and their implications within the research context [62].

5.3.2 Affinity Diagram

The method of affinity diagramming is used for organising large amounts of qualitative data into meaningful patterns or themes. This technique is useful during research analysis to help designers synthesise information from user studies [63]. The researchers write individual pieces of data or insights on sticky notes and then collaboratively group them based on similarities. Overarching themes or categories emerge through this grouping process and reveal insights. By engaging multiple team members it fosters diverse perspectives that lead to a more comprehensive understanding of the data [63]. This method is used to transform complex and unstructured information into clear, actionable insights that can guide the design process effectively [63].

5.3.3 Personas and Scenarios

Personas are fictional but realistic representations of users based on research data [64]. These representations help designers understand the needs, goals, and behaviours of their target users. Creating personas can ensure that user needs are taken into account throughout the design process. The purpose of personas is to create a shared understanding of user needs and to keep the user perspective central during ideation and decision making. It can help to make decisions about the features of the product and the overall user experience. They should be based on real user research since data from these sources is synthesised to create a representative character. Scenarios are narratives that describe how personas will interact with a product or service in specific contexts. They help contextualise the persona's needs and behaviours to gain a deeper understanding about user goals and expectations. Personas represents who we design for and scenarios provide a narrative for how and why they use the product [64]. The design team can create targeted and user-centred solutions that align with real-world needs with this method.

5.3.4 Requirements List

A requirements list is a structured document that captures all necessary features, functionalities, and constraints for a product [65]. It serves as a foundational reference to ensure that the final product meets user needs. The purpose is to systematically document user and system needs to serve as a reference for design, development, and testing[65]. User stories is one approach to capture requirements that represents the functionality of value for the user. It is presented in the following format: *As a <role> , I want <behaviour>, so that <benefit>* [48]. This also propose a solution to capture the user experience and usability goal of the designed product [48]. In this research, a requirements list is used to translate insights gathered from user research and expert input into actionable design goals to the Development phase.

5.4 Methods for Develop

The third phase of the Double Diamond aim bring ideas to life by transforming them into a tangible format. This involves creating prototypes with different resolutions with the purpose of evaluating the outcomes. The methods applied in this phase are brainstorming, low-fidelity prototyping, and high-fidelity prototyping described in this section.

5.4.1 Brainstorming

Brainstorming is a structured but free-flowing process designed to generate creative ideas by group collaboration. Effective brainstorming follows a disciplined approach to maximise creativity and innovation. According to Kelly [66], no idea should be immediately criticised or dismissed and unconventional ideas are welcomed. The ideas should be expanded and combined. There should also be a clear problem statement to keep the discussion productive. Sketches and prototypes are used as tools for expressing ideas. The goal is to generate as many ideas as possible before filtering [66]. In the context of this research, brainstorming at in the beginning of the Development phase can explore new design spaces and generate new ideas to be adapted into prototyping.

5.4.2 Prototyping

A prototype is one manifestation of a design that allows stakeholders to interact and explore its usability. Prototyping provides a concrete demonstration of an idea and acts as a tool for the designer to communicate their ideas to users [48]. This method will also help to support design choices, act as a communication device among the team members and a tool for evaluation.

In the design process, prototypes act as filters by helping designers focus on specific aspects of a product while disregarding others [67]. This allow designers to test core functionalities, user interactions, or aesthetic qualities without committing to a fully developed product. The filtering process ensures that critical design elements receive attention while unnecessary complexities are ignored during early development. They also serve as manifestations of design ideas by making abstract concepts concrete. Designers give form to an idea to evaluate feasibility, usability, and desirability while iterating toward a final product [67].

Prototypes vary in fidelity, ranging from low-fidelity sketches and wire frames to high-fidelity models. Each type of prototype provides different insights and guide design decisions at various stages of the process [48][67]. In this project, prototypes are used as tools for extrapolation to improve user experience through iterative development and testing

5.4.2.1 Rapid Prototyping

Rapid prototyping is an iterative design approach that enables designers to effectively create, test, and refine concepts before committing to a final product. This allows for early-stage feedback that informs design improvements and bridge the gap between conceptual design and real-world applications by allowing iterative adjustments based on user insights [68].

5.4.2.2 Low-Fidelity Prototype

Low-fidelity prototypes are easy and cost effective early prototypes. They require little time to create which allows designers to develop ideas rapidly and iterate through multiple versions in a short time frame with little resources. At this stage, it is possible to use low-fidelity prototypes to identify problems with the proposed solution, evaluate and determine whether it meets the requirements and user needs [69].

5.4.2.3 High-Fidelity Prototype

High-fidelity prototypes are more detailed and interactive representations that resemble the final product. These prototypes include actual user interface elements, colours, typography, and animations. This makes it suitable for advanced usability testing in the later stages of development [69].

5.5 Methods for Deliver

Deliver is the final phase of the Double Diamond framework where usability testing is conducted to evaluate the solutions and choose the most promising for delivery. This process can use several combined techniques, such as interviews, focus groups, and think-aloud methods. Combination of methods can provide valuable feedback from the participants.

5.5.1 Focus Group

Focus groups are a qualitative research method used to gather information on user experiences, opinions, and preferences about games and products. Lankoski and Björk [70] highlight focus groups as an effective way to collect subjective data through group discussions. The benefit of using focus groups is that it allows diverse issues to be raised that might otherwise have been missed and is a method to investigate shared issues. The size of the focus group ranges from three to twelve participants [48].

A focus group typically consists of a small number of participants who share common characteristics, such as being belonging to a target audience for a specific product. A moderator facilitates the discussion to guide participants through planned topics while allowing organic conversation to emerge. Participants build on each others responses that lead to deeper insights than individual interviews might provide. Researchers can identify patterns in opinions and attitudes. However, participants may conform to dominant opinions, reducing the diversity of responses, and the way questions are framed can shape responses. Participants should be selected according to relevant criteria, the moderator should use open-ended questions and avoid leading questions that could bias responses [70]. The objectives with with method is to gather users' opinions and attitudes on early stage prototypes to uncover expectations to bring into the second iteration.

5.5.2 Think-Aloud Protocol

The think-aloud protocol is a methodology used in psychology and interaction design to study cognitive processes. It involves asking participants to verbally describe their thoughts and actions while performing tasks, providing insight into their thought patterns and strategies [71]. This method provides an understanding of how working memory is utilised during a given task. The method encourage participants to verbalise their thinking process during the experiment, such as repeating information or using visualisation techniques, offering insight into how thought patterns and strategies relate to the task. It can also be used to identify errors and misunderstandings during the task. The usual procedure for the think-aloud protocol starts with warm-up interview, instructions on how to vocalise thoughts, wrap-up interview, and analysis of the answers [71]. In this research, we conducted an experiment using a think-aloud protocol to evaluate the prototype, as it allows us to observe the cognitive processes of participants while completing predefined tasks in the simulation.

5.5.3 Interview

Methodological triangulation means employing different data gathering techniques to validate the result of one inquiry referring to a similar result obtained through different perspectives [48]. Interviews can be used to compensate for limitations in the other methods. Using semi-structured interviews allows to combine features of both structured and unstructured interviews. There is a basic script with preplanned questions, but the nature of semi-structured interviews allow for follow-up questions such as *why* and *how* to gather a deeper understanding of the answers given by the interviewee [48]. Interviews could be used after the think-aloud protocol to ensure that we gathered information that the participant might not have shared during the test.

6
Planning

This chapter outlines the initial planning of the project, starting from the 20th of January 2025 until the submission of the final thesis in the end of May. The thesis project spans over 19 weeks with first submission to the opponent in the beginning of May. Supervision meetings with Chalmers' supervisor as well as the external supervisor at Volvo Cars were held weekly to ensure the progress and proper development of the project where the intentions of the thesis are held intact. Weekly online diary entries were made to document all project work with text, photos and impressions to support evaluations of the work made, and to help identify eventual modifications.

The project consists of four main phases: *Discover, Define, Develop* and *Deliver*. These follow the double diamond method described in section 3, which construction of the project is built around. Additionally, the phases Planning and Report Writing are meant to fulfil the academic requirements of the thesis. As the project is done at Volvo Cars, who has employed the writers as master thesis workers for a limited time, three presentations will be held at the request of the external supervisor to give insight into the thesis work and how it relates to the company and the future development of BEVs. The first one being an introduction as well as a presentation of benchmarking of competitor cars, the second a mid-presentation to inform of progress and the third one being a final report on findings summarizing the work.

6.1 Gantt Chart

A Gantt chart was created in the beginning of the project to visualize the initial time plan, with reservations for modifications which can occur during the working process. The visual representation of milestones, tasks and phases of the project was vital to keep track of progress and possible clashes of tasks, with the proposed structure seen in 6.1 and 6.2 the goals for a smooth process. The different phases discussed in the beginning of the chapter have been colour coded with corresponding colour filled cells representing weeks. Milestones and deadlines have been marked and written out such as scheduled presentations at Volvo Cars and submissions of the planning and final report. Weekly diary reports and synchronization between the writers of the thesis are incorporated into the planning, as well as weekly meetings with supervisors to ensure clear communication and opportunity to raise potential issues needing adjustment. No significant changes were made to the Gantt chart throughout the project.

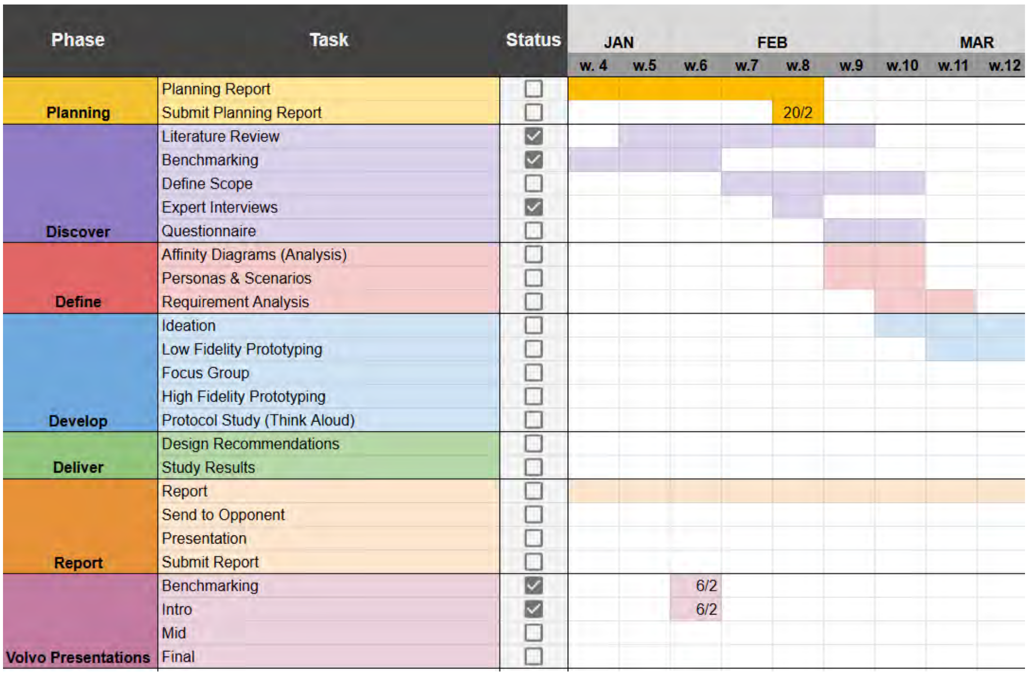


Figure 6.1: Gantt chart illustrating the planned time plan of the project colour coded and divided into phases with tasks from January to March

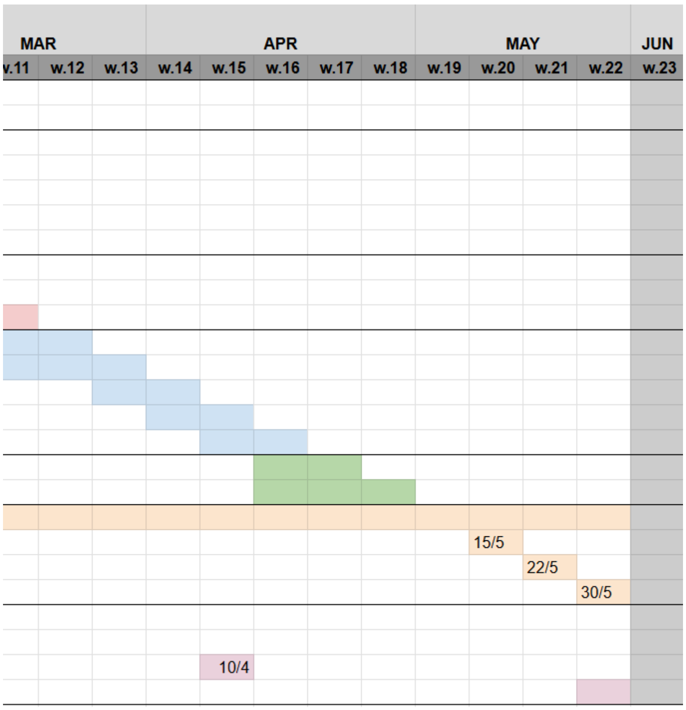


Figure 6.2: A print screen of a Gantt chart illustrating the time plan process of the project from March to May

7

Execution and Process

This chapter describes how the methods were applied and how they were executed in each phase of the Double Diamond framework in the interaction design process. It consists of four sections that correspond to the four phases of the Double Diamond which are the chosen interaction design framework for this thesis. The four phases of the Double Diamond includes *Discover, Define, Develop*, and *Deliver*. Refer to Chapter 5 for further explanation of the framework and methods applied.

The research process is organised into two main stages. The first stage, which consists of the Discover and Define phases, pictured in 7.1, involved comprehensive research, including competitor benchmarking, interviewing experts, and running a questionnaire. This helped creating personas and scenarios as well as develop a list of requirements. The focus was on defining and refining the scope of the project and understanding the specific user group for which the research would aim.

Figure 7.1: visualisation of the Double Diamond Design Framework with all included processes.

Following the first stage, the work progressed to the second part of the research that involved the Development and Deliver phases of the Double Diamond. The process of the second stage is visualised in 7.1. The iterative process was based on the previous requirements list and included brainstorming, prototyping, evaluation, and analysis of each iteration. The final result after two iterations was the establishment of design recommendations. Following sections describe each step of the process in detail.

7.1 Discover

The discovery phase aimed to gather a wide range of data. Both qualitative and quantitative information was collected to understand the problem and the needs and goals of the users. All of the methods mentioned were performed to gain an in-depth understanding of the problem space and to gather data for further research and development.

7.1.1 Benchmarking

In this research, competitive benchmarking was performed to evaluate the power consumption-related display functions of Volvo cars to direct competitors. The purpose was to understand how modern premium battery electric vehicles BEVs visualise energy usage and provide feedback to drivers, particularly in terms of promoting energy efficient driving behaviours. Competitive benchmarking was carried out in the early stages of the project to establish an understanding of how energy consumption data is currently presented across the market.

During the initial Discover phase, benchmarking was used to build domain knowledge about the BEV market, with a focus on Volvo Cars and their recent BEV releases. Since the prototypes developed in this project were intended to be integrated into or built around existing in-car interfaces, it was essential to gain an understanding of current interface designs and information visualisation strategies. Benchmarking included both Volvo Cars' vehicles and competitors' models to assess stylistic and functional variations, as well as to identify different visualisation techniques for energy-related information. The methodology regarding this benchmarking process is discussed further in Chapter 5, Section 5.2.1.

The benchmarking focused primarily on two display systems: the DIM and the CSD. Specific attributes of interest included the visualisation of power meters, range fluctuations (increase and decrease), OPD functionality, and the presence of eco-features. These are functions intended to promote environmentally friendly driving or optimize vehicle settings for energy efficiency. The aim was to discover established strategies to visualize energy consumption, provide actionable feedback, and manage cognitive load by balancing information complexity.

Volvo XC40 and EX30 models were compared with other BEVs from leading markets including Europe, Asia, and the United States. The cars tested were Polestar 2, Hyundai Ioniq 6, NIO ET5, XPENG G9, BMW X5, Tesla Model 3, Mercedes EQE, Mercedes EQS, Audi Q6, and Volkswagen ID.7. Differences were analysed in terms of metrics shown, their screen placements, stylistic approaches, and how real-time feedback was communicated through the DIM and CSD. Attention was also given to the presence and implementation of OPD and other Eco-driving modes.

The vehicles were evaluated in controlled driving scenarios on a test track as well as on the road in Gothenburg, Sweden. To avoid the activation of automatic energy-saving features, all test drives were conducted with a battery charge above 20%. Prior to each drive, the available energy-related information was reviewed in the

CSD while the car was stationary, with specific focus on the location and accessibility of SoE data, trip information, and historical consumption records. During the drive, the focus shifted to the immediate feedback offered in the DIM, such as real-time changes in the power meter and range. Where applicable, dynamic feedback in the CSD was also observed. For vehicles with a single display, emphasis was placed on evaluating the power meter and any dynamic feedback features. In cases where navigation was activated during the test, its impact on the visibility and prioritization of energy-related information was also assessed. One of the team members were assigned as a driver and the other team member were responsible for documentation by taking notes and photograph relevant findings.

Each benchmarking session involved a series of driving manoeuvrers including smooth acceleration, rapid acceleration, and harsh braking. These were performed both with standard two-pedal driving and OPD, when available. The purpose was to examine how driving patterns affected the feedback in the displays in terms of clarity and intuitiveness.

7.1.1.1 Summary of Benchmarking Result

Bellow are a summary of the main results from the benchmarking that were brought into consideration when developing design solutions. Refer to Chapter 8 in Section 8.1.1 for full result of the benchmarking.

- Volvo Cars performed well in providing accessible and clear visualisations of technical energy usage data.
- Driving interfaces displayed a modest amount of energy-related information during driving.
- Gamification was rare with only Mercedes EQE and EQS using scoring systems and visual feedback in Eco Mode.
- Power meter designs were largely consistent across brands, though colour and angle varied:
  - Green often indicated regeneration, potentially influenced by cultural associations.
  - Power usage visuals often presented in grey lacked visual prominence.
- Visual feedback during driving was generally positive and focusing on energy regeneration.
- 3 of 12 vehicles relied solely on the CSD, which offers limited and potentially distracting feedback, possibly indicating a trend away from dedicated driver interfaces such as the DIM.
- 4 of 12 cars offered an explicit Eco Mode that adjusted settings for better efficiency.
- Some vehicles included historical graphs, with a few breaking down energy usage by categories like speed, climate control, and driver behaviour.

7.1.2 Data Collection

Two complementary data collection methods were applied to explore the topic from different perspectives during the Discovery phase. Expert interviews and a questionnaire were the methods selected to investigate the technical feasibility of the proposed solution, as well as to better understand driver behaviour and attitudes. Expert interviews provided insights from professionals with relevant technical and industry expertise to assess feasibility and safety. In parallel, the questionnaire targeted end users to gather data on driving habits, behavioural patterns, and general attitudes related to the topic of energy efficient driving and visualisation of information on energy consumption.

7.1.2.1 Expert Interviews

To gain insights into both the complex technical aspects of battery electric vehicles BEVs and the human factors influencing driver behaviour, two expert interviews were conducted during the Discovery phase of the project. The aim of these interviews was to complement the user research by providing domain-specific knowledge that could guide design decisions and ensure technical feasibility and safety.

The study was designed as a qualitative inquiry using a semi-structured interview format. This approach allowed for a consistent thematic structure across the interviews while providing the flexibility to ask follow-up questions for deeper understanding of emerging topics. The script and prepared questions can be presented in Appendix A.

Both participants were two experts employed at Volvo Cars. The first expert specialised in energy management. The expert contributed with technical insights into how the BEV battery functions under different conditions. This interview addressed topics such as the role of regenerative braking, typical operational patterns, and the effects of one-pedal driving on battery performance relevant to the research questions. The objective was to develop a clear understanding of the technical factors influencing energy-efficiency in BEVs and what factors the driver can affect.

The second expert specialised in driver behaviour and risk management. This interview focused on how drivers interact with vehicle systems during real-world driving and the cognitive and behavioural risks associated with distraction. Particular attention was given to how real-time feedback might influence driver behaviour without compromising safety as it is a central consideration in the development of any driving intervention.

Each interview lasted approximately one hour and was conducted in person. Audio from both sessions was recorded and transcribed.

7.1.2.2 Questionnaire

A questionnaire study was conducted aiming to gather insights into the driving behaviour, perceived needs, and preferences of BEV users concerning energy efficient driving and consumption information. The goal was to understand how drivers currently perceive and interpret the energy consumption data presented in their vehicles, identify gaps in the information provided, and explore user preferences regarding how such data should communicated.

A digital questionnaire was designed to collect these insights using Microsoft Forms [72]. The questionnaire was distributed via the CoDev fleet team to approximately 400 Volvo Cars employees. The CoDev fleet is detailed in Section 8.1.3 of Chapter 2 and consist of employees who lease a BEV, either a Volvo or a Polestar, through the companys internal vehicle leasing program. This recruitment approach enabled access to a relevant and sizeable user group that made it possible to gather both quantitative and qualitative data at scale which would be difficult to achieve using qualitative methods alone.

In total, 176 respondents completed the questionnaire. The study targeted BEV drivers within the company to ensure that participants had experience with driving a BEV.

The questionnaire consisted of four sections designed to collect data:

1. Demographic information to understand respondents background.
2. General driving information to capture typical usage patterns.
3. Challenges to explore user pain points related to energy consumption feedback.
4. Improvements to collect needs and preferences for information presentation.

Respondents completed the questionnaire online at their convenience, and the questionnaire can be seen in Appendix B. The findings derived from this study are further analysed in Section 7.2.1.3.

7.2 Define

The objectives of the Define phase was to gain an understanding of the BEV drivers and their attitudes, wants, and needs, connected to energy efficient driving, to develop research-based prototypes. This was done by analysing the data collected during the Discovery phase with thematic analysis and affinity diagrams. The insights were used to create personas, scenarios, and a requirement list.

7.2.1 Data Analysis

As both qualitative and quantitative data were collected during the Discovery phase, separate analysis methods were applied to extract meaningful insights. The qualitative data obtained through two semi-structured expert interviews was analysed using thematic analysis to identify recurring themes relevant to energy efficient driving, energy consumption, and driver safety. To support this process, affinity diagramming was used to organise insights from open-ended responses to the questionnaire and interview transcripts. This analysis was conducted using Miro [73], an online collaboration tool.

The quantitative data gathered through a questionnaire distributed to BEV drivers within the CoDev fleet, was analysed using Microsoft Excel [72]. This was to identify trends in user behaviour and informational needs regarding energy consumption. This combined approach enabled a comprehensive understanding of both the technical and human factors relevant to the project.

7.2.1.1 Analysis of Expert Interviews

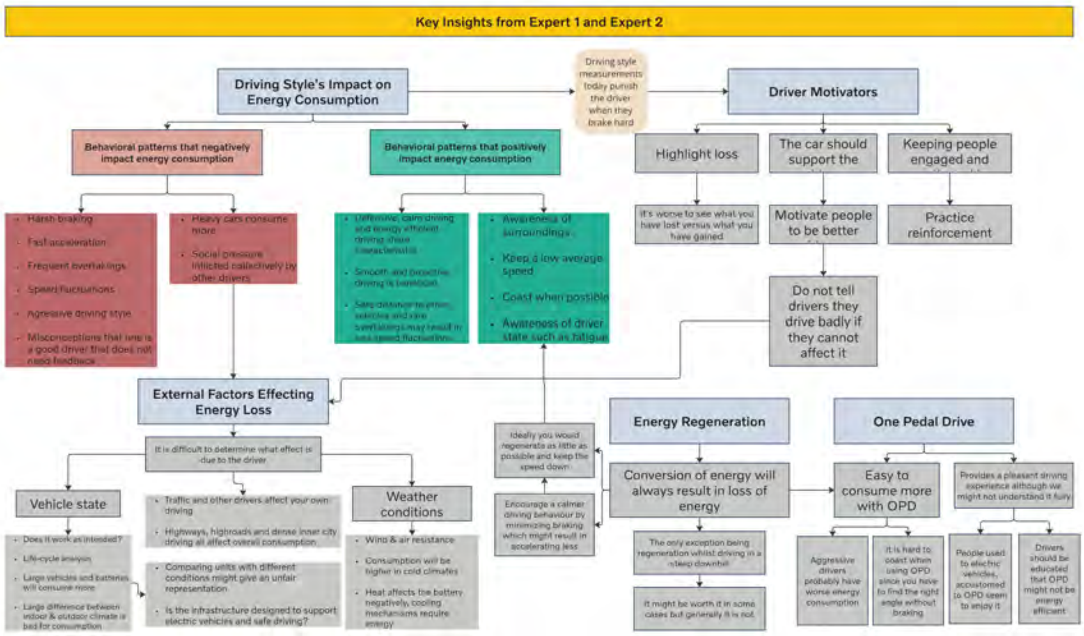


Figure 7.2: Key insights from expert interviews displayed in an Affinity Diagram.

The data collected from the expert interviews was analysed using inductive thematic analysis. The transcripts were first coded on a semantic level and then analysed on a latent level when grouping the emerged themes. Figure 7.2 shows an example of the initial coding of topics raised by the interviewees. The method for analysing was suitable to revile explicit statements but also the underlying ideas and meanings within participants responses.

