Flexible energy systems Leveraging the Optimal integration of EVs deployment Wave

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Improving UX of user interfaces of smart charging systems

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List of Acronyms

Acronym	Meaning
EV	Electric Vehicle
FST	Facets of System Trustworthiness
HMI	Human Machine Interface
M	Mean
PV	Photovoltaics
RES	Renewable Energy Source
SD	Standard Deviation
SE	Standard Error
SOC	State of Charge
SUS	System Usability Scale
UC	Use Case
UEQ	User Experience Questionnaire
UI	User Interface
UX	User Experience
V2G	Vehicle to Grid
V2H	Vehicle to Home
V2X	Vehicle to Everything

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Executive Summary

The objective of deliverable D2.3 *Improving UX of user interfaces of smart charging systems* is to provide recommendations for the implementation of user requirements in new smart charging user interfaces (UI), with the aim of improving user satisfaction when interacting with smart charging systems.

To provide an overview of the state of the art in research and development of user-centred smart charging concepts and HMI solutions, a desk research study was conducted. This included a review of national and international research projects, an extensive literature review and the investigation of current developments in the industry. The findings led to the development of a prototype of a charging app that incorporates innovative smart charging features, which were then subjected to evaluation. Furthermore, a laboratory study was conducted with the objective of evaluating existing smart charging UIs. This study aimed to identify common user requirements for (smart) charging apps in order to enhance user satisfaction.

Results show that there is a need to develop apps that offer a wide range of smart charging features for both public and private charging. Smart charging apps should meet the following user requirements:

- Give users control and autonomy: Features such as instant or immediate charging and charging schedules allow users to intervene in the automated smart charging process. The ability to set a departure time and charging limit allows users to take control of the charging process.
- Create clarity in complexity: Apps should be clear in design, structure and icons to be intuitive and easy to use.
- Provide transparency about the charging process itself, as well as financial aspects (pricing and cost savings) and environmental aspects (CO_2 savings).
- Allow personalisation, such as customisation of charging preferences and schedules.
- Consider integrating all vehicle functions (beyond smart charging functions) into a single app to enhance convenience for users.

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1. Background and Objectives

If users take part in smart charging, they must accept that the charging process can be partially controlled by an electricity supplier or grid operator. But there are still concerns among users regarding smart charging, which act as barriers to its use. These concerns include relinquishing control and the potential loss of control over the charging process which could lead to reduced spontaneity in mobility behaviour or affect battery aging (Daziano, 2022; Delmonte et al., 2020; Henriksen et al., 2021; Kämpfe et al., 2022; Schmalfuß et al., 2015; Schmalfuß et al., 2017). One possible solution to these concerns is to offer users more control through a UI, e.g., by adapting the system to the user's needs through user settings, as specifying departure time or desired state of charge (SOC). Furthermore, a UI can provide users with feedback and information that helps them to understand the charging system and the ongoing processes. This, in turn, can influence the perceived user experience, whereby an incorrect or incomplete system understanding can lead to negative emotions and low acceptance (Kämpfe & Braun, 2023). Therefore, Task T2.3 focuses on smart charging apps, as they are the preferred type of user interface for smart charging (Kämpfe et al., 2022). The objective is to identify user requirements that may encourage users to participate in smart charging and to provide a high degree of flexibility, e.g. through individual settings. To this end, general requirements and innovative strategies for smart charging apps will be developed and evaluated. The results will be reported in deliverables D2.3 and D2.4. D2.3 refers to general requirements for smart charging applications, while D2.4 lists specific recommendations for user interfaces in the testbeds and demos (WP6 and WP7).

2. State of the Art in Research and Development

2.1. Overview of Previous Literature & Technologies

In order to provide an overview of the state of the art in research and development of user-centred smart charging concepts and HMI solutions, a desk research study was conducted. This included a review of national and international research projects, an extensive literature review and the investigation of current developments in the industry using various sources such as app stores, web searches, wallbox manufacturers. The outcome of this comprehensive analysis is an overview that includes an assessment of the advantages and disadvantages of specific solutions. By synthesising these various sources of information, this overview serves as a valuable resource for understanding the current landscape of user-centred smart charging concepts and HMI solutions and as a foundation to generate design guidelines for future smart charging UIs.