The analysis process began with repeated reading of the transcripts to ensure familiarity with the data. Relevant statements were then coded and interpreted in relation to the research questions. Emerging codes were then grouped into overarching themes, which were refined and defined to ensure they accurately represented the data and provided meaningful insights. More details about the thematic analysis method is described in Chapter 5, Section 5.3.1. Miro [73] was used to support this process by visually organising codes and build an affinity diagram to identify patterns and relationships across the interviews. Figure 7.3 shows an example of codes grouped under the overarching themes of expert interviews. The results of the expert interviews are described in further detail in Section 8.1.2 of Chapter 8.

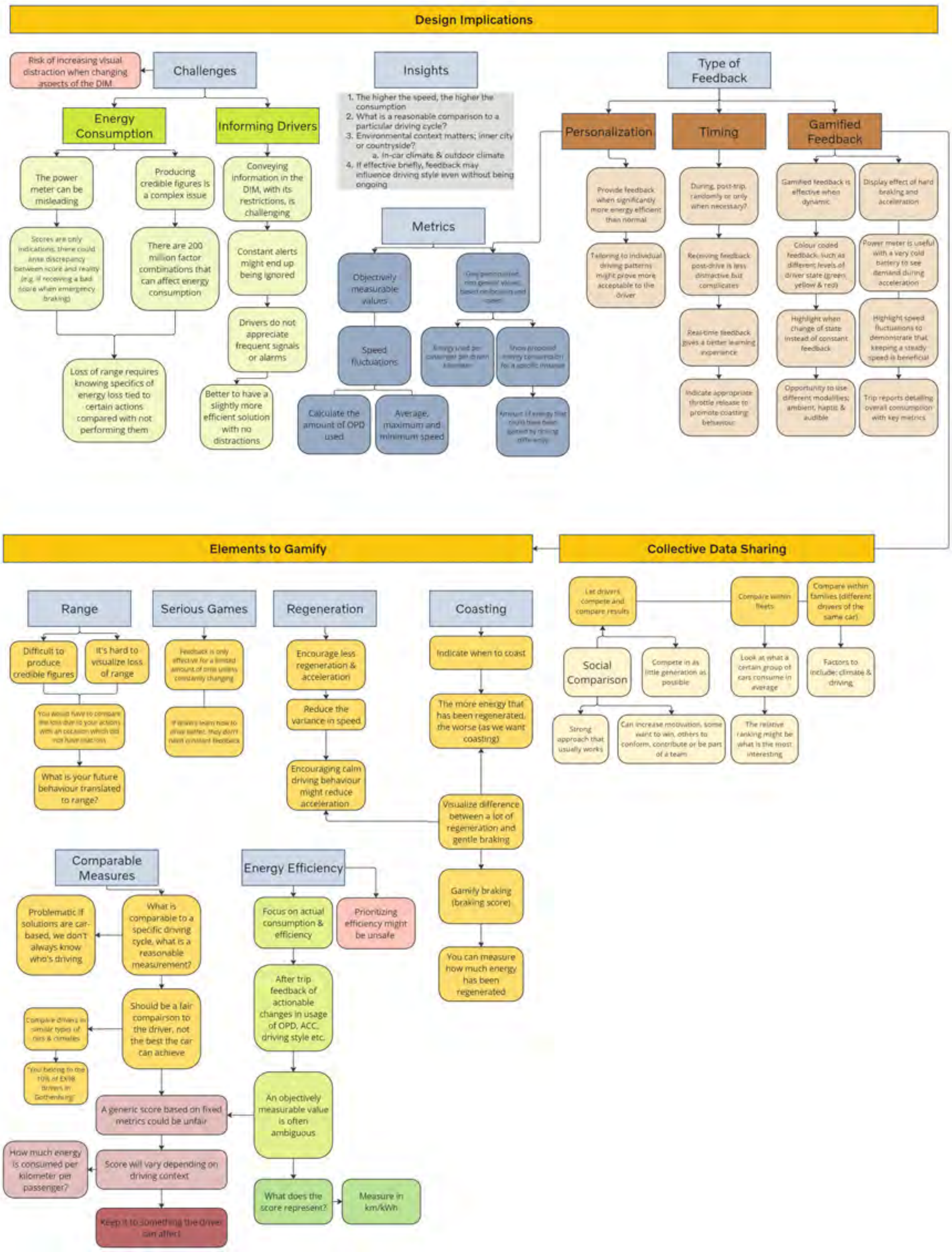


Figure 7.3: Affinity Diagram of overarching themes from expert interviews.

7.2.1.2 Summary of Expert Interview Result

In this section a brief summary of the result from the expert interviews are presented that were considered in the following phases. The analysis of the interviews are described in Section 7.2.1.1 and more extensive result of the interviews are presented in Section 8.1.2 of Chapter 8.

Efficient Driving Behaviour
Calm and defensive driving characterised by smooth acceleration, minimal braking, coasting, and maintaining low, consistent speeds reduces energy consumption. Aggressive behaviours like speeding, hard braking, and frequent overtaking lead to higher energy use.

Limitations of Regenerative Braking
Regeneration generally results in energy conversion loss. It is only beneficial in certain conditions such as driving downhill or when the vehicle speed must be reduced due to the surrounding traffic environment. OPD enhances driving comfort but may not allow for coasting and promote energy waste for inexperienced or aggressive drivers.

External and Uncontrollable Factors
Many influences on energy use such as weather, traffic, vehicle size, and social pressure are outside the driver's control. Feedback systems should avoid punishing drivers for factors they cannot affect and instead support positive behavioural change.

Gamified and Dynamic Feedback
Dynamic, real-time, and personalised feedback can effectively influence behaviour and maintain driver engagement. Gamified elements such as scoring, highlighting state changes, and social comparison can increase motivation if they focus on controllable actions.

Measuring Energy Use
Accurate performance metrics are difficult due to numerous variable factors. Displayed values should be objective and relevant.

7.2.1.3 Analysis of Questionnaire

The collected data from the questionnaire was analysed using a combination of quantitative and qualitative methods. The aggregated results of the closed questions were processed using Microsoft Excel [72]. Open-ended free-text responses were analysed using affinity diagramming in Miro [73], a method suited for identifying patterns and themes across large datasets. An example of an affinity diagram performed on the qualitative data from the questionnaire can be seen in figure 7.4.

7.2.1.4 Summary of Questionnaire Result

Following, a summary of the results from the questionnaire is presented that were the central for the development of requirement list, personas, scenarios and proposed design solutions. The full result is presented in Chapter 8, Section 8.1.3.

Motivation for Driving BEVs
Users are primarily motivated by environmental sustainability, followed by economic benefits, driving experience, and personal curiosity.

Energy-Efficient Driving Actions
Most users regulate speed, drive smoothly, and optimise in-vehicle systems. However,

Figure 7.4: Affinity diagram of free-text answers from the questionnaire.

many rely on intuition or outdated assumptions for example belief in the efficiency of OPD, and some take no conscious actions.

Difficulty Finding Information
Users find energy data scattered across the DIM, CSD, apps, or calculate it themselves. Many struggle with a lack of historical data, clear information, and some do not seek the information at all due to uncertainty about where or how to access it.

Difficulty Interpreting Information
Users report challenges in understanding real-time metrics, units of measurement, and regeneration mechanics. Feedback often lacks historical context or is too subtle to be noticed while driving.

Preferred Feedback Location
Users strongly prefer energy feedback in the DIM. They want clear, colour coded, contextual, and optionally interactive feedback that is easy to interpret, with the option for historical analysis and educational pop-ups.

Desire for Rewards and Competition
Many users are interested in gamification suggesting points, levels, performance comparisons, and competitions with family or past drives to boost motivation and engagement in energy-efficient driving.

7.2.2 Requirement Identification

To guide the upcoming development phase where design concepts will be created to promote energy efficient driving, a structured requirement identification process was carried out. The foundation for this process was built on the results from the questionnaire, complemented by insights from the expert interviews. The data was analysed to understand user behaviours and needs related to energy consumption in BEVs. From these insights, user characteristics and patterns were put into personas that represent typical BEV drivers. These personas were then used to create scenarios that illustrate realistic interactions and challenges users may face. Based on the personas, scenarios, and user feedback, a list of design requirements was compiled. This list served as the basis for design decisions in the development phase and ensures that the proposed solution aligns with both technical feasibility and user needs without compromising safety.

7.2.2.1 Creating Personas

Two personas were created to portray typical BEV users. The purpose of the personas was to create a common understanding of who the users are and refer to them while developing the design concepts. All the data collection in the Discovery phase was a basis for the personas. However, the result from the questionnaire acted as the main source since it was distributed to a large amount of drivers. The common denominator of BEV drivers were that they care about sustainability. However, the preferences and needs varied. Two main types of users could be identified by reviewing the material, either people who were interested in a technology-driven solution or who were interested in a simple solution. The personas were given different experience levels, lifestyles, and priorities to exemplify the diversity of ordinary BEV drivers. See Chapter 8, Section 8.1.4 for the personas created. Bellow is a brief summary of the personas created.

Persona 1:
A sustainability minded commuter and tech enthusiast who enjoys long trips but struggles with range anxiety and trip planning. He values real-time energy feedback and navigation support, especially for shared vehicle use.

Persona 2:
A performance-driven urban professional who values efficiency and simplicity. She uses OPD for city driving, prefers concise, actionable feedback, and is motivated by personal performance tracking.

7.2.2.2 Formulating Scenarios

Two representative scenarios was developed to capture the different driving contexts and user behaviours based on the insights gathered from the questionnaire and the previously defined personas. These scenarios aim to ground the design process in realistic situations to keep the development of the design user-centred.

Two scenarios were formulated. One scenario was driving long distances that reflects user behaviours involving highway travel or extended commutes that require route planning. This scenario correspond to a screen layout that includes navigation information and therefore limit the available space to give additional feedback. The second scenario focused on urban driving. This scenario align with an interface showing surrounded traffic and situational awareness. These scenarios address the problems raised by the respondents to questionnaire. The scenarios provided a foundation for developing and testing energy feedback concepts in the next phase and can be seen in Chapter 8, Section 8.1.5.

7.2.2.3 Establishing Requirements List

A requirement list was established to summarise the findings from the Define phase and represent the key user needs that emerged from the research. These requirements form the foundation for designing a solution that supports energy efficient driving. We were able to derive a set of user-centred requirements by identifying recurring patterns and needs across the sources. Each requirement was formulated as a user story following the structure: *As a <role>, I want <behaviour>, so that <benefit>* [48]. This format was chosen to maintain a clear connection between user goals and system functionality. Only requirements supported by multiple data points, such as shared user frustrations or needs were included. The resulting requirement list guided development phase, informing the creation of prototypes and acting as a first iteration toward more refined design recommendations. The list of requirements can be seen in the table bellow, and further explanation can be found in Chapter 8, Section 8.1.6.

Table 7.1: Summary of Requirements

No.	Requirement
R1	As a user, I want information to be minimalistic, clear and easy to understand so that I am not distracted as a driver.
R2	As a user, I want dynamic real-time feedback to highlight my behaviour so that I have the possibility of correction.
R3	As a user, I want my energy efficient driving behaviour to be rewarded so that I can be motivated to adopt energy efficient habits.
R4	As a user, I want to compare results of accumulated behaviour between drivers of the same vehicle under fixed conditions so that I can learn and be motivated to do better.
R5	As a user, I want to be shown in what ways I can improve my energy consumption, excluding factors which I cannot affect, so that feedback includes actionable solutions.
R6	As a user, I want to be encouraged to have a smooth drive with soft braking and slow acceleration where coasting is the ideal behaviour, so that my energy usage can be improved.
R7	As a user, I want colour coded visual feedback to be discrete, simple shifts in hue or shade should indicate consumption patterns so that I can easily understand the meaning of the feedback.
R8	As a user, I want to be shown numbers as objective values such as average speed where keeping an even speed is encouraged so that the feedback is fair to me.
R9	As a user, I want changes over time, such as average and historical measures of consumption, to be used to educate me so that I can easier understand the rapid changes of the dynamic power meter.

7.3 Develop

The Development phase began with brainstorming grounded in the findings from the Discover and Define phase. It was an iterative process that involved designing, testing and refining the design concepts and it was conducted in two iterations. The first low-fidelity design concepts were tested in two focus groups. The concepts were then consolidated into one refined design based on the feedback. The semi-functional prototype were tested using the think-aloud protocol method to gain deeper insight into the user experience. The details regarding the process and execution of the Development phase are described below.

7.3.1 Iteration 1

The first iteration in the development phase focused on transforming user needs and requirements into design concepts. Based on the outcomes from the brainstorming session guided by user insights and requirements identified during the Discovery and Define phases, four low-fidelity interface concepts were created. These concepts aimed to explore different ways of promoting energy efficient driving through in-car interfaces.

Two focus group sessions were conducted to evaluate these early-stage concepts. Focus groups were selected as the evaluation method due to the suitability for exploring initial reactions and concerns in a collaborative setting. This method allowed participants to reflect on the proposed designs and engage in discussions that generated valuable feedback beyond individual perspectives.

The goal of this iteration was to decide the overall direction of the concepts and identify usability concerns before continuing with more detailed prototyping and testing. The insights gathered during the focus groups informed the refinement of the concepts and the design of the next iteration.

7.3.1.1 Development of Low-Fidelity Prototypes

At the beginning of the Development phase, a brainstorming session was conducted to generate a wide range of initial design concepts that aim to promote efficient driving. The session focused on translating previously identified user requirements into interface ideas through rapid and time-constrained sketching. This time-constrained approach was intended to promote creative thinking during the early stages of ideation. The session included individual ideation followed by discussions where the ideas were presented to identify common themes and build upon each other's suggestions. Prioritising quantity over perfection allowed for exploration of a wide variety of ideas.

Following the brainstorming session, four promising concepts were selected based on how well they aligned with user needs and requirements. These concepts were iteratively refined and translated into wireframes using Figma [9]. Given the users' wants for real-time feedback in the DIM, this screen was chosen as the primary interface to focus on as presented in Chapter 8, Section 8.1.3. New prototypes were developed using existing Volvo Cars design components and design language to ensure visual consistency and brand alignment. The values in the concept are only for visual examples and do not necessarily reflect real-world values. Examples of values that was not considered in this research were range and battery state of charge. The resulting low-fidelity prototypes consisted of static frames to communicate layout and content structure without interactivity.

Concept A: Northern Lights Style Indicator
Concept A was developed as a solution to minimize distraction by providing peripheral feedback. It was based on the result of the expert interviews where concerns about distraction in real-world driving situations were raised. Responses from the questionnaire also reviled the need for dynamic-feedback and colour coded feedback. The prototype was intended to show different light settings behind DIM to give real-time ambient feedback on how energy efficient the user drives. The low-fidelity prototype of the concept that were presented to focus groups for evaluation is presented in figure 7.5.

Concept B: Balancing Energy Usage Level
Concept B was developed as a visual metaphor inspired by a water level aiming

Figure 7.5: Prototype of Concept A.

to communicate smooth and energy-efficient driving through balance and stability. Results from the expert interviews showed that smooth driving is essential for energy-efficiency. Initial user feedback from the questionnaire highlighted a preference for dynamic feedback in the DIM that require minimal cognitive effort while driving. Feedback also suggested the importance of colour coding. The presented prototype of Concept B can be seen in figure 7.6.

Concept C: Driving Style Meter
Concept C was developed with similar functionality as Concept B. The driving style iconography was already implemented in Volvo cars but in the CSD through the Range Assistant app. This concept could utilise familiarity to make it easier for users to understand the functionality. The prototype of Concept C that was presented to the focus groups is presented in figure 7.7.

Concept D: Coasting Score
Concept D was developed based on the user feedback about wanting a form of reward system. The user gets a score based on how much they have coasted, i.e. not used harsh brakes to stop. Welcome screen show the previous score form the last drive. Pop-ups appears when the driver has gained a point during the drive. When parked, the driver receives a new score and can compare the score with other drivers of the same vehicle. The last screen also contains objective metrics to inform the driver about the factors affecting the score. The prototype of concept D is shown in figure C.4d.

7.3.1.2 Focus Group to Evaluate Low-Fidelity Prototypes

The aim of the focus group study was to evaluate the four low-fidelity design concepts developed in the first iteration of the Development phase and gather early

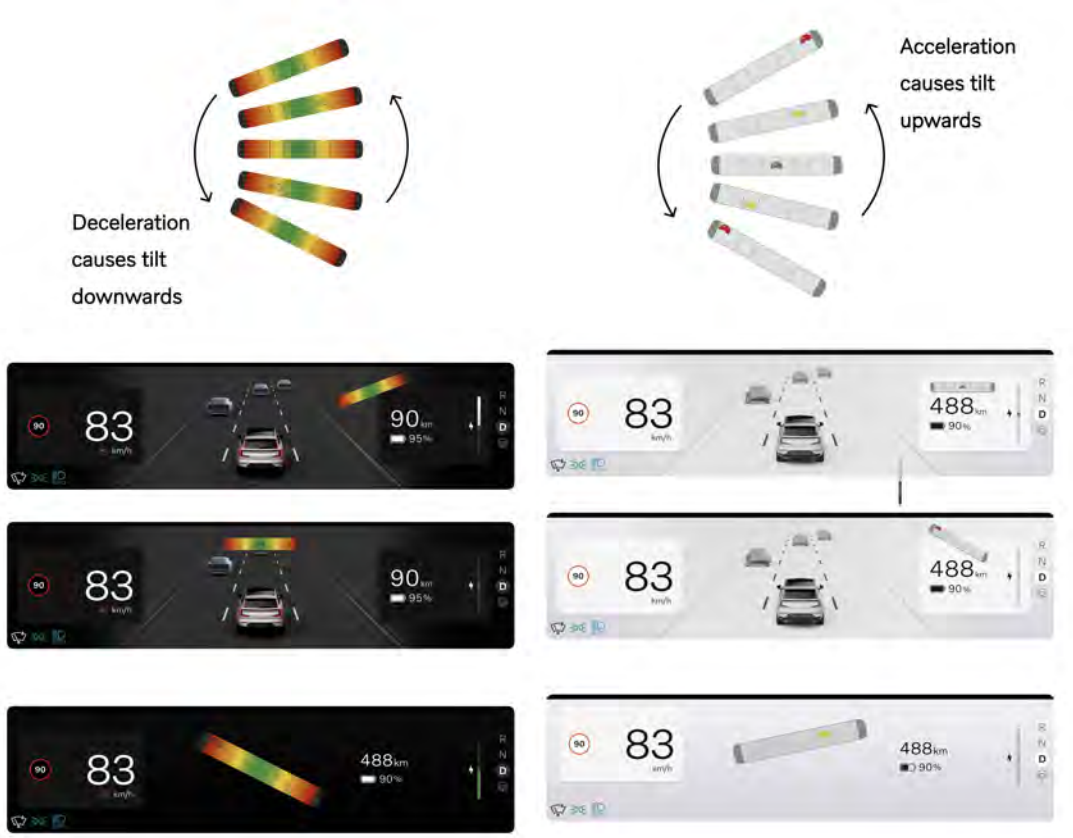


Figure 7.6: Prototype of Concept B.

Figure 7.7: Prototype of Concept C.

feedback on their perceived usefulness and potential for promoting energy-efficient

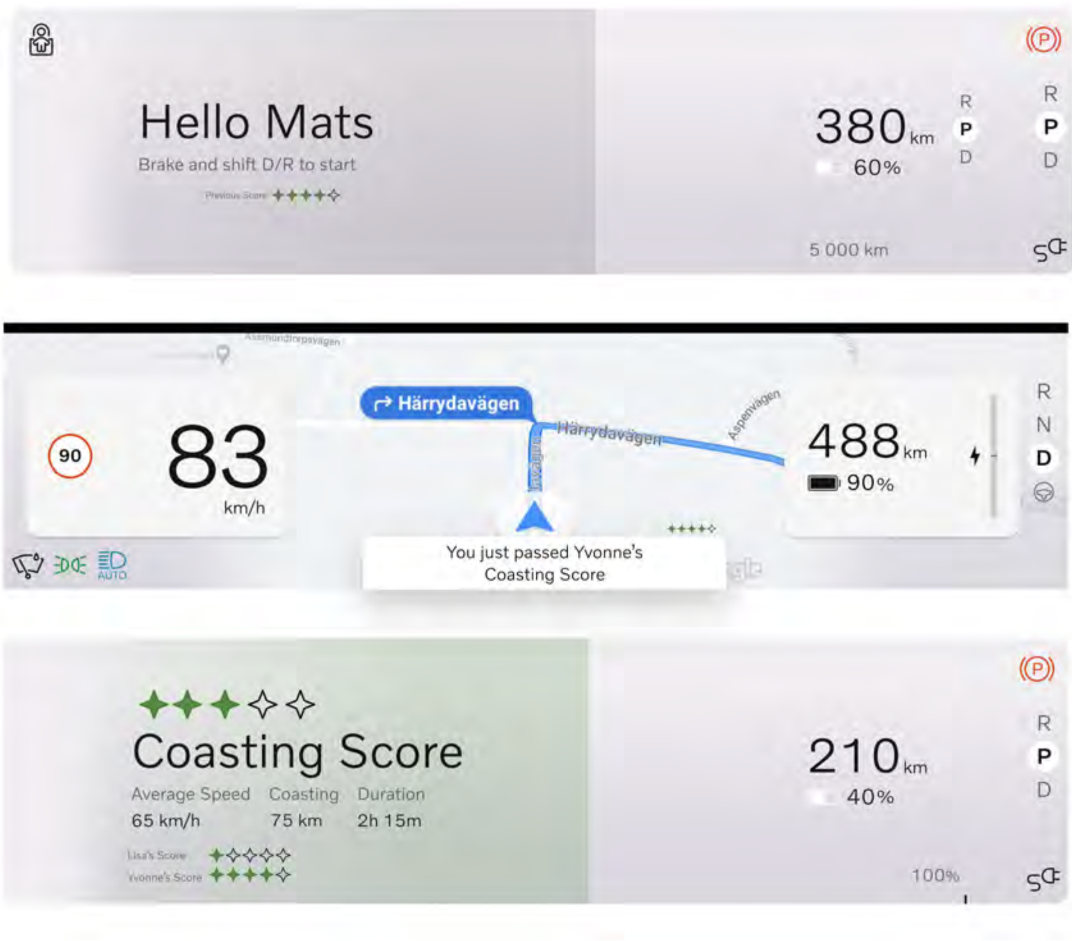


Figure 7.8: Prototype of Concept D.

driving. Focus groups were chosen as the method to generate qualitative insights through participant interaction and discussion. This method was used because of the exploratory nature in the early stages of design for participants to collaboratively reflect on and respond to ideas and suggestions for improvement for iterative refinement.

A total of two focus groups were held to increase the diversity of input while ensuring manageable group dynamics that support active participation from all attendees. Conducting two sessions allowed for cross-validation of insights and helped mitigate the risk of groupthink or overly dominant voices influencing the discussion in a single setting. A pilot focus group was conducted prior to the main session with two BEV drivers to make sure that the structure and materials were effective.

The participants in the focus groups were recruited via a post on Viva Engage, an internal social media platform used by Volvo Cars employees [72]. Posters and brochures were also printed and distributed in social areas on site at the Torslanda offices as seen in figure 7.9. The recruitment criteria specified that participants should be regular drivers of BEVs and currently employed at Volvo Cars. A second manual screening was performed to ensure diversity in background and demographic.

This ensured that the sample reflected the target user group and brought relevant experience to the evaluation. The full list of participants in each focus group can be seen in Table 7.2 and Table 7.3.

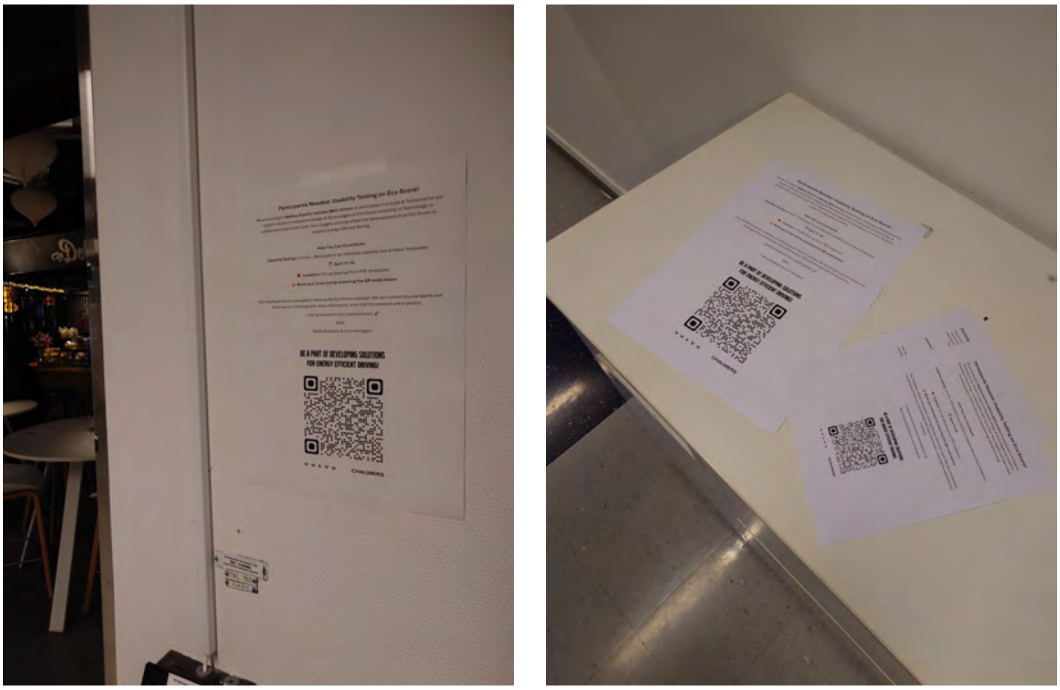


Figure 7.9: Examples of locations of poster and brochures distributed.

The first focus group included three participants and the second included four. Each participant was asked to sign a consent form before the session began to ensure ethical research practices. The participants were introduced to the topic of energy efficient driving and the purpose of the session. They were then presented with the personas and scenarios developed from the Define phase as seen in Section 8.1.4 and Section 8.1.5 of Chapter 8. These were projected on a screen and remained visible throughout the session to serve as reference points during the discussion. The four design concepts were printed on A3 sheets and physically distributed to participants. Each participant was provided with pen and paper to annotate the concepts, make sketches, and note suggested improvements.

Table 7.2: Participants Focus Group 1

Participant	**Age**	**Gender**	**Vehicle**	**Background**
P1	30-39	Male	BMW i3 REX	Software Engineer
P2	40-49	Male	Polestar 2	Innovation Lead
P3	30-39	Female	Volvo EC40	Design Engineer

A semi-structured discussion format was used with a set of prepared interview questions designed to steer the conversation while still allowing for flexibility and organic discussions. Participants were encouraged to express their thoughts freely, discuss differences in interpretation, and propose alternative ideas. Audio were recorded

Table 7.3: Participants Focus Group 2

Participant	Age	Gender	Vehicle	Background
P1	50-59	Female	Volvo EC40	Function Owner
P2	50-59	Male	Renault Megane E-Tech	Development Engineer
P3	18-29	Female	Volvo EX30	Design Engineer
P4	3039	Male	Volvo EX40	Senior Analysis Engineer

for transcription and later analysis. Photographs were taken to capture the setting and any physical sketches or annotations made by participants during the discussion. Refer to Appendix C for more details on the procedure and script of the focus groups. Example of the setup with participants can be seen in figure 7.10 where the screen is projected behind the experiment leader.

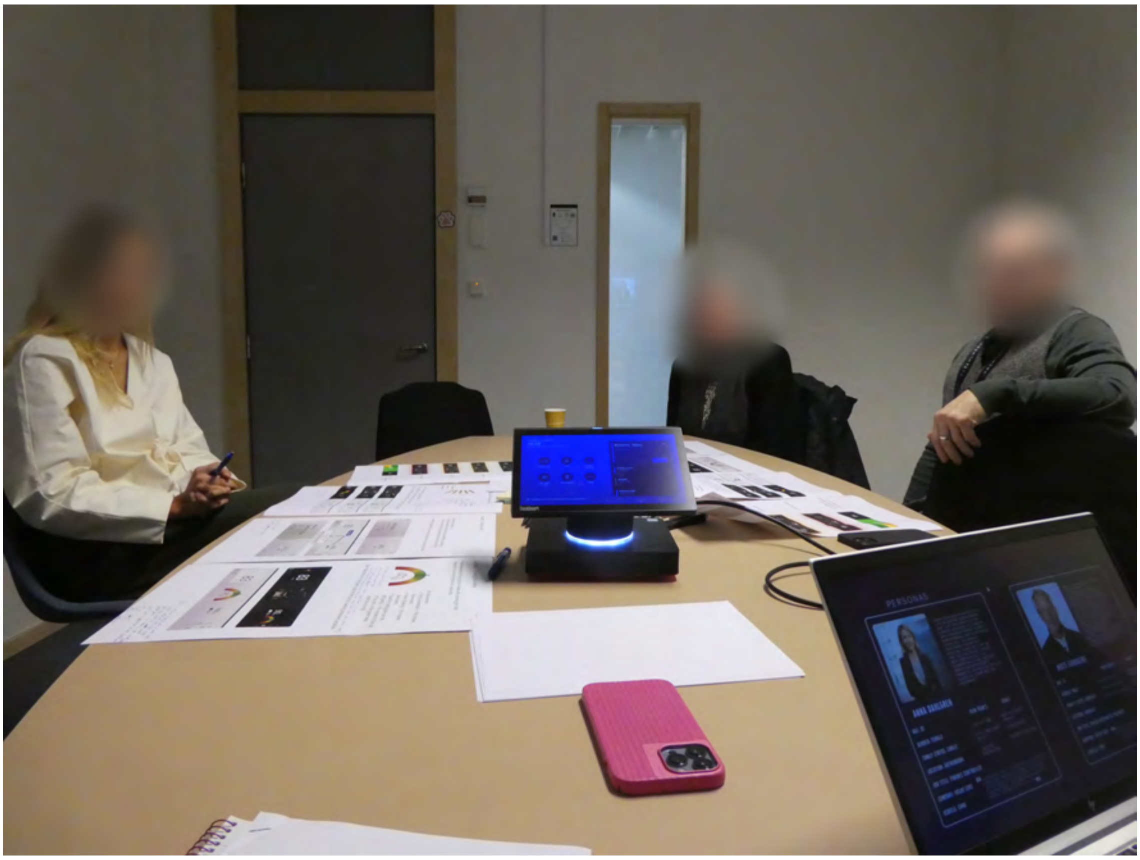


Figure 7.10: Focus group setup with participants.

7.3.1.3 Result Analysis of Iteration 1

The data from the first round of focus groups was analysed through qualitative thematic analysis supported by affinity diagramming to identify patterns and actionable insights. The goal of this analysis was to understand participants perceptions, interpretations, and preferences regarding the four low-fidelity prototypes for energy-efficient driving feedback.

Both focus group sessions were audio-recorded and transcribed. The coding of themes were an inductive approach where statements or segments of interest was tagged with a phrase or keyword that summarised the content. The analysis were conducted at a latent level focusing on interpreting the underlying meanings and patterns. This approach helped to identify deeper themes related to user motivations, conceptual understanding, and emotional responses to the design concepts. An affinity diagram was created in [73] to organise and group the initial codes. Each code was written on a digital sticky note and similar codes were grouped together to identify emerging patterns among the participants.

7.3.1.4 Summary of Iteration 1 Result

In this section a summary of key takeaways from Iteration 1 are presented. The final result is presented in Chapter 8, section 8.2.1, which was used to refine the design for the next iteration.

Peripheral and ambient feedback was well received, as it allowed drivers to gain insights on energy efficiency without diverting their attention from the road. However, sensitivity and colour use need refinement to avoid perceived punishment or confusion.

Concept B drew interest but required too much interpretation, increasing cognitive load and risk of distraction due to constant movement.

Concept C benefited from familiarity, making it easy to grasp but participants called for clearer colour coding and better clarity of function.

Scoring and comparison system was motivating for many, particularly when used to encourage positive behaviour through social comparison. However, fairness in comparisons and contextual accuracy of the metrics were concerns.

Overarching insights included that real-time feedback should be simple and intuitive, while post-drive summaries provide space for reflection and learning. Visual feedback that clearly links behaviour to energy consumption help drivers understand and improve over time.

7.3.2 Iteration 2

The second iteration aimed to refine the design concepts of Iteration 1 7.3.1 based on user insights and create a semi-functional prototype. This phase focused on addressing the issues identified in the previous iteration and explore new design directions. This included further prototyping and usability testing to assess the effectiveness of the prototype.

7.3.2.1 Development of Semi-Functional Prototype

Based on the insights gathered during the first iteration, a semi-functional prototype was developed for further user testing and evaluation. The goal of this prototype was to translate the design concepts into a interactive and more realistic experience. This was done for a more accurate assessment of usability. However, the prototype was not implemented in a functional car and instead tested in a simulation. The prototype was therefore considered semi-functional and not high-fidelity.

Following a second brainstorming session informed by the first iteration's evaluation, design elements from the four original concepts were combined. This aimed to incorporate the most positively received aspects from each, such as visual metaphors, ambient feedback, and motivational elements in the form of rewards and comparisons.

The prototype included a DIM interface, developed in Figma [9], with animated components that simulated real-time driving behaviour. These animations reflected energy-efficient and inefficient actions such as coasting or harsh braking through visual cues. These cues included colour changes and motion as well as pop-ups with tips on how to improve your driving in a subtle way.

A physical feedback system was developed in a addition to the digital prototype using an Arduino Uno board connected to an LED strip. This strip was programmed to switch between blue and orange light, reflecting different driving states. The result from the focus groups suggested that ambient feedback could be valuable as peripheral feedback to avoid distraction from the road. The Arduino board with LED can be seen in figure 7.11.

The ambient light incorporated with the digital prototype can be seen in figure 7.12 where the drive is energy-efficient.

The prototype consisted of several interface elements designed to provide real-time and post-drive feedback on energy-efficient driving. A welcome screen was displayed showing the drivers previous score to serve as an anchoring mechanism to set expectations and areas for potential improvement as seen in figure 7.13.

The main driving interface featured a redesigned power meter that emphasised energy efficiency rather than power output or regenerative braking. The meter was presented horizontally, with a central indicator that changed position and colour based on driving behaviour. During acceleration, the indicator moved to the right and during braking, it moved to the left. This design aspect was chosen because of behavioural standards in the western hemisphere, where reading is done from left to right, which is why the acceleration moving towards the right seemed intuitive and braking, meaning to regress and stop, was depicted as the power meter moving to the left. When the driver accelerated or braked harshly, the indicator reached the outer ends of the scale and turned orange to signal inefficient energy use or ineffective regenerative braking. In contrast, efficient driving kept the indicator near the centre under a leaf icon, with the indicator remaining blue. This design was intended to allow for normal driving dynamics including braking and acceleration without punishing the driver for context-driven behaviours such as adapting to sur-

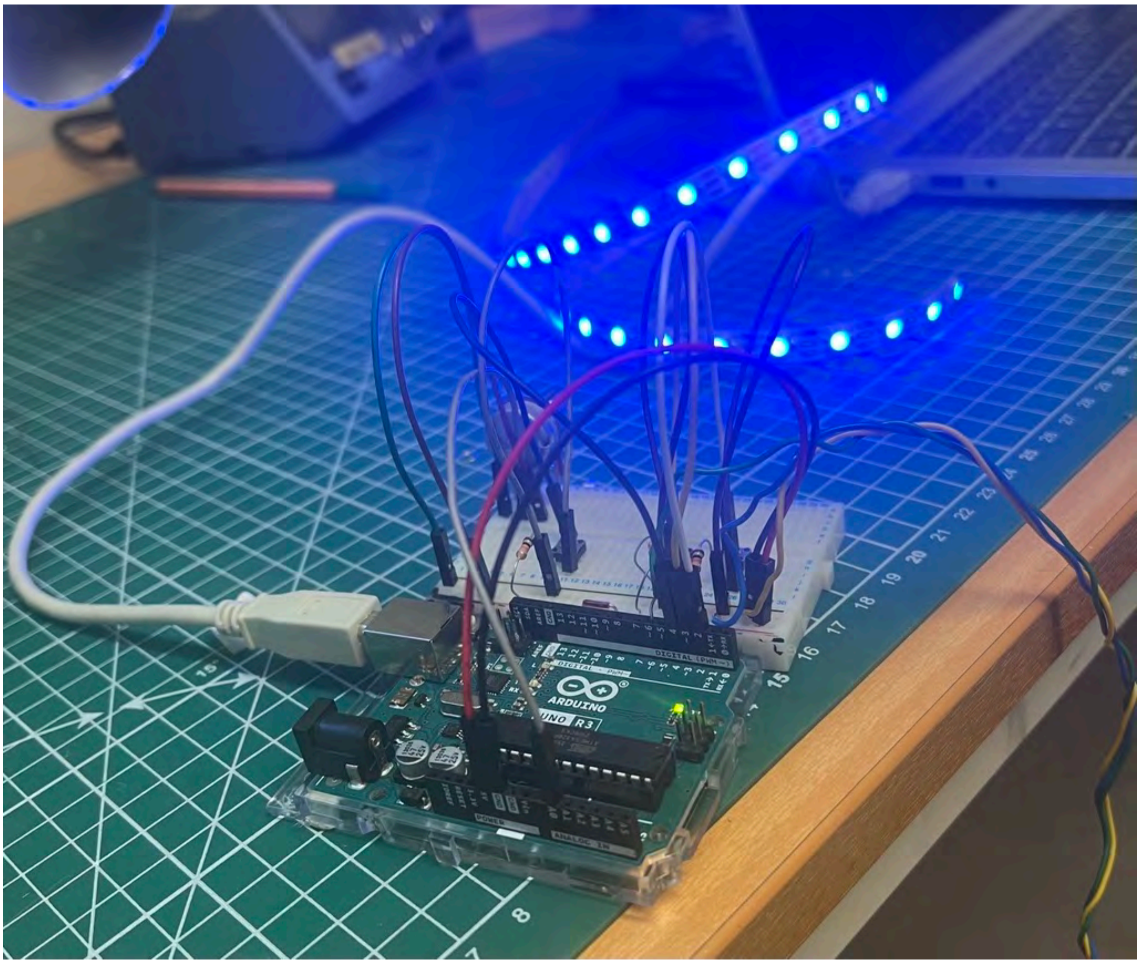


Figure 7.11: Arduino controller setup with LED strip.

rounding traffic. The meter it self is static compared to Concept B 7.3.1.1 where the meter was moving. The decision to only have a small moving indicator was based on the feedback from the participants in the focus groups who agreed that Concept B 7.3.1.1 was too distracting and Concept C 7.3.1.1 was too subtle. Figure 7.14 show the DIM prototype interface in which the drive is energy-efficient. Fast acceleration is demonstrated in figure 7.15, and figure 7.16 shows the DIM prototype interface when harsh braking.

Throughout the drive, pop-up messages appeared when relevant to offer Eco-driving suggestions, for instance coasting toward a red light or keeping even speed on highways. Examples of the pop-up appearing can be seen in figure 7.17 and figure 7.18. These tips aimed to teach energy-efficient driving strategies without overwhelming or distracting the user.

A Goodbye screen displayed the drivers accumulated score and a breakdown of the objective metrics that contributed to it after the drive. The screen also included comparative feedback for users to view how their score related to other drivers of the same vehicle model. The hue of the Goodbye screen differed depending on if the the driver had gained a leaf or lost a leaf. If the driver had gained a leaf or maintained the score, the gradient were blue while the loss of leaf resulted in orange. The two different interfaces are displayed in figure.

The choice of blue and orange aligned with Volvo Cars' existing colour-coding conventions used in their in-vehicle interfaces. Blue indicating normal or efficient states and orange signifying less desirable behaviours. This consistency aimed to reduce confusion and cognitive load. The colour choices were also influenced by the feedback from the focus groups where participants perceived red as too alarming. Furthermore, both the digital and physical prototypes were evaluated against accessibility guidelines [74]. These guidelines highlight the importance of colour contrast, not relying on colour alone to convey information, and visual clarity to support users with visual impairments.

7.3.2.2 Think-Aloud Protocol to Evaluate Semi-Functional Prototype

The aim of the usability testing was to evaluate how participants perceived and interacted with the semi-functional prototype of the Driver Information Monitor DIM. The think-aloud protocol study focused on the prototypes ability to support understanding and potential adoption of energy-efficient driving behaviours. The study also aimed to identify usability issues and gather qualitative insights for future design refinements. In total, each session lasted approximately 15 minutes. A pilot study was conducted to test the clarity of instructions, technical setup, think-aloud comfort, and data recording procedure. The pilot study was conducted with three participants since 65% of the problems can be identified which was deemed sufficient in a pilot context [75].

The usability test was conducted in a simulation room with a UX buck, which is a stationary physical mock-up of a car interior including a steering wheel, dashboard, seat, and displays. The vehicle could not be manoeuvred by the participant but rather used to simulate a realistic and safe driving environment. A five minute long driving video was recorded in advance along a route from Lindholmen to Torslanda in Gothenburg and was played on a large screen in front of the buck. The video was synchronised with interface changes in the DIM prototype to simulate real-time feedback. The CSD was visible and functional but the participants were informed that the focus of the study was on the DIM. Figure 7.21 shows the setup during one of the tests with blue and orange light.

The prototype of the DIM was created and animated in Figma [9] to changed according to the video and and ambient light placed behind the DIM changed colour to reflect driving performance. A slight delay was intentionally applied manually to the light transitions to prevent flashing effects. The Arduino board connected to the LED lights had buttons to change colour and dimmer to change the brightness (Figure 7.22). The light changes was done by the observer and the facilitator was responsible to encourage the participant to keep talking during the simulation (figure 7.23). Participants were instructed to use the think-aloud protocol throughout the drive. Following the simulation, a short semi-structured interview was conducted to gather additional feedback.

A total of 20 participants participated in the study. The criteria for participating was to be a regular driver of BEVs, employed by Volvo Cars, and available for a 15 minute session on site. The sample consisted of 7 female and 13 male participants. Ages ranged from 18 to 69 with most participants falling into the 30-39 and 18-29 brackets. Participants professional backgrounds included software engineering, design engineering, product owner, and manager of whom had backgrounds in automotive design or technology within Volvo Cars. The test group featured drivers of different BEVs, including Volvo EX30, EX40, EC40, and XC60, as well as Tesla Model S, BMW i3, Hyundai Ioniq, Mercedes EQS among others. This diversity reflect a range of experiences with BEV interfaces. Each participant was given an introduction of the studys purpose and asked to sign a research consent form before the study began.

Recommendation by Nielsen and Landauer [76] suggests that five participants can uncover the majority of usability issues. However, this study involved one iteration of the semi-functional prototype in a simulated driving context where user diversity and other factors could influence the findings. According to Faulkner [77], usability testing with one set of 20 participants can identify no less than 95% of problems compared to one set of five participants where the problems identified ranged from 55% to 100%. Therefore, 20 participants were included to increase the reliability and confidence in the generalisability of the insights.

The think-aloud protocol used in this research can be found in Appendix D.The analysis of the transcribed audio recorded from the sessions are described in 7.3.2.3. Refer to section 8.2.2 of Chapter 8 for result of the Think-Aloud Protocol study.

7.3.2.3 Result Analysis of Iteration 2

The analysis of the second iteration followed a similar process to the first 7.3.1.3. After the usability testing were completed, all audio recordings from the think-aloud protocols and post-test interviews were transcribed. A thematic analysis approach was used to identify patterns across participants experiences. The data was coded using an inductive approach for themes to emerge without pre-existing categories. Affinity diagramming used again as a collaborative method to cluster related codes and identify themes. These clusters reflected usability issues, feedback on the interface and ambient feedback system, as well as participants' understanding of energy-efficient driving cues.The coding and affinity mapping were conducted manually in [73] to maintain consistency with the first iteration. Figure 7.24 shows the affinity diagram form the analysis of the second iteration. The result of this analysis informed the final design and design recommendation. Refer to Section 8.2.2 of Chapter 8.

7.3.2.4 Summary of Iteration 2 Result

This section presents key takeaways from the second iteration that affected the final design recommendations and design. Refer to Section 8.2.2 of Chapter 8 for full result and explanation.

Colour as Communication
Blue and orange were generally interpreted as positive and negative feedback, re-

spectively. Red was seen as too alarming and softer hues were preferred for calm guidance. Blue was sometimes perceived as ambiguous or emotionally cold.

Visual Usability
Feedback elements need better spatial prominence and smoother colour transitions. Peripheral feedback such as the ambient lights was appreciated for being nondistracting.

Understanding Eco-Driving Feedback
Real-time indicators were helpful but sometimes unclear. Post-drive summaries promoted reflection but lacked transparency in scoring. Personalisation and contextual relevance were desired.

Cognitive Load and Context Sensitivity
Feedback should be minimal and context-aware to avoid distraction. Drivers disliked receiving tips during complex traffic situations.

Learning Efficient Driving
Participants valued feedback for learning and reflection. Metrics should be clear, contextual, and informative. Many felt uncertain about efficient EV driving practices.

Eco-Score System
The scoring system intrigued users but was often unclear. Participants wanted to understand how scores were calculated and how to improve.

Gamification and Motivation
Comparative and gamified feedback was motivating. Long-term engagement depends on meaningful, personalised feedback.

7.4 Deliver

The delivery phase was the final stage of the project where insights from previous iterations were combined into a set of concrete design recommendations and a refined final prototype. This phase aimed to bring together the research findings into actionable outcomes for future development.

7.4.1 Establishing Design Recommendations

The design recommendations began to be compiled and brainstormed after the first iteration. However, it was after the third evaluation that all of the insights were gathered to develop the final design recommendations for this research. These recommendations were supported with key takeaways from expert interviews, questionnaires, and feedback from both evaluation iterations. These recommendations serve as the researchs final result. They summarise all of the research conducted on promoting energy-efficient driving in BEVs. The final design recommendations can be found in section 8.2.3 of chapter 8.

7.4.2 Development and Evaluation of Final Design: Eco Score

Improvements were implemented in a final design based on the feedback gathered for the user evaluations. The redesigned power meter on the DIM was enlarged to improve visibility. In addition, the text within the pop-up messages was clarified so that the instructions and feedback were easy to understand and unambiguous. These changes were made to enhance the intuitiveness and effectiveness of the feedback provided during driving. The final prototype is presented in Section 8.3 of Chapter 8

The final prototype and design recommendations were presented to two key stakeholders at Volvo Cars. One stakeholder represented the Vehicle Energy Management team, while the other was from Preventative Safety Research through an informal interview. Their feedback was used to validate the feasibility and relevance of the design within context of Volvos strategy and goals.

The delivery of the final prototype and recommendations concludes the project and provide a foundation for potential future implementation or development within Volvo's in-vehicle energy systems.

(a) Close-up of the ambient light solution.

(b) Ambient light in use during prototype simulation.

Figure 7.12: Example of the ambient light feedback incorporated with the digital prototype.

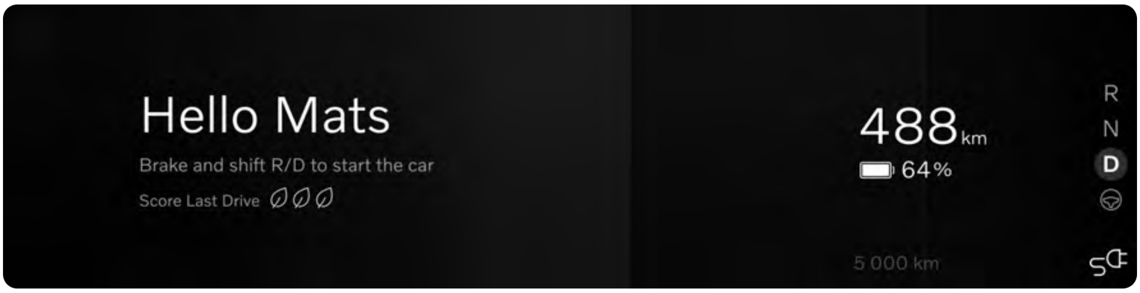


Figure 7.13: Prototype of welcome screen with previous score.

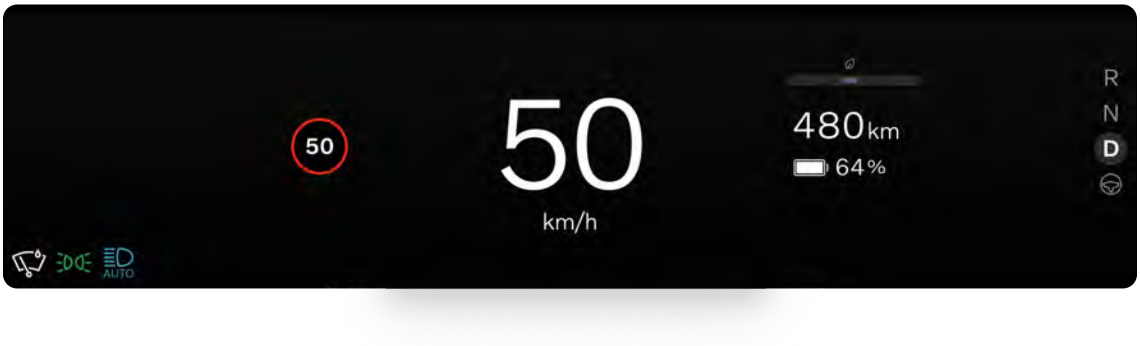


Figure 7.14: DIM prototype for energy-efficient driving

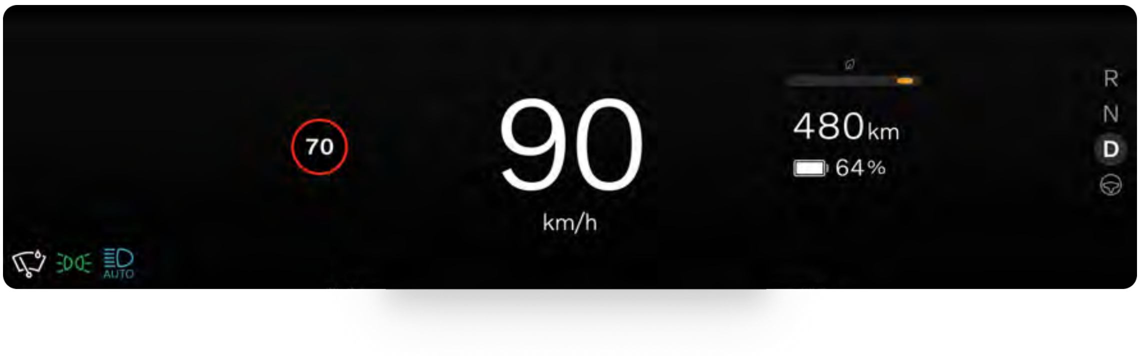


Figure 7.15: DIM prototype for energy-efficient driving showing fast acceleration.