2.1.1. Smart Charging Apps

A review of charging apps currently available for android or iOS devices revealed an overview of the status of user-centred HMI solutions for smart charging. The objective was to identify already existing smart charging features and the manner in which they are implemented. Therefore, a search through Google’s Play Store and Apple’s App Store has been conducted in English, German, Finnish, Swedish, Portuguese, Dutch, Spanish and Italian. Keywords used for the search were: "Smart Charging" or “Controlled Charging” or “Smart Grid”. Additionally, a web search was conducted in English using the search terms "smart charging", "app" and "electric vehicle". The websites of various wallbox

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manufacturers (e.g. Innogy eBox Smart, Juice Booster 2, Heidelberg Home Eco) were also examined. The search produced 40 apps. A catalogue was created containing these apps and their features. In an exploratory analysis each app's features were assessed to determine if they included smart charging features, e.g. shifting the starting time or modulating the instantaneous power absorbed during charging. Consequently, 23 apps were excluded from further examination as they did not support any smart charging features. At least one smart charging related feature was included in 17 apps, namingly *ChargeHQ, CKW Smart Charging, EO Smart Home, ev.energy, go-eCharger, Gridio, Jedlix, MeinZuhauseUndIch GO, MyBMW, Next Drive, Smappee, smart EQ control, Stekker, SVCE GridShift, Tessie, Tibber, Verdo Opladning.* Most commonly they supported charging schedules or setting up an individual departure time. Other popular features were price forecasts, price limits and charge limits (Figure 1).

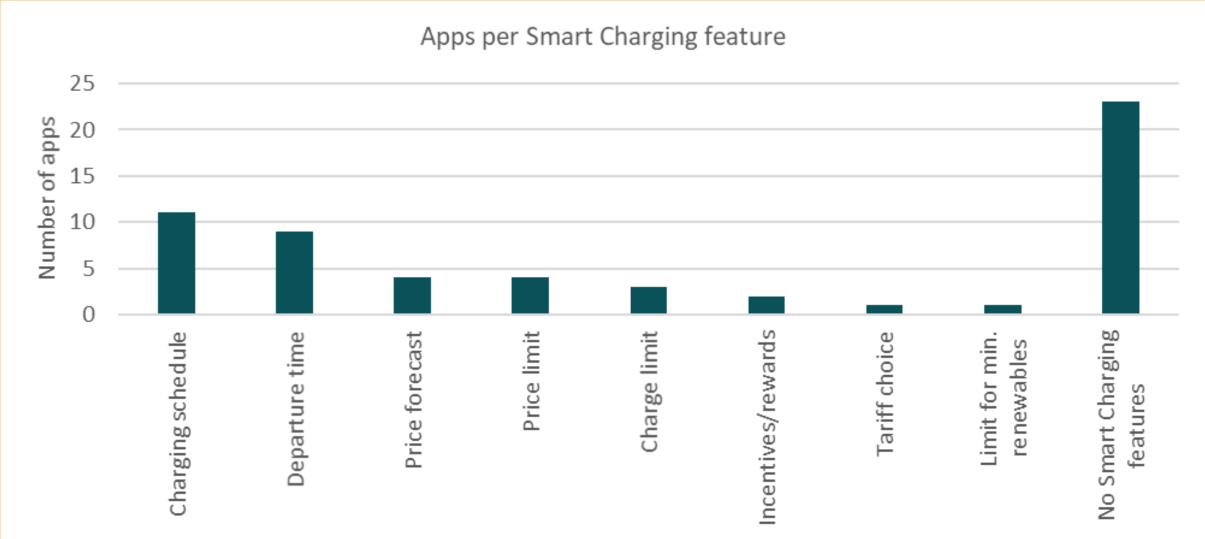

Figure 1. Results of exploratory app analysis.
Note: N **= 40 apps. Each app had either none or up to four different smart charging features.**

Most of the apps were available in several languages and countries and supported varying numbers of EV or charging station manufacturers. Therefore, rather than choosing one smart charging app per demo country, the smart charging apps containing at least two smart charging features were analysed in detail, including the app *MyBMW* operated by FLOW's project partner BMW. The app *Verdo Opladning* contained only one smart charging features but was added to the list since its provider Spirii is another partner of the FLOW project. The resulting eight apps to be looked at in more detail were MyBMW, Verdo Opladning, Jedlix, ev.energy, Gridio, Stekker, CKW Smart Charging and Charge HQ. While three of the apps were only available in a single language – Verdo Opladning in Danish, Gridio and Charge HQ in English – the other five apps were available in English as well as several other languages.