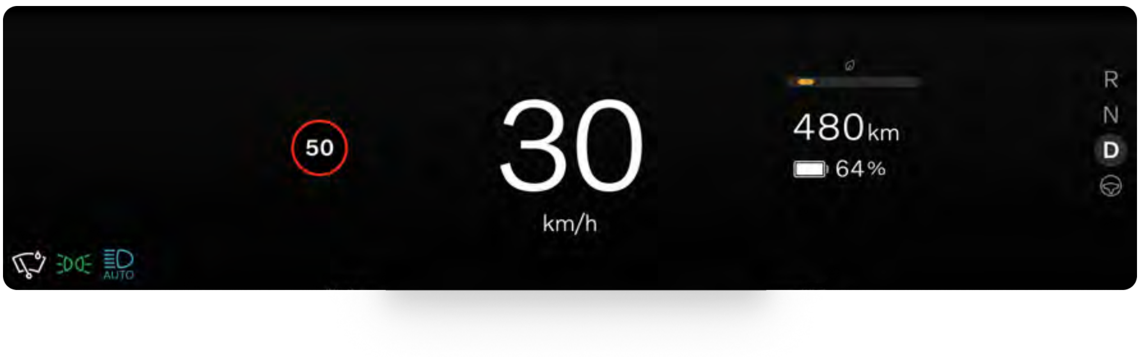


Figure 7.16: DIM prototype for energy-efficient driving showing harsh braking.

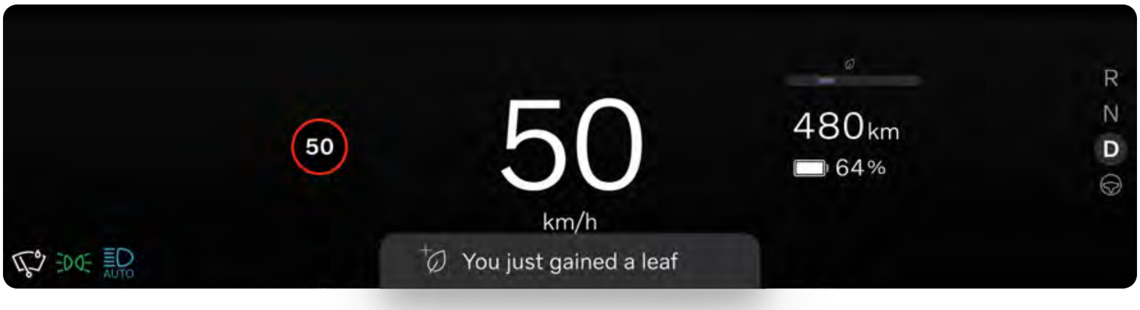


Figure 7.17: Example of pop-up when the driver has gained a leaf to the score.

Figure 7.18: Example of pop-up providing suggestions of improvements to the driver.

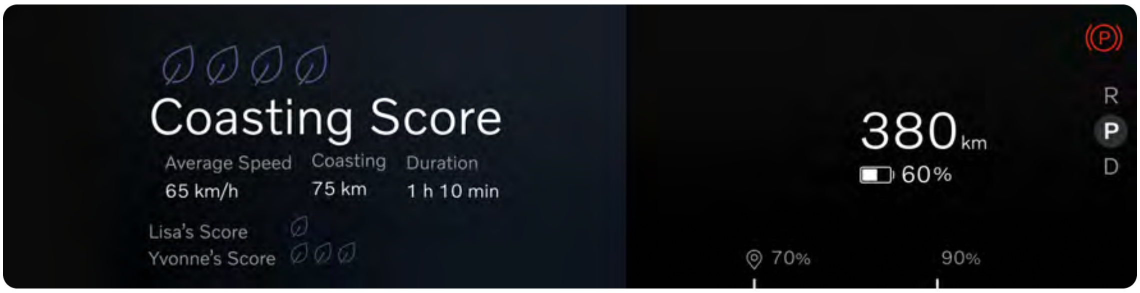


Figure 7.19: Goodbye screen displayed after drive where driver has gained or maintained their score.

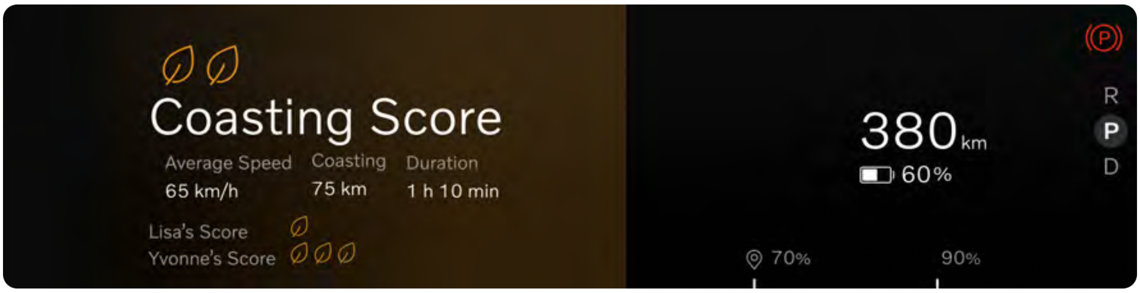
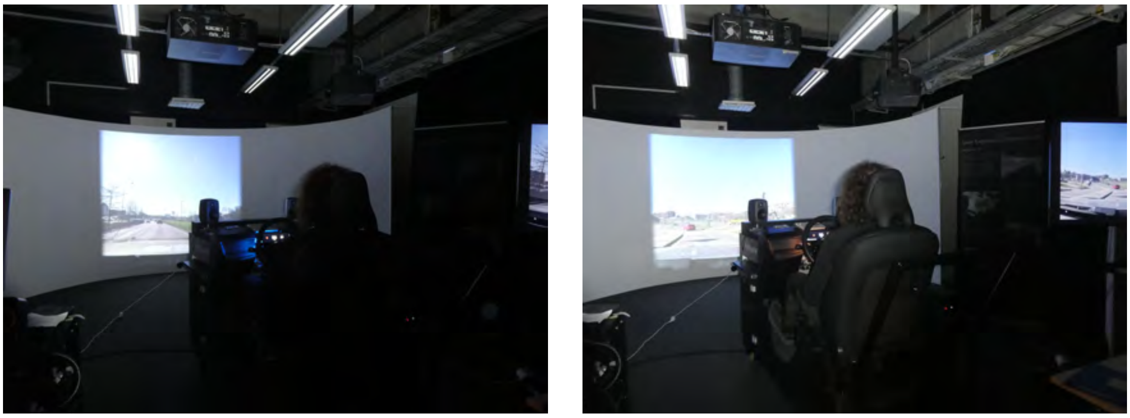


Figure 7.20: Goodbye screen displayed after drive where driver has lost a leaf.



a Prototype with blue ambient light

b Prototype with orange ambient light

Figure 7.21: Two examples from a user test in the UX buck, showing how the ambient lighting behind the DIM changes colour based on driving efficiency.

Figure 7.22: Setup of tools used positioned behind the buck.

Figure 7.23: Facilitator and participant during a user test.

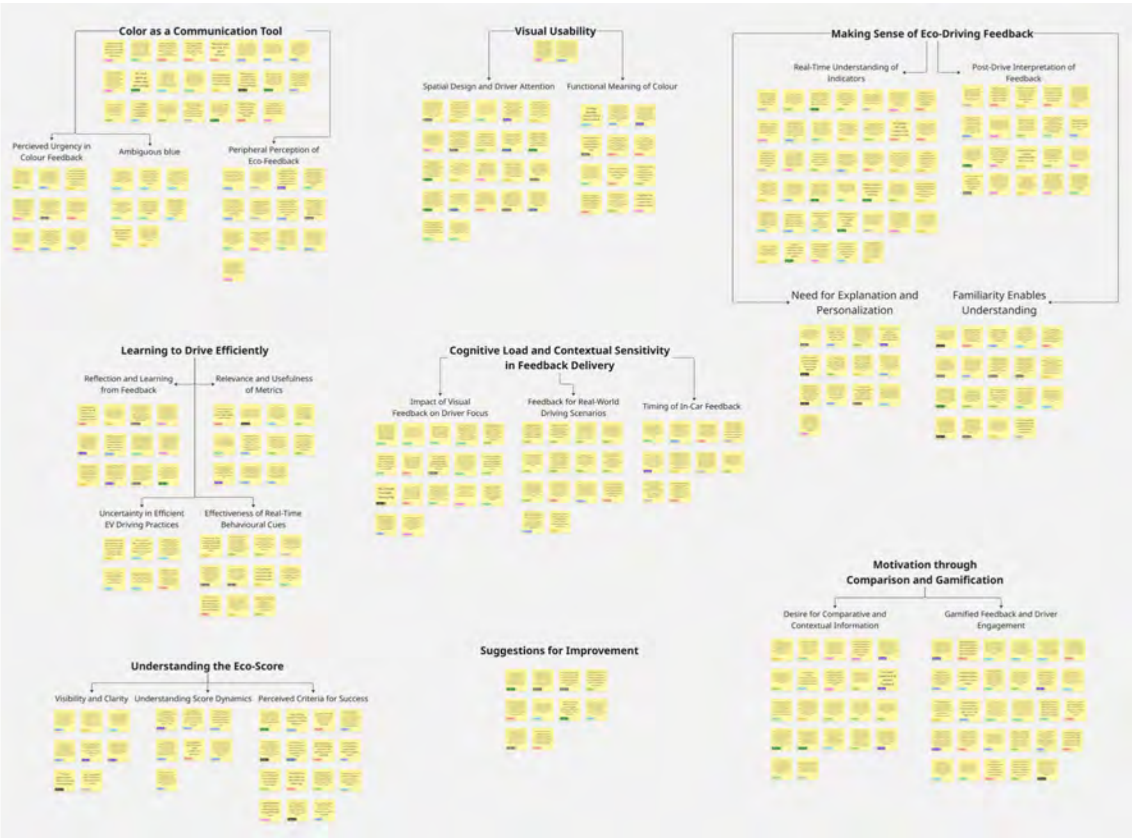


Figure 7.24: Affinity diagram of the usability testing for Iteration 2.

8

Results

In this chapter, the research findings will be presented. It will consist of two significant stages, similar to the Execution and Process chapter.

In the first stage, results of the data collection conducted during the Discover and Define phases will be presented. The first stage focused on getting familiar with BEV and the automotive market by Benchmarking vehicles up to modern industry standard, user research to understand the stakeholders and their needs by conducing expert interviews, questionnaires, developing personas and scenarios and organizing focus groups. These methods also served as a way of gaining technical insight into the requirements, limitations and possibilities of BEVs. The first iteration of low-fidelity prototypes took part in this phase as well. The analysis of the gathered data was used to develop a requirement list, which was the end goal of the first stage. This will be presented at the end of the next section.

The second stage had the aim of developing design recommendations, centred around the Develop and Deliver phases described in the Execution and Process chapter. The second iteration of a semi-functional prototype will be presented as well as the findings of the usability focused think-aloud protocol study conducted described in Section 7.3.2.2think-aloud-protocol. Concluding this stage, design recommendations developed by research through design will be presented.

8.1 Establishing the Requirements List

The following section presents the findings from the data collection and analysis conducted during the Discover and Define phases of the design process. Findings from each conducted method will be presented in chronological order, final conclusions will be presented as a requirement list at the end of this section.

8.1.1 Benchmarking

The process and the execution of the conducted benchmarking is described in Section 7.1.1, in this subsection the results will be presented as a summarisation of important findings. A total of 12 BEV were tested during the benchmark.

Volvo Cars was deemed to perform well with technical information available to the driver, the newest cars having a discrete approach to information visible to the driver whilst driving. Very few of the cars included in the benchmark had gameful elements, the ones that did clearly visualised the correlation between breakage and energy gain versus energy loss, as well as with acceleration. Another feature was scoring, potentially with the intention of motivating the driver. This gave the impression of successfully helping the driver to understand the value of changing driving behaviour.

The design language of the visualisation of the power meter was similar between most vehicles, with the same colour and the same type of bar to display breaking, acceleration and energy regeneration. These bars were often light in colour, with a slight change in nuance to simulate power, whilst regeneration often was of a contrasting colour such as blue or green. This gave the impression of the most noticeable feedback of the power meter being solely positive for the duration of the drive. Only one vehicle displayed friction brake power, meaning that no more energy can be regenerated at that instant.

An emerging trend in BEV are cars without a DIM, having the CSD be the only display. This gave the impression of too little actionable information during the drive as well as being a source of distraction because of the concentration of information in a single display. A few vehicles had features or driving modes which were implied to change the settings of the vehicle into more energy efficient ones, called Eco Mode or an equivalence to this. A few showed range history in graphs, some which had specific actions corresponding to data points. These were named with percentages of how much energy was used during the last drive by activities such as driving behaviour, climate control or speed.

Summary of Findings: Energy Usage Feedback visualisation in BEVs

- Volvo Cars' had a strong performance in availability and visualisation of technical information of the car's energy usage and consumption.
- The interface of the DIM and the CSD had a modest amount of information visible to the user whilst driving.
- Gameful elements were scarce amongst the benchmarked vehicles, Mercedes EQE and EQS were the only models utilizing gamified feedback to visualise energy consumption and vehicle state to the user whilst in Eco Mode, including scoring systems.
- The design language of power meters was consistent across all brands, some having differences in colour or angle.
  - The impression of positivity in regards to regeneration might be due to cultural bias to the colour green which was often used.
  - Often the visualisation of power usage was in dull colours such as grey, in contrast to black or white backgrounds it did not seem distinctive enough to grab the attention of the driver.
- Feedback during driving appeared mainly positive due to visual emphasis on regeneration of energy.

- 3 out of 12 cars were equipped only with a CSD, giving the impression of little actionable feedback during the drive as well as increased distraction. Newer vehicles not included in the benchmark share the same trait, insinuating that the exclusion or minimization of DIMs could be becoming an industry trend.
- 4 out of 12 cars had an explicitly stated optional driving setting equivalent to that of an Eco Mode, modifying in-car settings to increase energy efficiency.
- Historical graphs of range was used in some vehicles. A few broke down energy usage into categories such as climate control, speed and driver behaviour.

8.1.2 Expert Interviews

To gain understanding of human behavioural factors affecting driving behaviour as well as insight into technical aspects of BEVs, two expert interviews, process and execution described in Section 7.1.2.1, were conducted. These were necessary in order to continue with the project without overlooking or missing important technical and human factors related to receiving feedback during and after driving. To understand what mechanisms of EVs affect energy usage and consumption, range and what information about OPD and throttle usage can be displayed in the interfaces of the cars, a technical expert specialised in energy management was selected as the first interviewee. The second expert was specialized in driver behaviour and risk management and allowed for a deeper understanding on what motivates change of driver behaviour, what risks need to be considered when altering car interfaces and what information could be displayed during the act of driving.

The analysis of the expert interviews is described in Section 7.2.1.1. Figure 7.2 shows the finished affinity diagram with connections between topics and insights discussed by the experts, 7.2 shows key insights. The interviews confirmed existing knowledge and gave a thorough overview of driver behaviour and technical aspects of BEVs. Since the knowledge shared was quite extensive and not always within the scope of this project, only those insights which were significant to developing the process further will be presented. From the analysis of the data collected, 14 key insights were identified and extracted, they are listed below with the labels E1-E14. The insights relevant to the further development of the project were:

E1: Behavioural patterns that positively impact energy consumption
Driving is a complex task, although the energy consumption of a vehicle is dependant on technicalities and construction, driver behavioural patterns can affect overall energy usage and in extent consumption. As noted by the experts interviewed, some of the most important traits to consider adopting to lower one's energy usage in EVs is to drive in a defensive, calm manner, as this shares characteristics with energy efficient driving. Such a manner includes smooth driving, with no harsh braking or acceleration, being proactive and aware of one's surroundings by e.g. keeping safe distance to other vehicles and rarely overtaking other vehicles. These actions may lead to less speed fluctuations, which is a contributor to excessive energy usage. Keeping a low average speed and coasting whenever possible are two more things that could affect overall consumption as more energy is generally used at higher

speeds, and fast accelerations in environments with other vehicles nearby generally requires braking as well. Minimizing speed fluctuations would mean that the driver keeps to an average speed and an even energy consumption.

E2: Encouraging calm driving behaviour might increase energy efficiency
Ideally, a driver of a BEV would regenerate as little as possible as this would mean that braking has been minimized. Keeping the speed down would reduce the need of braking, in turn resulting in scarce fast accelerations. Encouraging a calm behaviour signified by the actions mentioned in E1might thus result in a more energy efficient driving style.

E3: Conversion of energy will always result in loss of energy
Generally the conversion of energy, regenerating energy back into the battery of the vehicle, is not worth the cost of energy it takes to create. As regeneration requires braking, it requires acceleration first, which often consumes more energy than what will be regenerated. One of the few exceptions to this is regenerating whilst driving in a steep downhill.

E4: Behavioural patterns that negatively impact energy consumption
Many small changes in driving behaviour could together impact general energy usage. As a general rule, the higher the speed of a vehicle the higher the consumption will be. Harsh braking, fast acceleration, frequent overtaking and speed fluctuations all contribute to a behavioural pattern which could be described as an aggressive driving style. These are not alone in having an impact on energy consumption but they are actions which the driver can directly affect themselves.

E5: It is difficult to determine what factors of energy loss are due to the driver versus external factors
As cars are becoming increasingly technically complex with more added features and functionality, it is difficult to determine the exact factors causing energy loss that are due to the driver, as many of them are independent of the driver's behaviour behind the wheel. Larger vehicles with larger batteries will consume more energy, differences between indoor and outdoor climate is bad for the energy consumption and weather conditions could have a significant effect not only temporarily on consumption but also on the health of the electric battery. Social pressure inflicted by other drivers could impact behaviour negatively and highways, high roads and dense inner city traffic situation all have different premises and affect consumption in different ways, this makes it important to not compare drivers without taking into account their different driving conditions.

E6: Drivers should not be punished for outcomes they cannot affect
As mentioned in E5 there are many factors of energy consumption which drivers cannot instantaneously affect, which supports the notion that drivers should not be punished unnecessarily as this might cause irritation and hopelessness. Feedback in the vehicle should support the driver to do better and motivate them to alter their behaviour positively.

E7: One Pedal Drive provides a pleasant driving experience although it allows for easier consumption of energy

OPD provides a pleasant experience for the driver although its full impact might not be understood yet. The expert implied that there is a possibility that aggressive drivers could have worse energy consumption with OPD. It is difficult to coast in a BEV, meaning the state when the car glides forward only using its existing momentum, because of the affordance of instantly regeneratively braking when the pressure of the accelerator pedal is lightened, coasting with this setting requires the right angle of applied pressure. This further confirms that BEV drivers should be educated in energy efficient driving practices and alternate ways of saving energy.

E8: Producing credible figures is a complex issue
Producing credible figures describing what factors lead to energy inefficiency is a complex issue. According to the technical expert, there are millions of factor combinations possible which could affect energy consumption within a BEV. This raises the issue that values presented to the driver describing their and the vehicle's performance should be objectively measurable. Such values could be energy used per kilometre during a trip and average speed.

E9: Gamified Feedback: highlight change of state
Highlighting a change of state of the vehicle to the driver could be an effective way of informing of the effect of actions taking during the driving manoeuvre. Feedback could be given when a trip is significantly more energy efficient than normal. Displaying the effect of hard braking and acceleration to the driver, which is a common but significant state which affects energy consumption, as well as speed fluctuations with the intention of demonstrating steady speed as beneficial could be done using gameful elements. Highlighting change of state instead providing constant feedback evades the driver being exposed to change blindness, filtering away stimuli which is constantly available.

E10: Gamified Feedback is effective when dynamic
Dynamic feedback within the DIM or CSD grabs the attention of the driver and making it dynamic in appearance and content increases the likelihood of keeping said attention. This could be done by tailoring the feedback to individual driving patterns which might prove more acceptable to the driver. The feedback could also be colour coded to indicate different levels, without alarming the driver. Providing gamified feedback in this manner opens up for the use of different modalities such as ambient feedback. Unless feedback is constantly changing, it is only effective for a limited amount of time, since the need for feedback would decrease with the improvement of the driver's skills, dynamic feedback sensitive to the driver's individual behavioural pattern could be beneficial.

E11: Practice reinforcement to keep drivers engaged and motivated
Keeping the engagement and in extent the motivation of drivers is difficult. By practising reinforcement in ways such as highlighting losses and reporting detailed trip consumption values with key metrics could be a way of engaging the driver into considering the effect of their own actions on their energy consumption.

E12: Real time feedback gives a better learning experience
Receiving feedback post-drive is less distracting than instant feedback, although it complicates interpretation since important contextual information might be lost to

the driver. Real-time feedback gives a better learning experience and in extent has a bigger chance of impacting behaviour long-term. A way to utilize this would be to indicate appropriate throttle usage with instant real-time feedback to promote energy efficient behaviour.

E13: Scoring should reflect something the driver can affect
If using scoring systems, the metrics used need to be values which the driver has had an affect on an could improve in future driving scenarios.

E14: Social comparison is a strong motivational approach
Social comparison between drivers could serve as a motivational incitement to perform better in future activities. Competitive elements could for some drivers mean that their desire to outperform others or contribute to a team would have an impact on their driving behaviour. This could be implemented within BEVs by creating ranking and scoring systems with the ability to compare drivers associated with the same vehicle, such as by driver profiles which is common in modern EVs.

8.1.3 Questionnaire

The aim of the study was to understand the user group by collecting data through a questionnaire distributed among Volvo Cars employees. The execution and process of the questionnaire is described in section 7.1.2.2 of chapter 7, and the questionnaire sent out to participant can be seen in Appendix B. A total of 176 respondents completed the questionnaire to gather insights into their driving behaviour, experience with BEVs, and preferences related to information regarding energy. The questionnaire helped identify user wants, needs, and challenges. Of the participants, 47 identified as female, 122 as male, and 3 preferred not to disclose their gender. The age distribution was a majority of participants aged 50-59 (96).

Respondents represented a range of departments within Volvo Cars with the largest group being from Engineering and Operations (96 participants), followed by Commercial Operations (16), Quality (13), Finance (9), and People Experience (8). The vast majority of participants were based in Sweden. In terms of BEV usage, the most commonly leased vehicles were the Volvo EC40 (72 responses) and Volvo XC40 (63), followed by EX30 (21) and EX90 (15). Regarding experience driving a BEV, 73% of participants had driven a BEV for more than 18 months while 32% had been driving one for less than 6 months. Most respondents reported that they primarily drive in urban environments and on highways.

Q1: Users want to drive sustainably
Participants described their motivations for leasing a BEV that revealed a range of incentives that can be grouped into four main categories including environmental sustainability, economic benefit, driving experience, and personal interest.

The most frequently mentioned incentive was environmental sustainability. A majority of participants expressed a desire to reduce their personal impact on the environment citing motivations such as reducing their CO footprint, helping the planet, people and animals, and move to zero emission transport. These responses reflect a sense of environmental responsibility and a desire to drive environmentally friendly.

Another subtheme was the economic benefit of BEVs highlighting the low total cost of usage. Several responses also mentioned BEVs as the cheapest option when considering leasing and fuel costs which suggest that financial considerations are a motivator for using BEVs. Participants mentioned the positive driving experience and appreciated features such as quietness and performance. They were also motivated by curiosity and learning. This variety of responses demonstrates that BEV adoption is driven by a combination of environmental values, financial incentives, user experience, and personal factors.

Q2: Users take ambiguous actions to drive more energy-efficient
Participants were asked to describe any specific actions they take to drive more energy-efficiently today. The responses showed a variety of strategies grouped into three subthemes including speed regulation, smooth driving behaviour, and system control. A smaller subset also reported not taking conscious actions.

The most common responses involved consciously lowering driving speeds. Participants reported that they try to keep the speed limits, never speed, or actively drive slower on highways. Others mentioned more deliberate strategies such as limiting highway speeds at maximum 100-110 km/h or monitoring average consumption to make adjustments. These actions reflect an awareness that higher speeds significantly increase energy consumption that align with insight from the expert interviews.

Participants stated efforts to drive smoothly including gentle acceleration and avoiding hard braking. Several were planning ahead to avoid unnecessary deceleration referred to as soft flow or anticipating traffic lights. These behaviours align with energy-efficient driving techniques and aim to minimize energy waste from frequent stops and starts.

In addition, participants reported optimising vehicle systems to support energy efficiency. This included in-vehicle climate control such as lowering cabin temperature. Users mentioned enabling specific energy-saving modes, such as Range Assistant. However, 71% responded that they believed OPD to be energy efficient which contradicts the optimal driving practices in BEVs.

Some respondents also admitted to taking no specific actions to drive more efficiently. Some expressed confidence in their vehicle's baseline efficiency or referred to other compensating efforts such as using solar panels for charging, and that they used to be more conscious when driving diesel cars, but now braking and accelerating do not seem to have as much impact.

Q3: Users find it challenging to locate information on energy-efficiency and consumption
The participant were asked where they find information or indications about their energy consumption. The responses were varied with participants stating that they find information in the DIM, the range assistant app in CSD, or the mobile app. For respondents getting their information from the DIM, there were a lack of information

to compare with. There are no clear result of your drive in the DIM and no historical data.

Participant expressed that they calculate their consumption themselves, where state of charge was compared before and after the drive. The battery percentage were referred to by multiple participants with some relying on navigation application to compare their current state of charge to the estimated percentage at arrival. The estimated range in the DIM was used for feedback during the drive to see how the driving style is affecting the range. Two respondents explicitly stated that they use the power meter as a source of information. Some expressed the need to locate information in multiple sources to get sufficient information.

Lastly, some participants stated that they never look for this kind of information, do not know where to locate it, and are not unsure of where to locate it.

Q4: Users find it challenging to interpret information on energy-efficiency and consumption
Participants expressed difficulties in interpreting the energy-related information provided in their vehicles regarding real-time feedback, units of measurement, and the relevance of the data to their driving behaviour. This reveal a gap in clarity, usability, and context for current in-vehicle energy information systems.

A recurring concern was real-time energy consumption metrics being too dynamic, expressing a desire for data over longer periods such as per trip or per day. While some users noted they had no problem interpreting the data, others found it hard to tell what the power meter means over time without historical data context. This suggests a need to provide actionable insights.

Confusion around units of measure and how energy is displayed was recurring among respondents. Some criticized the use of kWh/km since it reflects energy consumption and not power output, and called for more intuitive alternatives. The lack of clear units made users unsure whether their driving was efficient or not. Users also commented on the design and placement of the interface elements. The power meter was described as too small. Participants indicated that subtle energy feedback might go unnoticed or not be prioritised during active driving.

Some respondents also found it difficult to understand how regeneration works, particularly how braking behaviour affects energy recovery. Others requested more predictive insights such as available range considering driver habits and traffic.

Q5: Users prefer energy-related feedback in the Drivers Information Monitor DIM
Regarding suggestions of improvements, 121 participants responded that they would prefer to see information on energy consumption in the DIM rather than in the CSD or through audio or haptic feedback. Respondents missed a more dynamic figure in the DIM and it could be helpful with pop-up information for educational purposes. However, the pop-ups should be able to be turned off since it could be annoying or distracting in the long run according to one participant. If possible, feedback should be provided to the driver on how to drive more efficient in different traffic situations without jeopardising a safe journey according to responses. Clear colour coding was

suggested as a possible solution to indicate good versus bad driving style. A desire to provide historical data and post-drive analysis was also raised by respondents.

Q6: Users want rewards and competition related to energy-efficient driving
Respondents mentioned the idea of rewards or gamification to encourage energy-efficient driving. This includes points, levels, and comparisons with other drivers. Respondents stated that it would be motivating and fun to have some form of levels or points to achieve as in games. Some also thought it would be interesting to have the possibility to compare between several other drivers or drivers of the same car such as your family. The competitive elements among family and friends were thought to make interesting discussions. Another method of comparison proposed was a bar or % figure showing your performance as a driver compared to ideally energy efficient driving for the past distance. Comparing your current score with your previous score from last drive or a weekly summary was also raised.

These results were the main sources for creating the requirement list in 8.1.6.

8.1.4 Personas

User personas were developed to represent typical patterns, motivations, and needs among BEV drivers based on the questionnaire data and thematic analysis. These personas aimed to guide the design process by grounding the designs in user goals and challenges. The process and execution of the personas are described in Section 7.2.2.1 of Chapter 7.

One of the personas reflects a group of drivers combining a strong interest in technology with a focus on environmental sustainability. To capture the diversity of drivers, a second persona was created to present drivers who prioritise easy and accessible information. The avatars of the personas was created using Adobe Firefly [78] to represent realistic drivers. The visualisation of personas was designed in Figma [9].

Persona 1 is Mats who primarily uses the car for commuting, he also enjoys longer drives such as ski trips to northern Sweden and road trips across southern Europe during the summer. Mats is motivated by his interest in innovation and desire to minimize his environmental footprint. He actively seeks technology-driven solutions that support sustainable driving and enhance his experience. However, his pain points include longer journeys where he sometimes experiences range anxiety. As a shared vehicle, his BEV also needs to accommodate multiple drivers with varying behaviours and preferences. Additionally, he finds logistics and trip planning challenging when driving his BEV. He typically avoids OPD on highways but rely on navigation systems and values real-time feedback that can inform his energy use. Persona 1 is presented in figure 8.2.

Persona 2 is Anna that reflect a performance-driven user who seeks functionality with minimal friction in her daily routine. Anna lives in central Gothenburg where she lives a busy and socially active life. At the height of her career, she is highly motivated and goal-oriented, often competing with herself by striving to beat her personal running records each day. This drive for continuous improvement extends into how she interacts with her vehicle. Because she drives primarily in the city, Anna relies on OPD for its ease and comfort. She chose a BEV due to both financial incentives and her desire to reduce her carbon footprint, although environmental concerns plays a more pragmatic than emotional role in her decision making. Anna pain points include her lack of time, a preference for efficiency over detailed information, and limited energy awareness due to priorities. She appreciates quick and clear information that can inform her driving style without distraction. Her goals are to gain better insight into her energy usage and feedback that supports her competitive nature comparisons or summaries of performance. Persona 2 is presented in figure 8.2.

Figure 8.1: Persona 1.

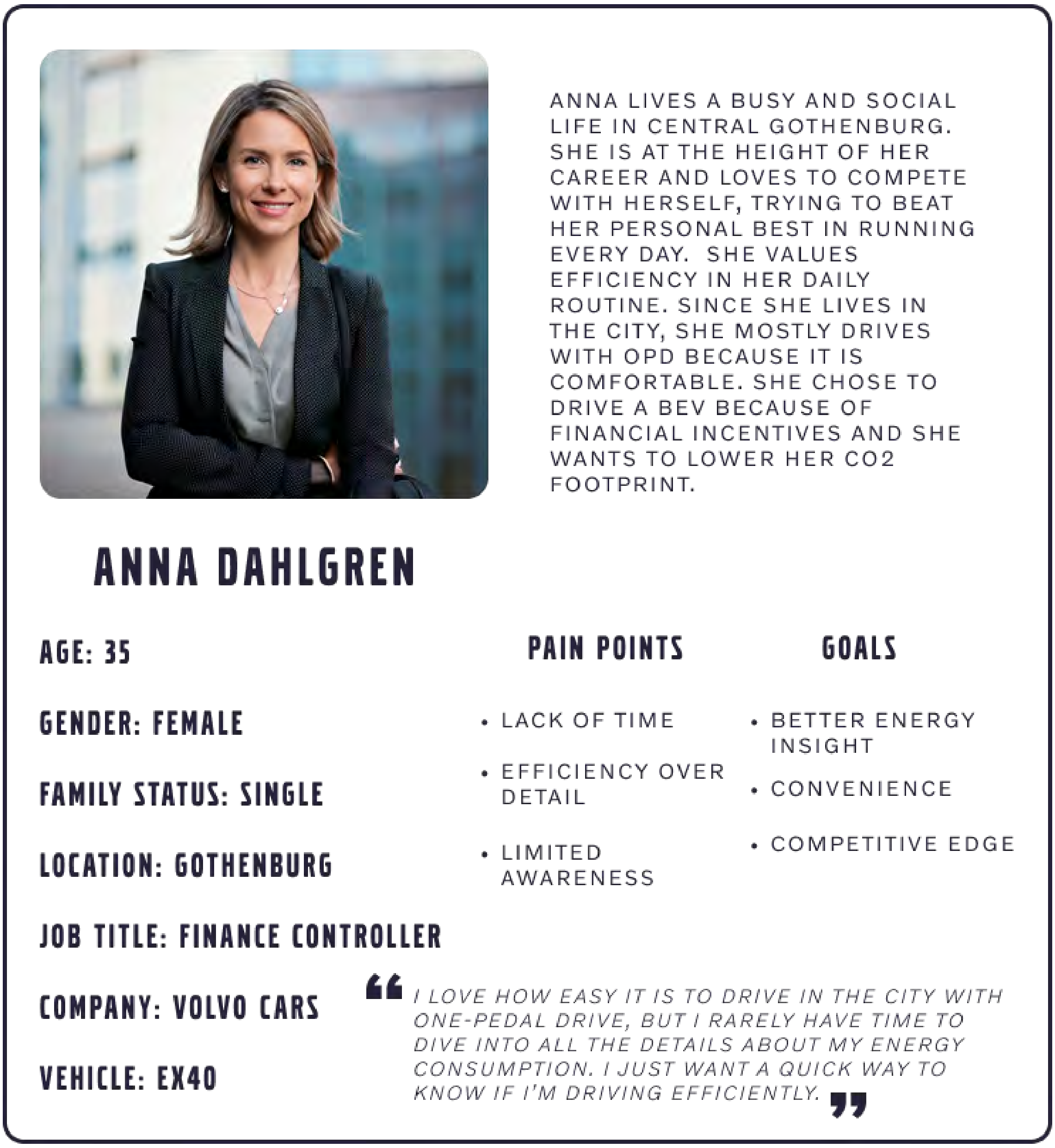


Figure 8.2: Persona 2.

8.1.5 Scenarios

Two scenarios were created to provide context to the personas and reflect typical driving situations identified through the questionnaire responses. Each scenario was linked to a different driving context to reflect already integrated interfaces with their requirements and limitations.

Scenario 1: Long-Distance Driving
Mats takes frequently long-distance trips for both work and leisure. He wants to make sure that he can complete his journeys without running into issues with battery range. His intention is to minimize charging stops and avoid unnecessary detours while also keeping track of his energy consumption. During the drive, Mats relies on the in-car navigation system, which occupies much of the DIM. Although energy feedback is available, the screen layout makes it difficult for him to clearly interpret how his driving is impacting the use of energy. He finds himself occasionally experiencing range anxiety, especially on unfamiliar routes. The resolution lies in designing a feedback solution that integrates with the navigation interface and offer energy information without creating cognitive load or taking up excessive screen space.

Scenario 2: Inner-City Driving
Annas motivation is to optimise her time and routines. She intends to stay informed about her vehicles energy usage but she finds the feedback about energy consumption to be subtle and easy to overlook in the high visual demands of city driving. She prefers to receive only the most relevant information. The resolution is a feedback system that offers concise, real-time insights that support energy-efficient driving, without diverting attention from navigating a complex and dynamic traffic environment.

These scenarios were used throughout the design process to evaluate how feedback could be adapted across different cognitive loads and interface priorities. They also served to ensure that the proposed solutions addressed real user challenges raised by users.

8.1.6 Requirement List

The process for identifying requirements was based on the summary of all key user needs which emerged from the data gathered during the discover and define phases. The process and execution of identifying the requirements is described in 7.2.2, establishing the requirements is described in 7.2.2.3. As a result of this, the list of requirements derived from the literature review, two expert interviews and a questionnaire. Each requirement was based on identified recurring patterns and needs found across all previously mentioned sources. References to the source material in form of themes emerged through the analysis of the data gathered with the focus groups and questionnaire will be presented together with the requirement list in Table 8.1. The requirements were formulated to fit into a user story, following the following format: As a user, I want <behaviour>, so that <benefit>.

Table 8.1: Requirement List

No.	Requirement	Source
R1	As a user, I want information to be minimalistic, clear and easy to understand so that not I am not distracted as a driver.	Q3, Q4
R2	As a user, I want dynamic real-time feedback to highlight my behaviour so that I have the possibility of correction.	E9, E12, Q4, Q5
R3	As a user, I want my energy efficient driving behaviour to be rewarded so that I can be motivated to adopt energy efficient habits.	E11, Q6
R4	As a user, I want to compare results of accumulated behaviour between drivers of the same vehicle under fixed conditions so that I can learn and be motivated to do better.	E14, Q6
R5	As I user, I want to be shown in what ways I can improve my energy consumption, excluding factors which I cannot affect, so that feedback includes actionable solutions.	E5, E6, E7, E13
R6	As a user, I want to be encouraged to have a smooth drive with soft braking and slow acceleration where coasting is the ideal behaviour, so that my energy usage can be improved.	E1, E2, Q2
R7	As a user, I want colour coded visual feedback to be discrete, simple shifts in hue or shade should indicate consumption patters so that I can easily understand the meaning of the feedback.	E10, Q5
R8	As a user, I want to be shown numbers as objective values such as average speed where keeping an even speed is encouraged so that the feedback is fair to me.	E8, E13, Q4
R9	As a user, I want changes over time, such as average and historical measures of consumptions, to be used to educate me so that I can easier understand the rapid changes of the dynamic power meter	Q3, Q3

8.2 Establishing Design Recommendations

At the end of the first stage, user needs and requirements had been identified and made into a requirement list. Entering the Development and Deliver phase, the brainstorming for design concepts based upholding the identified requirements began. The outcome of the initial brainstorming were four initial design concepts turned into low-fidelity prototypes.

This section will chronologically present the results of the iterative design process conducted, the evaluation of the first iteration and the result of the analysis, as well as how this result affected the development of the second and final iteration. The final iteration, a semi-functional prototype, was evaluated with a think-aloud protocol study as described in Section 7.3.2.2.

The end result of the second stage was a set of design recommendations addressing the research questions of the project, answering what information about One Pedal Drive OPD and throttle usage helps BEV drivers understand their energy consumption, as well as what the design recommendations are for displaying information to promote energy efficient driving.

8.2.1 Iteration 1: Focus Groups

The process and execution of the focus groups are described in 7.3.1.2 and the analysis of the result is described in Section 7.3.1.3. The development of the four concepts evaluated with the focus groups are described in Section 7.3.1.1. This subsection will describe the results of the thematic analysis done of the data collected during the two focus group. The results are divided into five parts, one for each concept evaluated as well as overarching insights regarding feedback of energy usage and energy efficiency. Key insights labelled F1-F10 from the analysis are presented as well as representative quotes from the participants.

8.2.1.1 Iteration 1 Concept A: Takeaways

A description of Concept A can be seen in Section 7.3.1.1, an image of the low-fidelity prototype can be seen in C.4a. The prototype was made with the intention to give ambient real-time feedback of how energy-efficient a current driving state is.

F1: Peripheral feedback gives you an impression without having to switch focus

A majority of the participants were positive to the idea of ambient lights behind the DIM to indicate energy efficient or inefficient driver behaviour. Several participants mentioned that it would be visible in the periphery and thus not distract the driver by requiring them to take their eyes off the road (P3, P1). This indicates that peripheral information could reduce cognitive load facing drivers when otherwise having to look down to the DIM for information. This opens up an opportunity to further develop the attribute of ambient lights as intuitive feedback for the iteration 2. P6 mentions that they do not look to the DIM for the information given by Concept A, suggestion that there is an information gap to be filled regarding instant feedback of energy consumption. P5 directly connects the feedback to a desire for understanding their own energy efficiency. As some other participants, P5 seems to be receptive to feedback mechanisms that gently guide behaviour towards optimizing energy efficiency.

> *"You get an impression of the colour without looking too much, you do not have to focus on it."* - P3

> *"You do not often look to the DIM for this type of information, ambient information is a good solution."* - P6

> *"The colours are like a gloria, something you perceive in the periphery."* - P1

> *"I would like to have something like this to understand how energy efficient I was driving."*- P5

F2: Ambient colour change should not be too sensitive

Several participants seemed to prefer ambient feedback which reflects behavioural patterns on a larger scale rather than reacting instantly to every input no matter the significance. Overly sensitive feedback, instantly changing the ambient lights to an alarming colour such as red or orange when braking harshly, could be perceived as punishment or be the cause of confusion if the driver had no other choice than to behave energy inefficiently due to contextual traffic demands. Some participants suggested the system to be tolerant of brief, but inefficient, actions and instead communicate trends or tendencies, or that it should be respondent to the car's sensors signalling that the action, deemed negative by the system, was necessary in that particular instant, such as emergency braking for an animal on the road or accelerating quickly when driving up on a highway.

> *"This shouldn't be too sensitive, so we can look at a bigger window of changing colour, if you have been accelerating a lot it turns orange, maybe it can stay orange a little longer until you drive better."*- P3

> *"If you are green, should it instantly turn orange when you accelerate, then go back to green, or should it show how you are driving over a longer period of time"* - P7

> *"I like the colours, but the sensitivity should allow small behavioural change without punishment"* - P1

F3: Choice of colour should address their cultural significance
Colours that could be considered as alarming or indicating a warning to the driver, such as red or green, were used in Concept A to signify consequences of driver behaviour. Some participants highlighted that colour is not culturally neutral, and when used in car interfaces which are to be available to the broader public, should be chosen carefully as certain hues carry strong emotional or situational associations. When colours associated with danger or warnings are used to represent energy usage in situations which are unavoidable, they might cause confusion, guilt, distrust or dismissal. Some participants expressed desire for contextually aware colour schemes and supportive colour changes which do not imply wrongdoing, but instead give the driver room for improvement.

> *"Sometimes it's necessary to push the pedal, driving up on a highway, if your DIM then turns red you would think you are doing something wrong whilst its exactly what you are supposed to do."* - P5

> *"More encouraging and less punishing, sometimes you might not really be in control of if it turns red or not."* - P4

8.2.1.2 Iteration 1 Concept B: Takeaways

A description of Concept B can be seen in 7.3.1.1, an image of the low-fidelity prototype can be seen in C.4b. The prototype was made as a visual metaphor inspired by a water level, aiming to communicate the positive effect on energy efficiency of having a smooth drive with little speed fluctuation. It was horizontal with a dynamic tilt to the left or right dependant of the vehicle either being in a state of braking or accelerating, with the meter being level if even speed or coasting was achieved.

F4: Ambiguous feedback could increase cognitive load
The water-level metaphor indicating the driver's accelerating and braking behaviours seemed to spark interest with the participant, although it required interpretation since the meaning of the movements and colours did not come across intuitively to the participants. Some mentioned that they struggled with deducing the meaning of the tilting movement of the horizontal bar, causing confusion and unnecessary cognitive load. This caused the feedback to be seen as less actionable than other concepts. Some participants questioned how the system would handle rapid changes in vehicle state, e.g. hard braking followed by acceleration, indicating that the lack of clarity reduced confidence in the low-fidelity prototype.

> *"This concept acts as a compliment to instant consumption where the driver typically has to decide what is good or bad."* - P2

> *"If you decelerate, you probably have to accelerate after. Then you would get double losses, do the sides compensate, can the bubble go straight to the other side? Let's say that you're breaking hard, then you're accelerating really hard, will the bar compensate?"* - P6

F5: Constant movement draws attention and could lead to distraction
The visually dynamic characteristics of the indicator - the tilting motion and the bubble moving back and forth - was considered as visually attention-grabbing. Some participants expressed a concerns with the possibility of the divided attention interfering with the driver's focus. Several participants mentioned that an alternate placement would be a good idea for this concept, placing it in the HUD (heads-up display) would take away the need of having to look down into the DIM whilst giving the driver feedback in their peripheral vision. Others emphasized their concern of constant movement being too much of a distraction, especially in an otherwise clean and tidy interface.

> *"When something is moving, you tend to look at that instead of the road."* - P6

8.2.1.3 Iteration 1 Concept C: Takeaways

A description of Concept C can be seen in 7.3.1.1, an image of the low-fidelity prototype can be seen in C.4c. Similar to Concept B, Concept C indicated driving style with a needle either pointing to the right or left; to braking or accelerating. It was intended to be mimic already iconography already used in Volvo car interfaces to create a sense of familiarity.

F6: Familiarity aids understanding but requires refinement for clarity
Several participants stated that they were familiar with and appreciated the design of Concept C, recognizing the iconography typical for car interfaces, this suggests that intuitive recognition could lead to acceptance and understanding of functionality. Some participants suggested redesigns and combining the functionality of Concept C with the other concepts, to create design with a broader relevance. The suggestions for refinement implied the need of redesigning the concept with clear functionality in mind. Some participants noted a sense of confusion with the colour scheme, stating

that the driving style meter would be easier to decode if the colours were uniform, removing the multi-faceted aesthetic to simplify the design.

8.2.1.4 Iteration 1 Concept D: Takeaways

A description of Concept D can be seen in 7.3.1.1, an image of the low-fidelity prototype can be seen in C.4d. After identifying a need for a reward system and the benefits of social comparisons in the first stage as seen in E14, in section 8.1.2, concept D was developed to meet those needs. Concept D revolved around giving the user feedback about positive driving behaviour as well as possible improvements, and after a trip the user would receive a score of their drive in a view of the interface which included objective metrics based on trip consumption. It also contained other driver profiles' score for an opportunity of comparison and competition.

F7: Comparisons and competition add value but must be framed carefully
Many of the participants seemed positive to a scoring system being implemented in BEV vehicles. Social comparison was considered as a clear motivator for improved driving behaviour, aligning with the insights extracted from the expert interviews as seen in E14. Some participants emphasized the importance of fairness across different type of trips in regards to comparing scores, e.g. commuting vs. long drives and a potential of unfair comparisons which could cause demotivation. This stresses what was expressed in E8, that values need to be objective and suitable for comparison across users if drivers are to be accepting of comparison and competition. The same could be applied for metrics exclusive to one driver profile and their historical values or scores, a driver getting a lesser score for a drive which is out of the ordinary could struggle to find the value in comparing that trip with other, positively scored, trips that they do on a daily basis. This raises the important issue of using metrics that are relevant and convey meaning on a broader scale, not being tied to trip specifics. An example of this would be to display energy usage per kilometre, average speed or coasting habits such as how many kilometres have been coasted out of the range of the trip.

> *"Comparison would make everyone try their best."* - P3

> *"You could tell someone in your family that they need to drive more carefully since you have seen their score."* - P1

> *"If you are constantly driving to work and then one day drive to Stockholm, you cannot compare those trips to each other"* - P7

> *"If you are on a long drive and you get a score for your drive, a comparison with the score you get for your daily commute would be unfair."* - P5

F8: Feedback should be contextual and available both during and after driving
The participants were overall positive to feedback during the drive, messages in pop-ups or prompts was a positively received idea. Several participants mentioned the importance of a post-drive summary that connects the instant feedback with the performance of the driver post-trip, connecting the prompts with the overall energy

consumption and the scoring would give room for reflection at the end of the drive. This was deemed as an important feature to allow the driver to understand not only the score but also their own driving habits and how they connect to energy efficiency, connecting the different feedback mechanism could then lead to a better learning experience.

> *"An overview or summary as the last thing before you leave the car is nice, not many people stay to go through their trip history otherwise."* - P1

> *"The view you get when you enter the car should present previous results, so you can make that connection if you get a different score (at the end)."* - P4

8.2.1.5 Overarching Takeaways Considering all Concepts

Parts of the discussions amongst the participants reflected over not only one of the specific concepts but of the importance of feedback and how it is visualised in a driving scenario. Some mentioned aspects of the different concepts that could be merged into a new design, and the value that would add to the driving experience. Insights which are overarching and applicable on the discussions of all concepts are presented below.

F9: Feedback should balance instant and reflective timing
The participants were divided on whether instant, real-time or post-drive feedback was the preferred medium of informing a driver of their energy consumption and helping them with changing their habits for a better energy usage pattern. Many of them agreed that a combination between the two would be the most valuable, as it would secure that the driver is aware of what caused the feedback in real-time as well as connecting that activity with post-drive values and scoring. Instant feedback would allow correction and post-drive feedback would help identify trends and opportunity to remedy negative behaviour. These insights imply that for the next design iteration, lightweight, actionable real-time feedback should be combined with rich contextual summaries in a post-drive view.

> *"Personally, I prefer instant feedback over post-drive feedback."* - P2

> *"After a drive, it's too late, then the feedback comes as a surprise."* - P4

F10: visualising driving behaviour encourages energy awareness
Many participants had a positive response to indicators visualising their immediate vehicle state and connecting it to energy usage. Showing where the driver is on a bar or with lights corresponding to acceleration, coasting and braking was implied to be a good learning opportunity and a pleasant addition to BEVs. If refined and implemented with clarity and less distractive properties, the driving style indicators were said to have the possibility of aiding drivers in:

- Identifying energy-efficient behaviour and states (e.g. coasting and keeping an even speed)
- Feeling in control of improving their habits and in extent their energy usage

- Comparing and competing with themselves in an motivational way
- visualising efficiency as a dynamic balance

These insights show that supporting the driver's self awareness of their own energy usage and behavioural patterns by visualising their instant acceleration and regeneration on a spectrum could prove fruitful if refined and implemented in a non-ambiguous, actionable way.

8.2.2 Iteration 2: Protocol Study Usability Testing

The process and execution of the usability testing done through a think-aloud protocol study are described in Section 7.3.2.2 and the analysis of the result is described in Section 7.3.2.3. The second iteration and the aim of this phase is described in 7.3.2, the development of the semi-functional prototype is described in 7.3.2.1.

Images depicting the different feedback seen in the semi-functional prototype are presented in Section 7.3.2.1. In 7.13, the welcome screen of the interface is shown, in 7.14 the neutral view of the DIM when driving the simulator vehicle is presented, in 7.15 the dynamics of the power meter driving style indicator is presented and in 7.17 and 7.18 examples of Eco Score rewarding feedback and Eco-tips prompts for energy efficient driving are shown. The final view visible after a trip has been finished with a summary of the drive in values relevant to energy efficiency as well as a personal Eco Score and a scoreboard comparing the driver to other drivers of the same vehicle can be seen in 7.19 and 7.20. The set-up of the simulation from the driver's perspective as well as of the ambient lighting feedback can be seen in 7.21a.

Results of the thematic analysis is presented in the following subsections, each corresponding to a theme. The seven themes are based on key insights extracted from the analysis of the collected data and have been named to represent the meaning of the data. They are labelled PS1-PS11. All themes contain sub-themes which will be presented in bold in each respective subsection. Some quotes with representative content is presented.