Out of these eight apps two apps, MyBMW and Verdo Opladning, offered features specifically for public charging such as maps and search functions for public charging points. The other apps limited their feature sets to charging at home or ignored location. Apart from that the apps' smart charging

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features were mainly structured into five major categories: *planning and initiating charging*, *monitoring charging*, *charging history and statistics* about past charges, *rewards and incentives* as well as *education and privacy* (Figure 2).

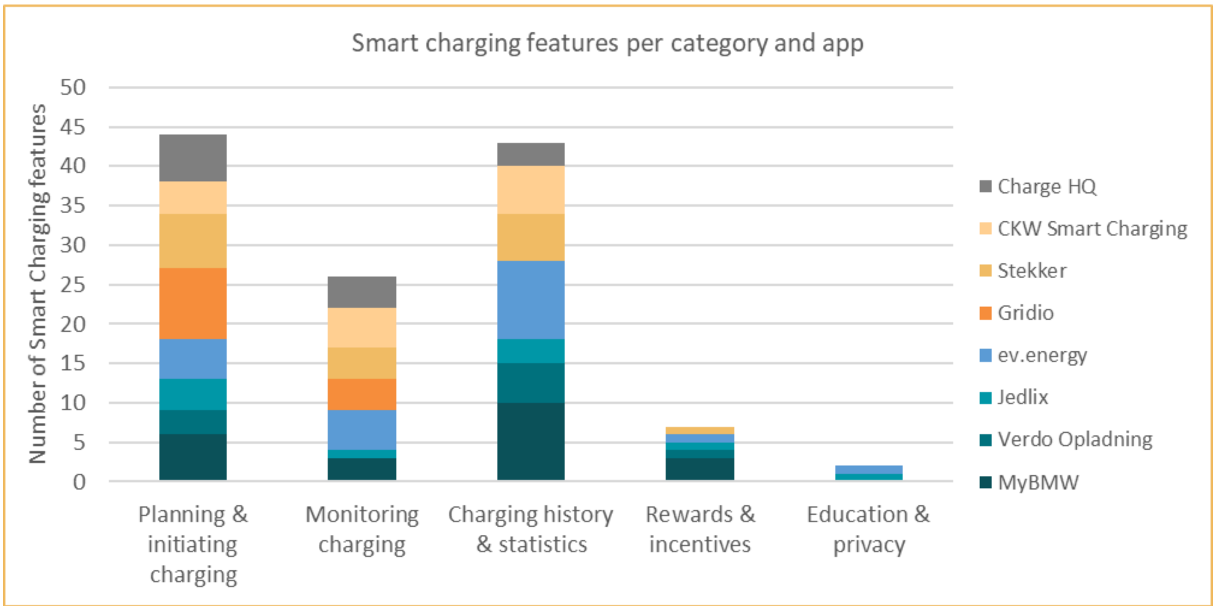

Figure 2. Smart Charging features of existing charging apps.

All eight apps contained features for *planning and initiating charging*. Among those, setting a target SOC or departure times were most popular. In addition, more than half of the apps offered energy price related features such as information about the energy price or price limits. Features regarding *monitoring charging* or *charging history and statistics* were offered by seven apps each. Yet, feature sets for *charging history and statistics* were often more extensive. To *monitor charging* for example most apps indicated the current SOC and half of the apps provided also a confirmation of the individual departure time. Features regarding *charging history and statistics* included primarily information about past charging events such as the date, amount of electricity charged, and price. A further three apps offered either a points system to *reward and incentivise* users or the possibility for user feedback. Only two apps offered *educational* features such as information on smart charging and none of the apps provided user-friendly information on *privacy* policies.

In summary, smart charging apps today offer only very limited sets of smart charging features. In fact, most apps do not support smart charging at all. One reason for this lack of support of smart charging features lies within todays charging infrastructure. While home chargers often allow users to regulate EV charging regarding parameters like charging time or the amount of energy to be charged, most public chargers do not support any user regulated charging yet, which leads to varying user demands on apps for public and private charging. Hence, most charging apps today focus on either public or private charging, making it necessary for EV users to install and work with different apps for different use cases.