8.2.2.1 U1: Colour as a Communication Tool

Many of the participants discussed the meaning of the colour scheme used in the interface as well as the ambient lights. As each test progressed, almost all participants correctly interpreted the colour blue as positive and insinuating energy efficient driving behaviour and orange as inefficient, this suggests that the colour scheme used aligns with user expectations and mental models used to decode meaning in visual feedback. Whilst the participants generally appreciated the ambient lighting, questions were raised regarding its visibility and effectiveness in brighter environments, due to the study being held in a dark room dedicated to simulation studies, the setting did not allow for this to be investigated further. Some participants remarked on rather harsh colour transitions, especially in regards to the ambient lighting, and wished for a more continuous, gradual transitions from blue to orange. Participants noted that the colour scheme seemed to be unified across the different views in the interface, and that it aligned well with the ambient lights behind the DIM. This seemed to produce a coherent experience where all functionalities were perceived as connected. Subthemes to the theme of Colour as a Communication Tool will be presented below.

U1.1: Perceived Urgency in Colour Feedback
This sub-theme explores the interpretations and emotional responses of the participants to the colour feedback received during the individual usability tests, particularly regarding a feeling of urgency that some participants felt regarding the feedback. Generally, the results of the analysis showed that the participants were sensitive to the emotional and cognitive impact of different colours, especially red, orange and yellow. The three main colours conveying direct feedback to the driver was blue, orange and green. It was noted that many participants perceived the orange hue as red or yellow, this could further emphasize the feeling of urgency that some felt. The colour red was described as negative or overly alarming as it is associated with error or danger. In contrast to this, orange and yellow were seen as milder signals indicating suboptimal performance, without creating the same sense of failure. Several participants stated explicitly that they valued the use of softer colours. This could suggest that choosing the right hues help in maintaining a sense of neutrality and calmness, inviting reflection instead of inducing stress or defensiveness. This further indicated the need for feedback that is guiding without judgement, gently nudging instead of scolding. The insights extracted from this subtheme suggests that colour feedback aimed at driving behaviour should be carefully calibrated to maintain a status as informative without overwhelming or alarming the driver.

> *"Now it is glowing red, which probably means Im entering the roundabout too fast and have to brake very hard."* - P17

> *"So it is actually good that it does not cause a real sense of urgency while informing you about the situation. And maybe red would feel more urgent, and then I would be disturbed or worried. So that is good, the ambient lights."* - P7

> *"A bit like a warning signal. It was quite calm at first when it was blue. I think it can be good to kind of warn yourself: think about this next time."* - P14

U1.2: Ambiguous Blue
The meaning of the colour blue was for many participants not intuitive, for some it took some time to decipher the meaning behind colour coded feedback and connect it with the other functionalities of the feedback system. While the colours green and red were interpreted with relative clarity, signalling good and bad behaviour, blue was described as ambiguous, sometimes emotionally cold, and disconnected from the overall implied environmentally and energy efficiency focused feedback. Some participants struggled to connect the colour blue to a clear value such as good or neutral. The lack of intuitive meaning challenges the usefulness of the colour scheme. However, some participants noted that the colour blue had a calming effect as it was associated with calm, it seemed to be appreciated especially in ambient feedback, as the colour would not disturb the driver but rather give feedback in a gentle manner.

Overall, blue was perceived by neutral, which for some led to detachment from functionality whilst others appreciated the subdued, non-intrusive, implications.

> *"Blue is cold, I do not associate blue with the environment, I think of green for that, and red is the opposite, while blue is maybe something in between."* - P16

U1.3: Peripheral Perception of Eco-Feedback
This theme is centred around how the participants interacted with the visual Eco- and energy efficiency coded feedback visible to their peripheral vision whilst driving, primarily due to the ambient lights installed behind the DIM in the car's dashboard. The overall impression of the ambient lighting feedback was that it efficiently provided real-time feedback without distracting from the action of driving because of its inherent quality of being perceptible in the driver's periphery. The data suggests that the participants generally were positively inclined to perceive this type of feedback, as some mentioned that it allowed them to remain focused on the road whilst still being aware of their driving behaviour and energy usage.

Many participants emphasized the value of peripheral cues and their affordance of informing the driver without having to be looked at directly. This allowed for quick assessment of the vehicle's state of energy usage. Since the peripheral feedback did not demand the driver to diverge their focus from the road, the feedback was deemed to enhance situational awareness and safety while driving. Colour changes acted as gentle reminders of correctable behaviour as well as triggers for further inspection of information in the interface of the DIM. Some participants noted that instant but short-lived signals could be interpreted as ambiguous, and that contextual support connected with further informative feedback in the DIM could remedy this.

> "The light actually gives more visual input while still allowing you to focus more on the road." - P6

> "Its easy to perceive the colours around it... I can perceive that colour without focusing, if its in the periphery." - P18

8.2.2.2 U2: Visual Usability

Visual usability in interfaces of vehicles are central to how drivers perceive and interpret feedback in the system. This theme revolves around that interpretation in regards of feedback about energy efficiency, driver behaviour and vehicle state of either braking or acceleration. Participants described both what they found challenging with the interface of the prototype as well as possible improvements of visual clarity. The spatial placement of elements in the DIM seemed particularly important, since the screen often was perceived as small there is limited space to utilize, and finding the right placement for feedback elements to facilitate a favourable driving experience was deemed vital. Two sub-themes emerged within this overarching theme, and they are presented below. Together the findings suggest that visual elements need to be optimized to allow for quick glances to be sufficient for information gathering, as well ensuring that their functionality is intuitive to the driver.

U2.1: Spatial Design and Driver Attention

Several participants expressed a need better spatial prominence of feedback elements. Small size, peripheral placement, low contrast in hue and rapid instantaneous feedback of the driving style indicator, the modified power meter, all seemed to lead to reduced noticeability during driving. Several participant stressed that the power meter was too small for them to track the movement of the bubble indicating acceleration or braking during the drive, even though the size of the bar was made to mimic the size of currently used power meters in BEV interfaces. Some participants pointed out that increases of size must be carefully done to avoid distraction, since a larger dynamic visual element might demand too much attention. Several participants expressed desire for feedback perceptible by a glance or in the periphery of their view, and some noted that over time, familiarity with the interface would compensate the initial feeling of decreased perception and understanding due to poor visibility.

> *"Then this little icon that moves... maybe its probably too small, because when youre driving... youre not constantly looking at the display."* - P10

> *"It very quickly reached the extreme point, or it felt like the bar was almost too short..."* - P9

> *"That thin little line where you move within the blue or orange area... its not prominent enough, I think."* - P5

U2.2: Functional Meaning of Colour
The overall impression of the participants regarding colour was that they relied heavily on the colours of the feedback systems of the prototype to interpret the meaning of the feedback. Some reported confusion about transitions between the colours blue and orange, even though they were interpreted correctly as positive and negative states respectively, as they often were perceived as abrupt. The participants requested smoother transition in favour of clearer mapping between colour and system behaviour, such as feedback of regenerative braking and acceleration. This would suggest that colour schemes should be both semantically intuitive as well as visually continuous.

> *"It grabbed my interest when it went from orange to blue."* - P5

> *"I would want it to change colour more smoothly, like a flowing scale."* - P12

8.2.2.3 U3: Making Sense of Eco-Driving Feedback

The extractions of the thematic analysis forming this theme captures how drivers interpret and make use of Eco-driving feedback in BEVs. The theme is divided into four sub-themes, surrounding real-time indicators, post-drive summaries, needs of clarity and personalization and prior experience enhancing understanding. Across these four sub-themes, participants showed varying levels of understanding and trust. The impressions leading to this theme suggests a need for feedback systems to balance simplicity with flexibility, to accommodate different levels of knowledge and to offer contextual relevance.

U3.1: Real-Time Understanding of Indicators
The analysis indicated that many of the participants made sense of real-time feedback through visual cues such as colour shifts, the movement of the driving style indicator bar (i.e. power meter) and Eco-coded symbols such as leaves. Most of the participants correctly understood that the middle position of the power meter was optimal for energy efficiency purposes, though some confusion about the extremities to the left or right arose. Interpretation of the interface often relied on trial and error during the drive, some comparing the prototype to familiar concepts such as video game contexts.

> *"It is pretty good. It was a kind of indicator, so it is comparable to the power meter we have now. And the colour changed depending on whether there was a bit of unnecessary force in acceleration or braking."* - P2

> *"Because now, with where it was centred, it became a bit difficult. You had to focus on where it was, and then it was hard to understand whether it was more to the right or more to the left, and whether that meant anything."* - P6

U3.2: Post-Drive Interpretation of Feedback
The overall impression of the post-drive summary of metrics associated with the energy usage and efficiency of the drive was that the contents were informative but sometimes vague. Several participants expressed a desire of knowing how the scores were calculated, whilst many simultaneously appreciated the colour-coded scoring and the numerical values associated with the drive. Some participants shared a sense of curiosity and showed interest in using the system in a real driving setting to see how they could influence the score. Many participants noted that the post-drive feedback allowed them to fully understand the meaning of the feedback received during the drive, suggesting that retrospective elements could aid in understanding the feedback system.

> *"Orange, yeah that is a bit worse... Yeah, its pretty nice to show with colour where you end up."* - P2

> *"So, just when I see this after driving, then I know that the orange is bad. Youre not exactly thrilled when you see that."* - P8

U3.3: Need for Explanation and Personalization
Several participants expressed desire for customizable options of the system and a need for the feedback to be explained. Many participants stressed that context should play a part in when feedback such as Eco-driving tips or prompts should be displayed to avoid them being intrusive in scenarios where they are deemed irrelevant, such as when in a rush or in heavy traffic. There was a wish for elaborations of the meaning of the tips, and it was suggested that these could be presented post-drive or accessed in the CSD. This was to understand what caused low scores or how improvements could be achieved.

> *"I like to look and modify stuff so I would like some tuning possibilities of this, or to be able to change to what I want to see."* - P12

> *"I could go in and read about my coasting score maybe (in the CSD), and get some additional information about it, maybe why I have 2 out of 5 leaves and the reason behind that."* - P13

> *"If I am driving and have other things to deal with in traffic, and a message pops up and disappears after a few seconds, I wont be paying attention to it at that moment."* - P4

U3.4: Familiarity Enables Understanding
During the analysis it became clear that participants with either more experience of EVs or with a technical educational or work background had an easier time in interpreting the information during and after the drive. Familiarity seemed to be associated with confidence, some participants mentioned that the system would be easier to use if they knew what to expect. This indicated that understanding Eco-driving and energy efficiency in a BEV is a skill that is developed, not innate.

> *"If I would do this again, I would know what options I have in the car. Then I would reflect on that from the beginning."* - P16

> *"Okay, so there is a warning there, but I am unsure what is meant by coasting to save energy."* - P14

8.2.2.4 U4: Cognitive Load and Contextual Sensitivity In Feedback Delivery

Although the overall impression was that feedback systems in vehicles can prove helpful, several participants agreed that they should be designed to minimize cognitive load and show sensitivity to contextual driving scenarios. Overly frequent feedback, both visual and in text, could reduce focus on the act of driving, and if misaligned with the intention of the driver it could result in being ignored. Feedback should be relevant, well-timed and contextually aware to support safe and efficient driving. This theme is divided into four sub-themes, each addressing a specific issue of feedback delivery.

U4.1: Impact of Visual Feedback on Driver Focus
Several participants highlighted that visual feedback would distract them if too bright, too frequent or poorly timed. Many seemed to have a strong preference of minimalistic cues such as symbols instead of text, and some concerns were raised of feedback making the driver shift attention from the road. If ambient lighting was to be used, they should not be perceived as blinking when changing colour as the change could further increase the cognitive load of the driver, possibly leading to paying excessive attention to the DIM during critical driving tasks. If using text as feedback, several participants noted that text should be easy to comprehend or intuitively understood if actionable, as well as short enough to not demand a strain on attention because of reading.

> *"And then some text popped up that you had to read quite clearly. And I felt that it was quite distracting from the traffic."* - P6

> *"I want to pay attention to the road at the same time and then at some point I feel like I stare at the DIM too much."* - P15

U4.2: Feedback for Real-World Driving Scenarios
Several participants expressed an importance of the feedback to accurately reflect real-world driving scenarios, such as not punishing the driver for energy inefficient behaviour in dense city centre conditions where they experience limited flexibility or for increasing acceleration when nearing an incline. Penalizing behaviour necessary to ensure a safe drive was viewed as unfair and possibly demotivating. Several participants had concerns about being the recipients of tips of energy efficient driving behaviour whilst in complex situations such as closing in to a roundabout with heavy traffic or a multi-lane red light crossroad where the cognitive demand of the driver would already be high.

> *"If you have cars in front and behind you, you need to keep up with the flow of traffic, and then maybe you shouldnt be penalized as much for your driving style."* - P2

> *"Even speed. It would get a bit annoying to write 'Keep even speed' when its dictated by the traffic around you."* - P4

U4.3: Timing of In-Car Feedback
The timing of feedback emerged as a critical factor of feedback delivery and its usefulness. Several participants noted that some textual feedback appeared when the action suggested was not applicable or when the traffic situation demanded attention. It was implied that feedback should be delivered in situations of low complexity, such as on highways. For feedback requiring more attention of the driver than glancing or peripheral perception, some participants preferred post-drive feedback.

> *"Maybe you need to find a balance in how often you give feedback and notifications so that it doesnt happen too frequently while driving."* - P2

> *"But one time at a roundabout a tip popped up and it was a bit distracting... it suddenly appears and it's like 'oh, now there's a lot going on'."* - P8

8.2.2.5 U5: Learning to Drive Efficiently

Many participants showed engagement in learning how to optimize their own driving behaviours to practice energy efficient behaviour whilst driving BEVs. Overall, efficiency was viewed as a learning process which could be enhanced by meaningful and actionable feedback. This theme with its four sub-themes focuses on the participants reception and reflection of feedback and how well they understood metrics, how they navigated uncertainties and responded to real-time behavioural cues.

U5.1: Reflection and Learning from Feedback
Participants seemed to appreciate the opportunity to reflect on their driving session after the drive, the opportunity which arose when presented with a summary of their drive with specific values as well as a score dedicated to their coasting habits. Since the score related to their energy efficiency, energy usage and driving

behavioural patterns, the feedback was seen as helpful in order to identify inefficient behaviours such as braking too hard and often or practice unnecessary acceleration habits. Some participants mentioned that this helped in making them aware of their own behaviour and possible adjustments.

> *"Thats what I want to try to learn which situations have been bad."* - P1

> "I wouldve thought a bit about why and then reflected back on the drive in that case." - P18

> "Afterwards, I might not remember what I did right there or during that stretch. So then it also becomes too disconnected." - P9

U5.2: Relevance and Usefulness of Metrics
Based on the result of the analysis it became clear that the participants wanted clear, contextually bound and varied metrics to understand what energy efficiency meant in relation to a BEV. A common request was to include data of energy consumption, coasting, speed and how climate settings influence energy usage. It was also mentioned that comparison, either of a driver's own scoring over time or with other drivers, would make metrics more meaningful. Some participants found that the existing values in the prototype's interface assigned to a specific drive were lacking contextual clarity.

> *"It is hard to get a reference to what this is being compared to."* - P6

U5.3: Uncertainty of Efficient EV Driving Practices
Several participants expressed their own uncertainty of their knowledge of what energy efficient driving of an EV entails or how it would be translated into actions or behavioural patterns in the vehicle. Unlike the traditional ICEV, EVs have differ in the dynamics of energy consumption and other factors such as regeneration play a part in energy usage. Several participants mentioned that they felt uninformed or under educated in this matter. The Eco-tips or prompts were seen as helpful in closing these knowledge gaps and clarifying what actions can be taken by the driver to increase efficiency, and there seemed to be an openness to receiving more guidance to navigate and adopt efficient BEV driving behaviour.

> *"I havent received any training or know how to drive economically with an electric car."* - P16

> *"That was nice. Now that I see this (drive summary), it makes sense to get them (Eco-tips), and if you follow these, then it gets better."* - P17

> *"What is it that affects an EV when I drive? Should I drive and brake or drive and let go and coast?"* - P16

> *"It was nice to get that bit (drive summary) because many people don't even know that, I guess."* - P1

U5.4: Effectiveness of Real-Time Behavioural Cues
Many participants seemed to respond positively to real-time feedback on what behaviours could be adjusted and how, and to being rewarded for specific behaviours.

Eco-tips text prompts, colour changes and a dynamic power meter efficiency indicator were generally appreciated as the cues encouraged efficient driving in the moment, making the feedback actionable but avoiding to overly criticize the driver. The combination of visual elements with instructive text and indicators made the feedback understandable. Some participants mentioned that the feedback could be less frequent or that the dynamic element of the power meter indicator could be less visually active.

> *"It's nice that when there's an Eco-indicator, you do tend to kind of want to follow it."* - P1

> *"The colours and the notification light effects can help to understand a bit what mode you are in."* - P2

> *"Coast to stop. That was a good tip. So no braking just before the red light, but instead release the accelerator pedal."* - P17

8.2.2.6 U6: Understanding the Eco Score

The Eco Score system, visible after a drive, including a summary of that drive with metrics tied to performance and energy efficiency, with a scoring system represented through 1-5 leaves, was deemed as intriguing and refreshing albeit sometimes unclear. The score triggered curiosity and reflection although the lack of information about the scoring logic and uncertain criteria for success left many participants unsure of what the meaning of the score was, how it reflected their performance and how they could improve themselves. This suggests that the effectiveness of an Eco Score id dependent on the knowledge of the driver, which could be supported in ways specified in other themes. The following three sub-themes will delve into specific parts of the Eco Score system which either aided the participants in their understanding or left them confused.

U6.1: Visibility and Clarity
Several participants often expressed confusion about where to locate their current leaf score, as many assumed that the leaf Eco symbol signalling the optimal position of the power meter efficiency indicator was a visualisation of their current score. There was also questions about what the number of leaves represents and how many are possible to get. The visuals of the goodbye screen, seen in*ref fig*, were appreciated for its clean aesthetics and clear colour coding, but was by some deemed to lack indication of progress. This could be assigned to the fact that the participants went into the study unknowing of the design, as a score of the supposed previous drive of the vehicle was visible in the first welcoming view of the DIM interface, seen in *ref fig*, something when pointed out was recognized as easy to miss if one was new to using the system. The ambiguous perception of the Eco Score sometimes lead to an increase of misunderstanding the real-time feedback.

> *"Since I don't know how many leaves I can gain, maybe I would like to have the full amount here... the problem is I don't know what's possible."* - P7

U6.2: Understanding Score Dynamics

Several participants shared feelings of doubts regarding the calculation of the scores, it seemed to be uncertain what the criteria for gaining leaves were, how they could be lost and how different contexts such as driving on highways vs. in cities affected the scoring. Many of the participants saw great potential in implementing gamified elements into BEV interfaces, emphasizing that it if implemented the rules of the system need to be transparent. This suggests that drivers of BEVs feel a need for feedback in the vehicle to be responsive and informative for how their own behaviour affects potential scoring.

> *"Since this is gamified I would like to get as many points as possible... It would be nice if you could lose leaves too."* - P20

> *"I don't know how the leaves are calculated... is this (other participant's scores) a fair comparison?"* - P7

> *"If I would have driven longer I would like to see if it's possible to lose leaves by driving bad."* - P20

U6.3: Perceived Criteria for Success
Since the understanding of the Eco Score dynamics was unclear to many of the participants, some tried to apply logic to the system and by reason alone try to figure out what type of actions would gain them a leaf. They did so by linking the rewards to actions like coasting, gentle braking or balancing in the desired area of energy consumption in the power meter efficiency indicator. Although these assumptions were often linked to the reasoning behind the prototype, the participants still experienced uncertainty or contradictory information when applying their own logic to the system. Overall, the lack of clear criteria often made users rely on their own capacity of guessing. This suggests that the information supplied in the DIM alone for the protocol study was not enough to satisfy the inquiries of the participants.

> *"I'm assuming that when the blue lights show up, I gain a leaf... maybe I use the pedals too much when its yellow."* - P15

> *"I probably got a leaf because I stopped in time or in the right way, with the braking."* - P16

> *"It's hard to understand why I got a leaf, but I assume it was because of how much I coasted. But how long are you supposed to coast?"* - P13

8.2.2.7 U7: Motivation through Comparison and Gamification

This theme revolves around the final view of the DIM based interface in the semi-functional prototype, the goodbye-screen in which the drivers got a summary of their drive in dynamic values relevant to energy efficiency as well as their own score in leaves and scores from other driver profiles of the same vehicle. Participants seemed to be motivated by the idea of comparing their own performance either with their historical scores or with others, and found the gamified feedback such as visualised rewards to be engaging. Some shared the idea that for the system to be truly motivating and a part in creating energy efficient driving behaviour, scoring systems and gamified elements would have to be clearly anchored in context and personalized to increase the chances of the driver relating to what they see on the screen.

U7.1: Desire for Comparative and Contextual Information
Overall, the results of the analysis suggest that the majority of the participants experienced a desire for clarity, context and comparability in feedback. Connecting to the Eco Score presented to them at the end of their simulated drive, many were confused about the meaning of the score, the number of attainable leaves, what the different scoring presented meant and what aspects of their drive was being compared to other drivers in the scoring board. The participants wanted clear comparisons, they wanted to know if their specific behaviour was comparable with someone else's and in that case, what had caused their score. Some mentioned a need of suggestions on how to improve in the same view. Many participants expressed that they would prioritize the ability of comparing themselves with their own older scores instead of others to see if they had improved their efficiency. Several participants also expressed the need of contextualized metrics such as consumption per route. This suggests that feedback at the end of the drive should be customized to fit the needs of drivers who wish to improve their energy efficiency, and the feedback needs to allow them to interpret how that improvement could be achieved.

> *"What is the maximum score? What should I have done to get even more points?"* - P18

> *"I want to know how Yvonne got three stars. And how come I only got two?"* - P8

> *"Could you get it in a more specific context then (scores)? Like, this stretch you just drove, here is what others have scored on this exact stretch."* - P2

> *"No, well. I do not think it helped me that much (comparisons with others). I was more focused on my own driving and maybe comparing with myself, my previous drive."* - P10

U7.2: Gamified Feedback and Driver Engagement
The gamified elements in the semi-functional prototype were received seemingly positively, gaining leaves (scores), improving your score and comparing yourself with others was described as fun and motivating, especially if it helped improve energy efficiency and by that reduce personal costs for the driver. However, the engagement of the driver was closely tied to that of meaningful feedback. Some participants mentioned that driver engagement with the Eco Score might fade over time or that preferences vary across different personality types since not everyone values energy efficient driving behaviour. This suggests that for some drivers, even if interested in increasing their efficiency, it is necessary to identify motivators and ways of keeping them engaged over time.

8.2.3 Design Recommendations

The design recommendations presented in 8.2 are suggestions of what information about one pedal drive (OPD) and throttle usage helps drivers understand their energy consumption. The project has focused this information to be that which is displayed in the DIM of BEV. The recommendations have emerged by the iterative process of research through design, the process and execution of which is presented in the Chapter 7. The collected result of the data analyses conducted during the project have lead to a greater understanding of what information should be displayed to driver to drivers about their energy usage, the motivator behind behavioural change regarding energy efficient driver and how such information can be displayed in an in-car setting. See section 7.4.1 for the process of establishing the design recommendations.

The ten recommendations, each motivated with sources linked to the expert interviews, referred to as e.g. E1, seen in Section 8.1.2, the analysis of the conducted questionnaire presented in Section 8.1.3, referred to as e.g. Q1, and the results of the protocol study usability tests seen in Section 8.2.2, referred to as e.g. U1.