Charging apps specialising on private charging focus on initiating, monitoring and regulating charging sessions. Individual apps often support home chargers of only a small number of manufacturers, thus

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limiting users' choice of which app to use with their specific home charger. On the other hand, these apps typically offer a wider range of smart charging features, and some apps enable charging independently of location. Generally, apps focussing on private charging enable users to define some basic parameters of the smart charging process like departure times and target SOCs or switching between instant and smart charging mode. However, modifying more specific parameters, for example, by enabling users to set limits for maximum price, current or minimum rate of RES, is supported only infrequently. Furthermore, these apps focus mainly on optimising charging time and cost. In matters of sustainability users are often put in a passive role. Most apps may highlight the positive effects of smart charging on the environment and some apps additionally illustrate the impact of the user's charging behaviour or use of smart charging on sustainability factors. But only a few apps enable users to actively modify sustainability related parameters such as features regarding rate of RES in the energy mix drawn from the grid or integration of private solar systems. Almost no apps support V2G features yet.

In contrast, charging apps that specialise in public charging focus mainly on planning and initiating charging, offering features like searching for nearby public charging points, providing information like availability and equipment of public chargers, and initiating and paying for charging sessions. These apps usually provide users with a comprehensive public charging network spanning nationwide or across international areas. However, smart charging features are mostly limited to information about pricing and enabling users to choose the cheapest charge point within an area.

In conclusion, there is a need to develop apps that offer a wide range of smart charging features for both public and private charging. In addition, these apps should ideally function regardless of home charger manufacturer or be compatible with a wide range of them. To achieve a high level of user acceptance of new developments, they should be designed from the outset to address user needs.

2.1.2. User Requirements on Smart Charging Concepts

The literature review (Google Scholar and Scopus, with additional forward and backward searches) revealed certain requirements that should potentially be integrated into the UI. Furthermore, we assessed the extent to which these requirements are already implemented in identified smart charging apps.

In particular, requirements for *planning and initiating smart charging* could address users' concerns about losing control. For example, users should be given the ability to override smart charging to provide the user with a sense of control (Alexeenko & Bitar, 2023; Gardien, Refa, & Tamis, 2020; Yilmaz et al., 2021; Will & Schuller, 2016). Certain functions integrated into the app should enable users to determine the timing and method of charging their vehicle, e.g., in a conventional way, cost-efficient, CO_2-efficient (Kubli et al., 2018). This includes the option of setting charging schedules with users selecting a time slot for charging and a desired departure time (Baumann et al., 2016; Will & Schuller, 2016). In addition, users should have the option to set a minimum range requirement (Baumann et al., 2016, Delmonte et al., 2020; Will & Schuller, 2016). The interface should allow users to set their desired SOC, including minimum and maximum, in both percentage and kilometres. This feature allows users to maintain control over the charging process and ensures that their individual needs and preferences are considered. The app interface shall offer the option of smart charging as a viable alternative to

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immediate charging with clear and assessable information about SOC and available range (Schmalfuß et al., 2017). Existing smart charging applications already meet these requirements to a certain extent. In particular, switching between different charging modes and setting a target SOC or departure times were the most popular smart charging features.

Referring to *monitoring smart charging* as well as to *statistics and charging history*, the information provided and the way it is provided are highly relevant to the understanding and use of smart charging. In particular, there seems to be a high level of interest in detailed information about the user's individual electricity consumption (Paetz et al., 2012; Paetz et al., 2011; Marxen et al., 2022), real-time electricity price data and daily tariff forecasts (Paetz et al., 2012; Paetz et al.; Geelen et al., 2013), the financial consequences, e.g., cost savings (Paetz et al., 2011; Delmonte et al., 2020) or the respective carbon footprint of a user (Marxen et al., 2022) and the availability of locally generated energy (Geelen et al., 2013). To improve the applicability of V2G and V2H technologies, the UI should offer users sufficient feedback on the processes and conditions (Kämpfe & Braun, 2023). Therefore, detailed feedback on the charging process and its contribution to grid stability (Schmalfuß et al., 2015) and the current SOC of the EV (Lagomarsino et al., 2022) should be provided. While existing smart charging apps provide a wide range of statistics and information, they mostly either focus on historical charging events (e.g. amount and cost of electricity charged) or monitor current states (e.g. SOC) or settings (e.g. departure time). The challenge seems to be to present various real-time information in such a way that users have the option of setting the charging times according to their individual preferences. Especially the incorporation of environmental information is still lacking.