Table 8.2: Design Recommendations

No.	Design Recommendation	Description	Source
	Visual and Spatial Presentation of Information		
DR1	Use colour strategically to indicate energy consumption	Use universally understood, non-alarming, colours in feedback systems to reduce misinterpretation of meaning. Visual cues such as colour shifts could help users map driver behaviour to the use of OPD and throttle.	U1, U1.2, U1.3, U2.2, U5.4, Q5, F2, F3
DR2	Design for peripheral visibility	Peripheral cues can be used to inform users of system states tied to OPD or throttle usage without demanding the redirection of their attention, allowing for quick assessment of feedback and enhancing situational awareness without compromising safety.	U1.3, U2.1, U4.1, Q4, Q3, F1
DR3	Employ ambient feedback for unobtrusive information delivery	Ambient feedback opens up for gently nudging users, indicating positively or negatively charged OPD or throttle usage in real-time. When implemented, it should be pleasing in hue, brightness and dynamics to stay non-intrusive.	U1.2, U1.3, U1.4, Q3, Q4, F1

No.	Design Recommendation	Description	Source
DR4	Structure feedback with spatial and visual clarity	In the limited space of the DIM, important indicators should be placed near the drivers natural line of sight. When implementing instant feedback mechanisms such as dynamic indicators of OPD or throttle usage, spatial design needs to be clear enough for users to understand the feedback instantly to minimise excessive cognitive load.	U2, U2.1, U4.1, Q5, F5
DR5	Feedback should be contextually relevant to reduce cognitive load	To not overwhelm the user with requiring extensive interpretation, feedback should be subtle but meaningful. Detailed feedback can be used in calm environments, but constant or overly distracting signals should be avoided since this could result in it and other important information being disregarded.	U4, U4.1, U4.2, U4.3, U5.4
Promoting the Acquisition of Eco-Driving Habits			
DR6	Combine instant and retrospective feedback for a better learning experience	Users benefit from understanding feedback in the moment of action as well as being reminded of their behaviour post-drive. Retrospective reflection could enhance the learning experience of adopting energy efficient driving behaviour. Instant feedback becomes richer if complemented by post-drive feedback.	U3.1, U3.2, U5.1, E12,F8, F9
DR7	Build trust to feedback systems by transparency and consistency	The shift from Internal Combustion Engine Vehicles to Battery Electric Vehicles with the introduction of OPD has left some drivers unaware of how energy efficient driving habits are translated to electric cars. Drivers want to understand what efficient behaviour is. Feedback used to increase efficiency should be transparent and predictable since inconsistencies undermine trust.	U3.2, U3.3, U3.4, U5.3, U6.2, Q1, F6, F10
DR8	Provide actionable feedback	Instant feedback can be used to highlight wasteful driving behaviour and identify actionable areas for improvement in real time, helping drivers adjust their habits to achieve greater energy efficiency.	U1.3, U5.1, U5.4, E12, E13, F10
Motivating Energy Efficiency With Gameful Elements in DIM			

No.	Design Recommendation	Description	Source
DR9	Let users compare with past performances	Clear and contextually bound metrics can be used to help drivers understand their impact on energy usage in a Battery Electric Vehicle. Enabling drivers to track improvement over time could act as a motivator for behavioural change. Creating an environment of competition by allowing for comparisons between drivers could further motivate changed behaviour and by that create new habits.	U5.2, U7, U7.1, E14, Q6, F7
DR10	Keep gameful elements subtle and context-aware	Gamified elements used in in-car design should be subtle during driving as to not increase cognitive load on the expense of safety. Scoring systems are beneficial for drivers who are motivated by competition, but should if used be transparent in their rules to not become demotivating and instead steer focus to self-improvement.	U6.3, U6.2, U7.1, U7.2, E13, Q6, E9, F9
DR11	Informative feedback should support the driver without critique	To inspire behavioural change by informing of energy efficient driving behaviour, feedback should support the users decisions without overly directive messages. The tone of feedback should align with a non-intrusive driving experience.	U4.2,U5.4, E11, E6

8.2.3.1 Visual and Spatial Presentation of Information

The following recommendations aim to suggest how information through instant, real-time feedback can be displayed via the DIM or by ambient lighting surrounding the DIM in a way that safely and unobtrusively informs, educates, motivates and enhances drivers' driving experience in the moment. Through the use of these recommendations, drivers could get real-time indicators of how their live OPD and throttle usage effect their energy usage and in what ways they could optimise their driving behaviour for better energy efficiency.

DR1: Use colour strategically to indicate energy consumption
As colour have cultural and emotional meaning, in in-car environments, universally understood colours should be used. They should be non-alarming as to not demand immediate attention when such is not necessary, and to not distract the user from driving in a safe manner. When using colour to indicate energy consumption, colour should be chosen strategically as to not open for misinterpretation of meaning, as this could lead to drivers disregard of feedback in the long run or assumptions of the cause and effect of their energy consumption to not be meaningfully connected

to the feedback. Visual cues such as colour shifts indicating energy usage and driver behaviour could help users map their behaviour to their use of OPD and the throttle.

DR2: Design for peripheral visibility
Peripheral cues can be used in the DIM to inform drivers of vehicle and system states tied to OPD and throttle usage. By using peripheral cues, the driver is not demanded to redirect their attention from the act of driving when prompted with real-time feedback. This allows for quick assessment of the feedback and allows for further closer investigation of the information, but does not make it necessary, enhancing and sustaining the driver's situational awareness without compromising safety.

DR3: Employ ambient feedback for unobtrusive information delivery
Using ambient lighting to provide real-time, instant feedback to indicate use of OPD and throttle usage in BEV opens up for the possibility gentle use of nudging of the drivers into adopting energy efficient driving habits. Indicating cause of energy consumption by referencing to the effect of the consumption as feedback of ambient light could help educate and remind drivers of the consequences or benefits of their behaviour. If ambient lighting is used in an in-car environment, actions must be taken to ensure that it is pleasing to a broad range of drivers in hue, brightness and dynamic aspects such as colours shifts, to keep it non-intrusive. his design recommendation align with previous finding by Rodríguez et al. [33], where ambient feedback promoted natural interactions without distraction.

DR4: Structure feedback with spatial and visual clarity
Since the DIM of BEVs are becoming increasingly smaller as new industry standards are set, the interfaces available to the driver during the drive need to be structured to benefit visual and spatial clarity. Important indicators should be placed in the driver's natural line of sight, ensuring that they do not have to add extra cognitive and physical strain to the simple act of glancing at the DIM.When implementing instant feedback mechanisms such as dynamic indicators of OPD and throttle usage like the power meter, spatial design needs to be clear for users to understand. There is little room for misinterpretation, as this could cause driver's to misunderstand their own effect on the energy consumption of their vehicle. Adopting this in practise could result in the reduction of cognitive load whilst driving as supported by Wickens [55].

DR5: Feedback should be contextually relevant to reduce to cognitive load
Feedback delivered to drivers during the act of driving should be subtle but meaningful, as to not increase cognitive load by requiring extensive interpretation of complex material. Information should be intuitively understood or otherwise explained to driver's in a way that is safe but educational, such as providing opportunities for explanation whilst the car is not in motion. Constant or overly distracting signals from feedback should be avoided as this could result in drivers neglecting information in the DIM and with this create a habit of disregarding content, which could cause vital information to be overlooked. These findings align with previous studies that highlight the importance of finding a balance to not risk cognitive overload

by providing too much information, but also not providing too little information resulting in cognitive underload [56].

8.2.3.2 Promoting the Acquisition of Eco-Driving Habits

To achieve energy efficient driving by adopting behaviours that optimise energy usage dependent on driver behaviour, the mechanisms of energy usage need to be understood by the driver. To promote the adoption of Eco-driving habits, instant as well as retrospective feedback could be used.

DR6: Combine instant and retrospective feedback for a better learning experience
When being faced with new types of feedback, drivers might feel a lack of information. Since there is limited space in in-car interfaces and every centimetre needs to have its purpose, it would not be wise to further explain information together with instant feedback. Utilizing a combination of real-time and retrospective feedback could provide a greater learning experience, as drivers would get the opportunity to make connections between their own energy related behaviours and summaries of their trips, this could lead to a greater understanding for energy consumption and what actions could be taken to optimize one's driving behaviour to achieve improved energy efficiency. Reflection after a drive, enabled by easy-to-comprehend visual cues and contextually relevant informative metrics could create a richer driving experience.

DR7: Build trust to feedback systems by transparency and consistency
Since BEVs have risen in popularity, the differences between driving electric cars and ICEV are not completely unknown to many, however there are still some habits of driving which do not translate entirely to that of EVs. Some drivers are unaware of how they should behave in an efficient way, and want to be informed of this even though this information is often not explanatory enough to have an effect if the driver does not posses a great interest in the topic. Feedback used with the purpose of increasing efficiency should be transparent so it can be understood, and predictable in nature since inconsistencies could confuse drivers and undermine their trust. One key factor in UX design refers to credibility where users need to trust the system through transparency [50].

DR8: Provide actionable feedback
A way of informing about efficient use of OPD and throttle usage is by actionable feedback. This could be used to highlight wasteful behaviour and to help drivers identify areas in which they themselves could have an effect on their energy usage in real time. Providing actionable feedback could drive a learning experience in efficient BEV driving.

8.2.3.3 Motivating Energy Efficient Behaviour With Gameful Elements in Driver Information Monitors

Using gameful elements in user-centred interfaces such as the DIM could enrich the driving experience by providing motivating and playful feedback. The use of competitive elements could further enhance the experience by motivating drivers to better themselves and their behaviour, and in turn other drivers.

DR9: Let users compare with past performances
As many users experience comparisons and competition to be motivational elements, this could be extended to come of use in a in-car environment. Clear and contextually bound metrics which reflect a driven trip could be used for drivers to understand the impact they have had on their energy consumption and in extent their energy efficiency. Enabling drivers to track their improvement over time could further enrich the experience. Allowing for competition between drivers could further motivate behavioural change by creating new and energy efficient habits. The positive outcomes of implementing gameful element of social comparison is supported by previous work [35][34].

DR10: Keep gameful elements subtle and context-aware
Using gamified elements in interfaces such as that of the DIM should be subtly done when feedback is given during driving as to not increase cognitive load at the expense of safety. Scoring systems and competitive elements are beneficial for self-improvement but should be transparent in and of its meaning as to not demotivate the driver.

DR11: Informative feedback should support the driver without critique
To avoid penalizing the driver through feedback, information or suggestions of correcting driving behaviour as to improve energy consumption should be done without being too directional. The tone of the feedback should align with that of an non-intrusive and pleasant driving experience. Finding the right balance between challenge and achievement is crucial for an enjoyable driving experience [45].

8.3 Final Design: Eco Score

Improvements derived from the result of the analysis of the second iteration as seen in Section 8.2.2 and the suggested design recommendations presented in Table 8.2 and Section 8.2.3 resulted in the development of a final design solution which we have chosen to call Eco Score. This development did not follow a strict process, and the description of it can be seen in Section 7.4.2. The numbers and metrics shown in the visualisations of the final design should not be seen as representative of Volvo Cars' BEV interfaces but are placeholders for visualisation purposes. The final design was presented to stakeholders in order to verify if it fulfilled their needs. To evaluate it, first impressions by stakeholders were gathered. The two key stakeholders which provided feedback which verified that measures had been taken to fulfil the interest of identifying what information about one pedal drive (OPD) and throttle usage helps drivers understand their energy consumption. Images of the final design will be presented below as well as quotes from the two key stakeholders.

The final design Eco Score was built on the previous design used for the protocol study usability testing, which can be seen in 7.3.2. The views of the interface were alter to fit identified needs. Some of these improvements can be seen in the figures that follow, in 8.3, it can be seen how the driver is greeted when first entering their car with the Eco Score of their previous trip, highlighted in blue which signifies an efficient drive.

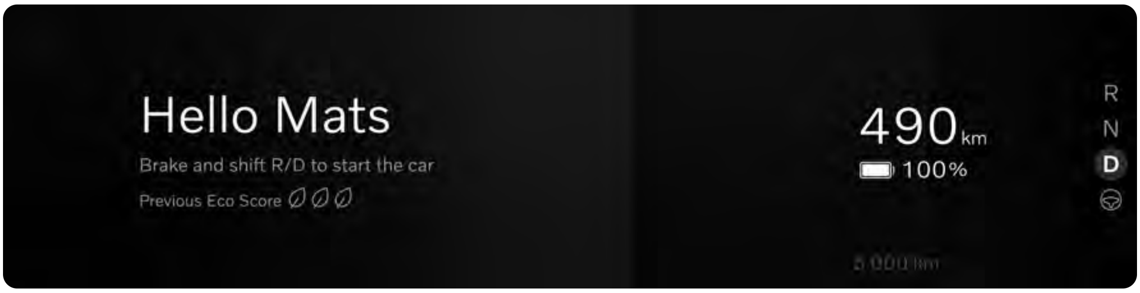


Figure 8.3: View of the welcoming screen of the DIM, greeting the driver and showing the Eco Score of their latest drive.

> *"To inspire motivation it is important to be able to compare yourself with something else, in this case it is very good that you can compare yourself to your old score in the beginning of the drive or to other users afterwards."* - Member of the Preventive Safety Research Team

In 8.4, a view of the DIM interface made for informing the driver of their energy usage in real-time is visible. With this design, the power meter energy usage indicator was improved by enlargement as well as clearer boundaries to the left and right, indicating when either acceleration or braking is severe and might cause excessive energy consumption. The view also features a prompt informing the driver that they have gained a leaf, as a part of the gamified elements of the Eco Score, by driving efficiently.

Figure 8.4: View of the DIM during an active drive, showing a message prompt of the driver gaining a leaf when driving energy efficiently.

> *(Regarding ambient lighting real-time feedback) "It is good that people do not have to look down so much. This actually removes the need to know where you are on the scale of the power meter, you do not have to know, you only need to know the colour because that is your position on the power meter."* - Member of the Preventive Safety Research Team

In 8.5, another view of the interface whilst the car is in motion is showed. This time, the power meter is indicating that the vehicle is accelerating fast, making the coloured indicator of the power meter go far to the right and turn orange from its neutral blue colour. In this scenario, the driver gets an Eco-Tip prompt encouraging them to keep an even speed.

Figure 8.5: View of the DIM during an active drive, with an power meter efficiency indicator indicating high acceleration as well as an Eco-tip prompt suggesting the driver to keep even speed.

> *"The messages are good, especially since they are short. It is good to get instant feedback, you need that information during the drive since that is when you can act on it and take in the information, afterwards you might have forgotten the context. You should be able to remove them and not get that type of instant feedback if you want to."*- Member of the Vehicle Energy Management Team

> *"The power meter allows you to understand what the car is doing. If you would use a longitudinal driver support system, you could look at the power meter to understand what the car is doing. By adding the leaf to the power meter it becomes better, since you can understand what effect the meter is indicating."* - Member of the Preventive Safety Research Team

In 8.6, a view visible when the car is parked directly after a finished trip is visible. The interface then features a summary of metrics and values tied to the energy efficiency of the driver's performance. The driver would get their Eco Score, which in this image is four out of five leaves. What was added to this design were the average consumption of the drive, as well as non-gained leaves being visible but not coloured to indicate how high of a score is achievable. Other drivers' scores are also highlighted with colour, showing that those who have gotten lower than three leaves have performed undesirably low by having their leaves be orange instead of blue. Another improvement was that of changing the previous name of the summary to 'Eco Score' instead of 'Coasting Score', to accentuate the Eco and energy efficiency perspective of the system.

> *"The measurements allow me to understand that this is something that*

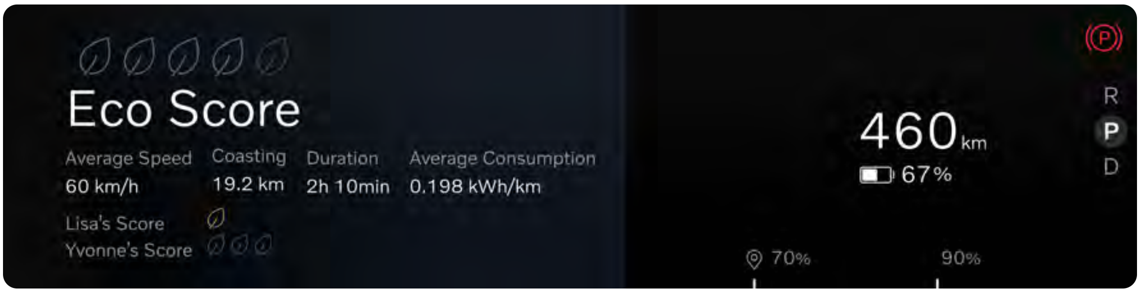


Figure 8.6: View of the DIM when parked post-drive, an Eco Score summary of the drive is visible with individual scoring, a scoring board featuring other drivers and metrics connected to the efficiency of the recent drive indicating that the drive was efficient.

> *I need to know and keep track of to drive energy efficiently, this could be good for people who otherwise do not know much about the subject, and it would maybe serve in an educational way."* - Member of the Vehicle Energy Management Team

> *"People do different kinds of trips, if the last time you drove was for 2 hours and then you drive for 10 minutes to the store the time after that, the trips are not comparable. You could do a smarter version of this: you could use routes common to the user, set routes like to school or to work, since it knows where you begin the drive and where the drive ends, which is very useful, you can build on this functionality and the use of navigation."* - Member of the Preventive Safety Research Team

Lastly, in 8.7 a view of the interface can be seen where the driver is faced with a summary of their performance together with their Eco Score, this time with two out of five leaves, coloured in orange. This indicates that the performance of the trip was below the threshold of being qualified as energy efficient, which is why the interface is coded in orange. Another feature is that part of the background is in a semi-transparent, subdued orange. This is to replace the existing charging visualisation in Volvo cars with this type of DIM today, where the background of the view would be indicating the percentage of the battery. This view keeps the functionality, but adds a perspective of energy efficiency to it, making the design coherent.

> *(The orange fill of the interface indicates charging and battery percentage) "It seems like you have thought of the details and how every aspect could fit into the Eco concept, adding an Eco perspective into the different views that already exists."* - Member of the Vehicle Energy Management Team

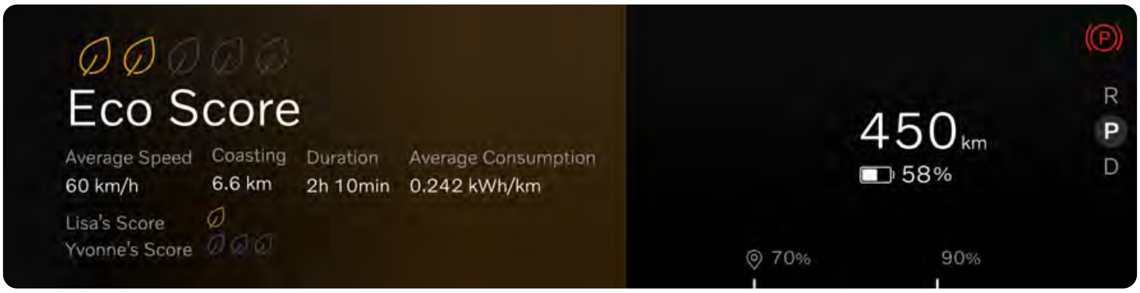


Figure 8.7: View of the DIM when parked post-drive, an Eco Score summary of the drive is visible with individual scoring, a scoring board featuring other drivers and metrics connected to the efficiency of the recent drive indicating that the drive was inefficient.

9

Discussion

This chapter discusses the outcomes of the thesis, starting with a reflection on the work process and the methods used. The findings from the research are interpreted in relation to the research questions and previous literature. The chapter also addresses challenges and limitations of the project followed by ethical considerations. Lastly, suggestions for future work are presented on how the outcomes of this research could inform the continued development of energy feedback in BEVs.

9.1 Work Process and Connected Theories

The challenge of promoting energy-efficient driving behaviour in BEVs reflects several of the characteristics of a Wicked Problem [46]. Promoting energy-efficient driving is complex since it involves an interplay of many factors. The driving task it self and the field of Human-Vehicle Interaction is inherently complex since it involves the drivers physical and cognitive capabilities as well as external factors including other drivers, environmental factors, and other unpredictable circumstances. The BEV is also a complex artifact and understanding the technology behind and the best practices was necessary to take into account in this research. In this case, there is not one correct solution to the problem. However, following a user-centred and iterative approach can suggest a promising design and design recommendations. The work process of this thesis was grounded in RtD and UCD that provided both a structured and explorative foundation for working in a complex problem space where user behaviour, technology, and sustainability intersect.

Users have varying motivations, needs, and experiences so any solution must balance sustainability goals, safety, usability, and driver experience. Addressing this required a flexible design process where prototyping and user testing was central. The RtD framework was suitable as it supported the generation of design knowledge through creation and evaluation of prototypes. User evaluations were used to ensure that the final design solutions were usable, findable, credible, desirable, accessible, and provided value to the users, fulfilling the seven factors of a good UX [50].

The process followed the Double Diamond framework where the initial discovery phase involved expert interviews and questionnaire that aimed to understand user behaviours, attitudes, and pain points related to BEV driving and energy efficiency. Expert interviews also helped frame the problem related to the technicalities of BEVs. The methods were analysed through thematic analysis to identify patterns that were used in the development of personas, scenarios, and requirement list. These approaches helped translating user data into clear design goals of the concept development. Bechmarking was an addition to the process to understand the growing BEV market and conventions of displaying energy related information. This also ensured that the design solution provided value for the users and for Volvo Cars.

The iterative nature of the process of moving from low-fidelity to semi-functional prototypes enabled early testing and continuous refinement. Focus groups and think-aloud usability tests provided important insights into both interface comprehension and behavioural reactions. These methods helped mitigate the wickedness of the problems by continuously allowing the user insights to drive the process and direction of development.

The design and evaluation of the Eco Score concept were informed by the principles of gameful design with the intention to motivate more energy-efficient driving without creating distractions or undermining user trust. Gamification, in this context, was not implemented as point systems or competitive leaderboards alone, but rather as feedback that included subtle cues, progress indicators, and ambient visualization to promote learning and understanding. Elements such as real-time feedback, progress tracking, and post-drive comparison were designed to encourage drivers to behave energy-efficient to balance challenge with achievement to reach the flow state and making the driving experience enjoyable. Results from the questionnaire and user testing indicated that users valued systems that could clarify the link between behaviour and consumption and the final design addressed this by integrating the horizontal meter supported by ambient light to give dynamic real-time feedback. The addition of pop-up tips reinforced learning, while the post-drive Eco Score and social comparison supported reflection and motivation.

However, the research also highlighted the challenges of applying gamification in vehicle contexts regarding driver distraction, cognitive overload, and variations in user motivations. Not all users were motivated by competition or social comparison. For some, the interest was in personal improvement. These differences suggest the importance of designing gameful elements that are customizable or optional.

When reflecting on the methods used in this project, the recruitment of participant was more time consuming than anticipated. Since the result of the study reflects the participants personal opinions, the time constraints could have affected the outcomes. The focus groups were relatively small compared to standard research practices even if three and four participants are considered sufficient [48]. More iterations and a more diverse sample could have yielded a different outcome.

9.2 Result

According to the results that emerged through the analysis of the data gathered throughout the project, drivers of BEV have a need and desire for receiving information of their OPD and throttle usage in order to help them better understand their energy consumption. A benefit of this was that the results discussed in Chapter8 real-time instant and post-drive feedback could be used to potentially increase the energy efficiency dependent of the independent actions of drivers during the act of driving. In this project, these actions refer to behaviour of throttle usage, either with OPD activated or not, resulting in acceleration or breakage and regeneration of energy. An important insight discovered during the expert interviews, presented in E1, E2, E3 and supported by findings in the literature review seen in 2.3.1 was that there is a limit to the benefits of regenerating energy. This knowledge is not universal, and many BEV drivers admit that they experience uncertainty in regards to energy efficient driving practices in EVs. This influenced the designs of the first and second iteration of low-fidelity and semi-functional prototypes, described in Section 7.3.1 and 7.3.2, where information conveyed through ambient lighting feedback, a real-time dynamic power meter indicating energy usage and gameful elements included in a post-drive summary of metrics and values assigned to the conducted trip were used to score the performance of the driver providing opportunity for improvement as well as comparisons with other drivers of the same vehicle.

Despite Eco-feedback in BEV today might not be too common of a practice, the results indicated that many users were positive to receiving feedback of their performance, actionable tips and scoring of their performance to identify learning opportunities. The results also indicated that an Eco-perspective in the presentation of information in the DIM, if combining real-time and post-drive feedback, could promote interest and expansion of knowledge of energy usage, and in extend help create new, efficient driving habits.

The results revealed that despite the interest of feedback regarding energy usage seemed to be a welcomed new potential functionality, not all drivers included in the studies were as inclined to have added information and dynamic feedback into their in-car environment. A concern for distraction or annoyance of the drivers was voiced, this would suggest that such feedback could be assigned to a specific driver mode. This would give users a choice of applying this type of feedback into their immediate interfaces, not forcing unnecessary feedback onto them.

Key insights emerging from analyses of the focus groups and the protocol study, presented in F1 and U1.3 respectively, indicated that the use of ambient feedback in in-car environments is a topic which should be researched further. Many participants were interested in the possibilities provided by peripheral feedback, as this would reduce the need for the driver to look away from the road whilst still being able to register feedback of vehicle state and the effect of their immediate behaviour in the vehicle. This is also supported by the impressions provided by a key stakeholder, a member of the Preventative Safety Research Team, presented in Section 8.3. This suggests that the field of ambient feedback and peripheral feedback in general is of interest to drivers and stands as an option of reducing cognitive load and derestriction of drivers, and could be an option in providing information as instant feedback in an non-obtrusive way.

The deliverables of this project are a set of design recommendations, seen in table 8.2, based on a process of research through design with a user-centred perspective. These derive from a first set of requirements, presented in 8.1which were formed through the first stage of the project, involving the discover and develop phases. Implementing all of these recommendations could prove challenging. Since they consider several different areas of information presentation and discuss both real time, retrospective, ambient and gamified feedback, they indicate that the options for informing drivers of their energy usage in an in-car settings are many. Meaningful information of OPD and throttle usage to help drivers understand energy consumption can be formed in several ways according too the presented recommendations, although a key finding was that combining multiple channels of feedback such as during and after the drive could create a greater learning experience, encouraging drivers of BEV to contemplate their behaviour and identify their own habits and possible improvements.

9.3 Limitations and Challenges

The results of this thesis gave useful information about how to make Eco Score and feedback system that encourage energy-efficient driving in BEVs, but there were challenges and limitations that affected the scope and depth of the work.

The time frame of the thesis project allowed for two main design iterations. These gave the chance to evaluate and improve the designs, but they also made it difficult to conduct more extensive user testing and longitudinal behavioural studies. These types of studies could have investigated learning and adopting energy-efficient driving habits. More design iterations might have helped to further validate the design and recommendations.

A second limitation was the sample of participants. Most of the participants had similar professional background. Since a majority worked in engineering or related fields, this could affect their prior knowledge of BEV technology and motivations. The focus groups and think-aloud user testing were conducted in Gothenburg which resulted in participants living in the same area. Furthermore, the majority of respondents were male and between the ages of 40 and 59, which may not fully represent the diversity of BEV users in the broader population. These factors could potentially bias the result even if manual screening of participants were executed to promote diversity. This could affects the generalisability of the findings.

It was also challenging logistically to recruit participants and make sure that everyone was available for interviews, focus groups, and usability testing. Some planned sessions had to be rescheduled or adapted and participants willing to engage in longer session such as focus groups was limited.

The think-aloud user testing took place in a simulated setting with a UX buck and pre-recorded driving videos. While this provided a controlled and repeatable environment for usability testing, it did not fully capture the complexity and unpredictability of real-world driving. In real situations, some aspects of how users act and pay attention may be different.

Another limitation is that the design exploration focused on manual driving, excluding the use of Advanced Driver Assistance Systems (ADAS) such as Pilot Assist. Understanding how energy feedback interacts with assisted driving modes remains as Volvo Car BEVs include semi-autonomous driving features.

Finally, the project focused on the DIM even if most Volvo Cars BEVs use multiple displays. This project chose to limit the scope to one interface. Including multiple screens could have introduced complexity that was beyond the feasible scope of this thesis.

Even with these challenges and limitations, the results provide a base for more research and development. A larger and more varied sample, more design iterations, and longitudinal testing in real-world driving situations would help validate the conclusions drawn from this project.

9.4 Ethical Considerations

Several ethical considerations were taken into account throughout the project to protect the safety, inclusivity, and integrity of the research process and proposed design solutions.

Driver safety and distraction was a central consideration. Since the design explored the use of gamified elements and real-time feedback in the DIM, care was taken to avoid introducing features that could compromise attention while driving through expert interviews and testing. The prototypes aimed to balance dynamic feedback and avoiding distractions by using ambient feedback and subtle cues to communicate energy efficiency without requiring frequent or long attention shifts. However, there remains a risk of cognitive overload or misinterpretation when incorporating any feedback in vehicles. Future implementations should consider safety evaluations in real driving conditions to not negatively impact driving experience and performance.

Accessibility was another important concern. While the prototype followed basic accessibility guidelines including the use of Volvos design guidelines and global accessibility regulations [74], more could be done to validate that the interface accommodates a wider range of users. For instance, the use of colour coded feedback was appreciated by many participants, but additional modalities such as haptic or auditory cues may be needed to support inclusive design.

In terms of data privacy, all research activities involving participants were conducted according to GDPR regulations. Participation in interviews, focus groups, and usability testing was voluntary. Informed consent was gathered in advance and participants were informed of their right to withdraw at any time without consequence. No personally identifiable information was collected or stored beyond what was necessary for analysis and all data were anonymized during processing and presentation to protect participant privacy.

Overall, the project aimed to balance innovation in sustainable behaviour changing technology with careful consideration of ethical risks related to safety, inclusivity, and privacy. As systems in vehicles become more intelligent and interactive, these considerations will remain essential to future developments.

9.5 Future Work

While this project provides an initial exploration of gamified feedback for promoting energy-efficient driving in BEVs, several opportunities exist for extending the research and addressing the limitations of this this project.

First, longitudinal studies would be valuable to assess how the proposed Eco Score and feedback influence user behaviour and learning over time. This thesis focused on user impressions and experiences in a simulated environment. Future work could investigate whether the motivational effects of gamified elements persist during everyday use and how drivers adapt to feedback once the novelty wears off.

Second, the study was limited to manual driving scenarios. As and semi-autonomous functions like Pilot Assist become more prevalent, future research could explore how energy feedback can be adapted to these contexts.

The third suggestion for future iterations is to consider multi-display coordination. While this thesis focused on the DIM, BEVs often include CSD and mobile application. Investigating how different types of feedback can be distributed across displays and devices could improve usability.

It would also be interesting to explore additional features in the cabin such as different light sources for ambient lights. There are also an opportunity for future work to explore the possibility of implementing similar solutions in heads-up displays that are becoming more common and would support the recommendations of minimal distraction from the road.

Additionally, expanding sample size and diversity of participants could improve generalizability. A more diverse user group in terms of geography, age, and familiarity with BEVs could reveal different needs and expectations, and help refine the solution for a broader audience.

Lastly, future work could explore how different comparisons could motivate drivers to behave more energy-efficient. Exploring the possibility to compare scores with drivers of the same model of vehicle may open new paths for promoting sustainable behaviour on a larger scale.

10

Conclusion

The transition from ICEV to BEV introduce a shifts in the vehicle mechanics and in the mental models and user interactions. This thesis aimed to support this transition by investigating how information regarding OPD and throttle usage can help BEV drivers to better understand their energy consumption. This was done by conducting RtD to formulate actionable design recommendations for displaying this information to promote energy-efficient driving.

To answer the research question: *What information about One Pedal Drive and throttle usage helps BEV drivers understand their energy consumption?*, the Double Diamond framework was applied. The process included discovering user wants, needs, and challenges through expert interviews and a questionnaire sent out to BEV users. Insights from the experts and benchmarking helped to understand the technical feasibility and BEV market. The results from the Discovery phase helped define personas, scenarios, and a requirement list to guide the development of prototypes. Two iterations of brainstorming, prototyping and user testing resulted in several design solutions to display information to help users to better understand their energy consumption.

Real-time feedback on acceleration and deceleration help drivers connect throttle input to energy consumption. Visual indicators such as power meters and ambient lighting that dynamically respond to throttle usage allow users to develop an intuitive understanding of energy impact. Clear feedback when decelerating using OPD help reinforce the positive situations of regenerative braking. Indicators showing when and how much energy is being recuperated through colour-coding and dynamic feedback provide immediate, understandable information of efficient driving.

Contextual tips, such as prompts suggesting smoother throttle input or maintaining even speed, support learning and sustainable behaviour change. These tips work best when delivered with minimal cognitive load during driving, and with more detailed feedback available post-drive.

Comparative and cumulative feedback, such as Eco Scores based on OPD and throttle patterns over time supports learning and reflection. Drivers benefit from seeing trends and patterns in their energy use and how changes in pedal use can affect the consumption.

This research also proposes a set of eleven design recommendations, presented below as DR1-DR11, for the full description of each recommendation and the motivations for them, see table 8.2 and Section 8.2.3. These were informed by user-centred design to answer the research question: *What are the design recommendations for displaying information to promote energy-efficient driving?*

- **DR1:** Use colour strategically to indicate energy consumption
- **DR2:** Design for peripheral visibility
- **DR3**: Employ ambient feedback for unobtrusive information delivery
- **DR4:** Structure feedback with spatial and visual clarity
- **DR5:** Feedback should be contextually relevant to reduce cognitive load
- **DR6:** Combine instant and retrospective feedback for a better learning experience
- **DR7:** Build trust to feedback systems by transparency and consistency
- **DR8:** Provide actionable feedback
- **DR9:** Let users compare with past performances
- **DR10:** Keep gameful elements subtle and context-aware
- **DR11:** Informative feedback should support the driver without critique

Information should be accessible at a glance without requiring much attention. Visual feedback is effective for communicating real-time energy usage. Drivers respond well to contextual messages that are delivered during relevant moments without compromising the driving experience and safety.

Elements like earning or losing points based on efficiency, comparison with past performance or other drivers, and clear visual rewards increase engagement. However, these must be subtle to avoid distraction and preferably displayed after the drive. More detailed information of energy consumption should be provided after the drive for reflection and learning to take place. Using ambient cues can provide peripheral feedback without overwhelming the driver. The feedback should help users learn over time, gradually introducing more complex insights as they become more familiar with BEVs.

In conclusion, this thesis shows that context-aware, user-friendly visualisations of OPD and throttle behaviour can enhance drivers understanding of energy consumption. The proposed design recommendations aim to improve user experience but also to encourage sustainable and energy-efficient driving behaviours. These insights contribute to the ongoing development to create intuitive human-vehicle interfaces for the next generation of BEVs. Future work could explore the long-term behavioural impact of these design solutions in real-world driving conditions and investigate how this kind of feedback and Eco Score might further support user needs.

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A

Appendix: Expert Interview

Technical Expert - Driver Behaviour: Risk Management Principles

Title: Investigating the Implementation of an Eco Score Based on Driver Behaviour and Risk Management Principles
Date: 2025-02-20
Location: In-person, PV4B Volvo Torslanda

Aim of the Interview

The aim of the two planned expert interviews is to define and understand our user group and the problem space of the project. They are part of the discovery phase, and the insights gathered will guide further research and form the basis for questionnaires sent to battery electric vehicle BEV drivers. The goal is to gather expert knowledge to assess the viability of different project directions.

Introduction

Thank you for taking the time to participate in this interview. Your expertise is valuable and will help us understand and define the problem space.

Our research explores how gamified feedback in the Driver Information Monitor DIM can inform drivers of their energy usage and its effect on consumption, particularly focusing on how One Pedal Drive and throttle usage influence energy efficiency.

The interview will take approximately 45 minutes. Data will be handled according to GDPR and remain confidential unless otherwise agreed upon. You will remain anonymous.

- Do you consent to being recorded for internal documentation?
- Have you signed the consent form?

Questions

- Can you briefly introduce yourself and your experience in the field of risk management and driving behaviour?

- Can you tell us about your position at Volvo Cars and what it entails?
- In what ways do you apply your knowledge of driver behaviour and risk management?
- What are the key principles of risk management in driving?
- How do they relate to eco-friendly driving behaviour?
- How does energy consumption influence driver behaviour?
- Do you see difficulties with researching driving behaviour related to energy consumption?
- Are there differences in driving behaviour by age, gender, or location?
- What are key behaviour that lead to inefficient or environmentally harmful driving?
- Are there different driver types that influence energy consumption?
- Are there social behaviour that impact energy consumption?
- How does One Pedal Drive OPD affect driving behaviour and safety?
- What are the main challenges in combining risk management with sustainable driving?
- How do acceleration, speed control, and route choice affect energy consumption?
- Are there existing systems that monitor eco-driving? How could they be improved?
- Should an Eco Score consider external factors (e.g., road, traffic, weather)? How?
- How should these factors be communicated to drivers?
- What limitations or risks come with implementing an Eco Score?
- What metrics should be included?
- Would gamified feedback help visualize or inform drivers about energy use?
- What are the biggest challenges in accurately analysing eco-driving habits?
- Is it feasible to design this without causing distraction or confusion?
- Should gamified elements behave differently with OPD activated?
- How might drivers respond to gamified feedback based on behaviour?
- Should social comparisons or collective scoring be used?
- What are the differences between feedback in the DIM vs. infotainment screen?
- What is more effective: real-time feedback or summaries after driving?

- What feedback or incentives would encourage eco-friendly driving? (e.g., energy savings, high scores, comparisons)
- What information should we gather from BEV drivers?
- Are there risk management practices we should adopt?
- Any relevant practices from other industries?
- What are key steps in the next phase of development, testing, and evaluation?
- Do you have any final thoughts or recommendations?

Closing

- Would you like to receive a copy of the final thesis?
- May we follow up with further questions or share next steps?

Technical Expert - Energy Management

Title: Investigating the Implementation of an Eco Score for Car Batteries
Date: 2025-02-21
Location: In-person, PV4B Volvo Torslanda

Introduction

(Same as above)

Questions

- Can you introduce yourself and your experience in energy management and BEV battery technology?
- What is your role at Volvo Cars?
- How do you apply your knowledge of energy management and BEV batteries?
- What are the core principles of energy management for BEVs?
- How do these relate to eco-driving behaviour?
- What environmental concerns relate to your area of expertise?
- How does energy consumption work in a BEV?
- What factors affect battery drain and State of Health ?
- What are the limitations of using data for driver feedback?
- Are these limitations changing with new technology?

- What determines battery efficiency and sustainability?
- What are the challenges in displaying battery/energy info in the DIM or infotainment?
- How does One Pedal Drive and speed control affect battery use?
- What driving behaviour support sustainable energy use?
- What should be considered from a and environmental view?
- Are there external conditions that must be accounted for?
- Are there existing use cases of gamified battery or energy feedback?
- What types of gameful design could work? (eco score, leaderboards, collective scoring)
- Can real-time or historical data be used to generate feedback?
- What BEV sensors or data sources could support this?
- How could such feedback be visualized in the DIM?
- What are the challenges in standardizing this across models and battery types?
- What value would drivers get from this kind of gamified system?
- Could it lead to more sustainable battery use?
- What should we understand from BEV drivers?
- Whats the most important technical factor to include in the final design?
- What are our next steps in development and testing?
- Do you have any final thoughts or suggestions?

Closing

- Would you like to receive a copy of the final thesis?
- May we follow up if needed?

B

Appendix: Questionnaire

Introduction

You are invited to participate in a research study for a master's thesis in Interaction Design and Technologies at Chalmers University of Technology, in collaboration with Volvo Cars. This study explores how an Eco Score system can encourage energy-efficient driving through user-centered design.

The survey takes approximately 6 minutes, and your participation is completely voluntary. Your responses will remain anonymous and confidential. You may withdraw at any time, including withdrawal of any information provided. If you agree to participate, please provide your consent below.

Thank you for your time!

Statement of Understanding and Consent

- I have read and understood the participant form, and I have the opportunity to ask questions if necessary.
- I understand that my participation is voluntary and that I am free to withdraw at any time during the study without giving any reason. If I withdraw, my data will be removed and destroyed.
- I understand that the data collected in this study will be used for further analysis.
- I agree to participate in this study, and I consent to the publication of the results of the study with the understanding that anonymity will be preserved.

○ Yes, I consent.

○ No, I do not consent.

Background

1. What is your age?

○ 18-29

○ 30-39

- ◯ 40-49
- ◯ 50-59
- ◯ 60-69
- ◯ 70 or older

2. What is your gender?

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

3. What is your department in Volvo Cars?

- ◯ Legal and Corporate Governance
- ◯ Engineering and Operations
- ◯ Commercial Operations
- ◯ People Experience
- ◯ Communication
- ◯ Finance
- ◯ Quality
- ◯ Sustainability
- ◯ Design
- ◯ Other

4. Is your office located in Gothenburg?

- ◯ Yes
- ◯ No

5. Are you living in Sweden and leasing a Battery Electric Vehicle?

- ◯ Yes
- ◯ No

6. Please select your vehicle:

- ◯ EC40 (C40)
- ◯ EX40
- ◯ EX30
- ◯ EX90
- ◯ Polestar 2
- ◯ Polestar 3
- ◯ Other

7. Why did you choose to lease a BEV?

(free text)

8. How long have you driven a BEV?

- ◯ Less than 6 months
- ◯ 6-12 months
- ◯ 12-18 months
- ◯ More than 18 months

9. Please select which option is most accurate. You can mark more than one. I mostly drive:

- ☐ In cities
- ☐ On highways
- ☐ On country side roads
- ☐ None of the above

10. Do you use the One Pedal Drive feature?

- ◯ Yes
- ◯ Sometimes
- ◯ No

11. Do you believe driving with One Pedal Drive is energy-efficient?

◯ Yes

◯ No

12. Do you consider yourself aware of your energy consumption?

◯ Yes

◯ No

13. What actions do you take to drive more energy efficient?

(free text)

14. Please rank the factors that affect energy consumption, 1. being the factor consuming the most energy.

In-vehicle climate configuration
Acceleration
Braking
Speed
Changes in speed

15. When driving, what do you prioritize most? Please rank the options, 1. being what best describes your driving style.

I focus on following traffic rules and minimizing risks.
I try to drive in an eco-friendly way.
I enjoy quick acceleration and maintaining a high speed.
I prioritize a smooth and relaxed driving experience.
I focus on getting to my destination as quickly as possible.
I try to drive in an cost-effective way.

16. How energy efficient do you believe your driving to be?

1 = not efficient, 5= very efficient

1	2	3	4	5
◯	◯	◯	◯	◯

Challenges

We want to understand the everyday challenges in driving Battery Electric Vehicles, how they relate to energy efficient driving, and the priorities of drivers.

17. Where do you find information or indications of your energy consumption?

(free text)

18. If you would like to know more about your energy consumption, how would you like to see the information in the vehicle?

a Driver Information Monitor

b Infotainment Screen

Figure B.1: The images demonstrate the different types of screens available in the vehicles.

- ☐ Static feedback on Driver Information Monitor
- ☐ Static feedback on Infotainment Screen
- ☐ Pop-up notifications on Driver Information Monitor
- ☐ Pop-up notification on Infotainment screen
- ☐ Audio feedback
- ☐ Haptic feedback
- ☐ Other

19. If "other", please specify.

(free text)

20. How do you perceive the current information about energy consumption in your vehicle?

	Too little	Option 2	**Just enough**	Option 4	**Too much**
In the Driver Information Monitor					
In the Infotainment Screen					

21. What problems do you experience when interpreting the power meter and the regeneration of energy in the vehicle?

(free text)

22. How does your driving affect the range and energy consumption of your vehicle?

(free text)

Suggestions of improvment

23. Would you appreciate your vehicle providing tips on how to drive more energy efficient?

◯ Yes

◯ No

24. Would you appreciate dynamic feedback on how your driving affects the range of your vehicle?

◯ Yes

◯ No

25. What improvements would you like to see in the display of information to make

it easier for you to drive energy efficient?

(free text)

C

Appendix: Focus Group Protocol

This protocol outlines the procedure for conducting focus group sessions to evaluate four design concepts related to the study. The session is designed to last approximately 60 minutes.

Introduction and Warm-up

- Welcome participants and introduce the moderators. Consent form and demographic questionnaire is handed out. Continue when consent form is signed.
- Present the purpose of the study: *"We are conducting research to promote energy efficient driving. You will discuss concepts that aim to support environmentally friendly driving behaviours in battery electric vehicles (BEVs)."*
- *"Please introduce your selves and what car you are currently driving." What are your experience driving BEV."* See figure C.1
- Ground rules: respectful discussion, open sharing, feel free to sketch and annotate the prototypes and new ideas.

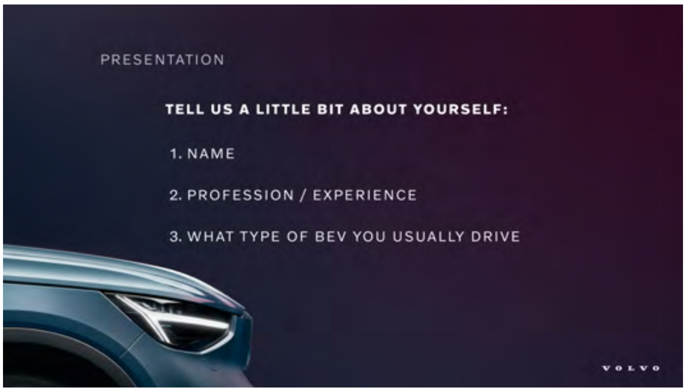


Figure C.1: Warm-up session presented to participants in focus groups.

Presentation of Personas and Scenarios

- Introduction of two personas that represent typical users identified in the research as seen in figure C.2
- Present scenarios that the personas may encounter as seen in figure C.3

- *"Can you relate to any of these personas or situations?"*

Figure C.2: Presentation of the two personas in focus groups.

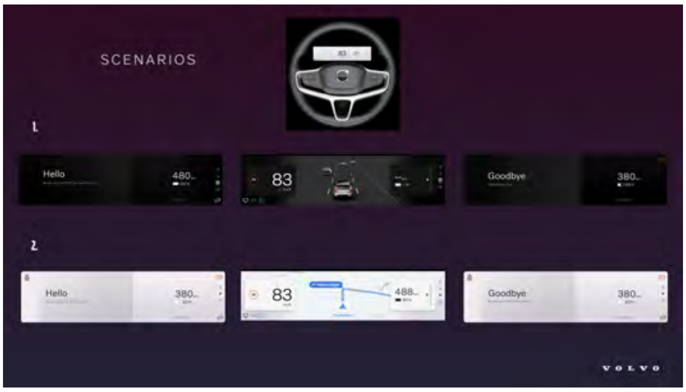


Figure C.3: Presentation of calm screen, surrounding traffic, and navigation scenarios in Focus groups.

Prototype Presentation

Introduce the four design concepts A seen in figure C.4a, B seen in figure C.4b, C seen in figure C.4c, and D seen in figure C.4d. Hand out A3 papers with concepts.

Introduction to the prototypes: Now that you have seen the personas and scenarios, we would like to present four early design concepts aimed at supporting more energy-efficient driving behaviour. Each concept is meant to give drivers feedback about how theyre driving.

Concept A C.4a is inspired by the northern lights. It is an ambient lighting solution positioned behind the driver information monitor DIM. The light changes colour depending on how energy-efficient your driving is. For example, if you are coasting or keeping an even speed, it will glow green. But if you accelerate aggressively or brake hard, the light shifts to red. The idea is to provide a cue that reflects your driving style in real-time.

Concept B C.4b is inspired by the balance of a water level. You can imagine a bubble or balance indicator on the screen that you try to keep centered by driving smoothly. When you maintain consistent energy-efficient behaviour, bar remains balanced. Strong accelerations or stops cause it to tilt.

Concept C C.4c builds on the same idea but with a more segmented display. It features a coloured arch with a movable pin. The pin shifts across the arch, landing on colours from red to green depending on your driving efficiency. Green indicates energy-efficient driving and red reflects poor efficiency.

Finally, Concept D C.4d introduces a more gamified approach. It includes a coasting score where you earn stars for energy-efficient actions like coasting and smooth acceleration. At the end of your trip, your score is summarized and you can compare it to other drivers who have used the same vehicle.

- *"What are your first impression of these concepts?"*
- *"How well do you think this would work for you?"*
- *"How well do you think this would work for the personas?"*
- *"What would you change or improve?"*

4. Comparative Discussion

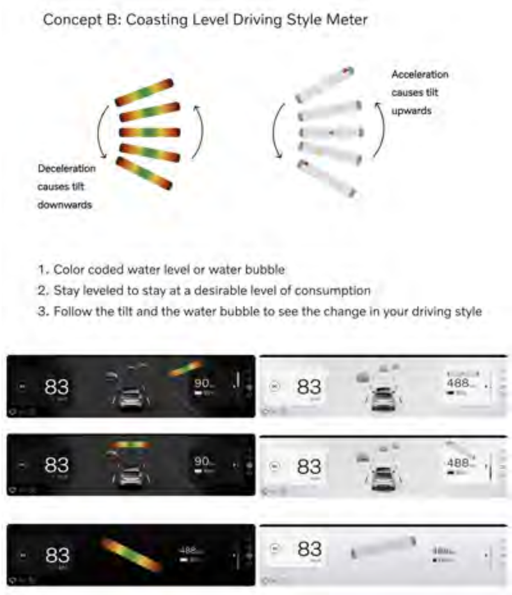
Encourage participants to compare the four concepts. If needed, refer to personas and scenarios to stimulate discussion.

- *"Which concept do you find most compelling, and why?*
- *"Which one do you think would best support energy-efficient driving?"*
- *"Are there any combinations of features across concepts that might work better together?"*

Wrap-Up and Closing

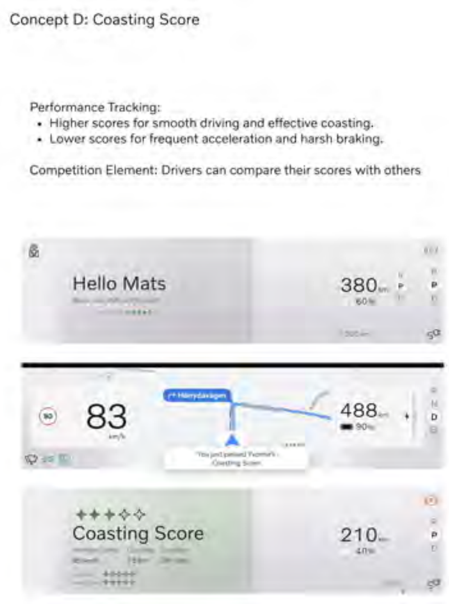
- Summarize insights discussed.
- *"Is there anything else youd like to add that you have not already discussed?"*
- Thank participants for their time and contributions. If participants are interested in the topic, we offer to send the final report to them once the master thesis is completed

a Concept A



b Concept B

c Concept C



d Concept D

Figure C.4: The four presented low-fidelity prototypes in the focus groups

D

Appendix: Think-Aloud Protocol

The objectives of the think-aloud protocol is to observe how participants perceive and interpret an energy-efficiency feedback solution during a simulated drive.

Materials:

- Participant consent form
- UX Buck D.1a
- Driving simulation video of a pre-recorded route.
- Drivers monitor display DIM showing the prototype interface D.1
- Arduino with LED strip mounted behind DIM
- Audio recording equipment D.1c

Preparation:

- All equipment is functioning
- DIM prototype is set up
- Ambient light set to blue
- Video is queued to starting point
- Consent form is signed

Introduction and Consent

Thank you for participating in this study. The purpose of this session is to explore how you interpret an in-car interface designed to promote energy-efficient driving. You will be asked to observe a driving simulation and verbalize your thoughts as you go.

(Wait until consent form is completed.)

Instructions

You will sit in this vehicle buck and watch a video that simulates a driving route. You will not be driving, but we want you to imagine yourself driving. Your focus should be on the driver monitor display DIM in front of you, nothing will change in the centre stack display CSD.

a Example from user test with blue light

b Example from user test with orange light

c Example of equipments

d Usability Test Example with facilitator and participant

Figure D.1: Setup of the buck and simulation room

When the video plays, say everything that comes to your mind. Please say what you see, think, and feel. There are no right or wrong answers. This is about understanding your thought process.

If needed during session:

Please keep talking. What are you thinking right now?

Wrap-Up

That is the end of the simulation. I will ask you a few short follow-up questions.

- *How did you interpret the feedback shown on the display?*
- *How did that overall experience feel to you?*
- *Did anything confuse or distract you?*
- *"Is there anything that you feel is missing in the information that you got?"*
- *What aspects of the feedback did you find useful or motivating?*
- *"Is there anything that you would like to share that we did not cover?"*

Thank you for your participation.