In order to encourage users to adopt smart charging, it is recommended that the UI be designed with the incorporation of various *incentives and rewards*, such as financial incentives (Geske & Schumann, 2018; Huber et al., 2019), battery-related incentives, such as battery-life expectancy (Delmonte et al., 2020) or environmental incentives (Delmonte et al., 2020; Geske & Schumann, 2018). Financial incentives could compensate for perceived additional effort and restricted flexibility. Additionally, cost benefits for owners of photovoltaic systems can be defined (Paetz et al., 2011). Only a few apps offer real incentives, such as point systems or rewards, which are primarily cost-based. Battery or environment related rewards are missing or reduced to highlight the positive effects of smart charging on the environment or illustrate the impact of the user’s charging behaviour on sustainability factors.

Further, individual user characteristics serve as influencing factors. In particular, different levels of affinity for technology should be considered when designing UIs (Geske & Schumann, 2018; Henriksen et al., 2021). The UI should be intuitive and user-friendly to appeal to less technologically inclined users (Lagomarsino et al., 2022). A clear and understandable presentation of functions and options is crucial to ensure a positive user experience. On the other hand, technologically inclined users should benefit from the interfaces by providing them with detailed information through the app (Henriksen et al., 2021). When designing UIs for smart charging, it is important to consider practical aspects such as integrating location information to display the nearest charging stations to the user (Kämpfe et al., 2022). Providing real-time information on the availability of charging stations can assist users in planning their charging process (Paetz et al., 2011). Furthermore, the literature review indicates that it is crucial to present all relevant information about the charging process in a clear and understandable manner to the user (Kämpfe et al., 2022; Lagomarsino et al., 2022). This includes displaying the current SOC in both percentage and kilometres (Lagomarsino et al., 2022), the estimated charging duration

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(Schmalfuß et al., 2015; Lagomarsino et al., 2022), and the cost of the charging process (Delmonte et al., 2020; Paetz et al., 2011). A clear and user-friendly presentation of this information enables users to better comprehend and manage the charging process.

Overall, the UI should be transparent and provide the user with feedback. The UI should allow to control smart charging and for customisation of content in order to incorporate individual preferences, such as renewable energy, costs, guaranteed minimum charge. Existing smart charging apps mostly fulfil these requirements and offer the basic functionalities and information needed to control smart charging. However, the personalisation of apps with regard to individual preferences is important for new and further developments. This includes, for example, the presentation of preferred information or the optimisation of the charging process regarding preferred parameters.

2.2. Present Research

The desk research study has identified a variety of user requirements for smart charging systems that should be considered when designing smart charging. However, existing charging apps only offer a few specific functions for smart charging and only address some of those requirements. The main challenge seems to be to design apps that allow for personalisation according to user preferences and motivations. Therefore, the objectives of the present contribution were to design and test innovative smart charging features that consider the identified requirements with a focus on personalisation. Secondly, key user requirements for charging apps were to be identified and evaluated.

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3. Development and Expert Evaluation of a Prototypical Smart Charging App

3.1. Aim

Based on an extensive literature research including current research efforts and smart charging solutions (see chapter 2.1), we developed a prototypical smart charging app and invited eight experts to evaluate the prototype. The aim of this approach was to gain insights from experts on the factors identified in the literature and how they were implemented in the prototypical app interface, and to gather further information for the future development of a smart charging app. In the next step, the experts' opinions were used for future activities with the ultimate goal of providing an ideal user-centred smart charging app. The prototype serves as an intermediate step in an overall process and focuses on functions and menu structure rather than on design (e.g., colours, font sizes, illustrations).

3.2. Methodology

3.2.1. Prototype

The prototype encompasses six functional areas. Five of them cover the three identified categories *planning and initiating charging*, *monitoring charging* and *charging history and statistics*:

- The *Main Screen* encompasses monitoring the charging process and all charging settings.
- *Spontaneous Charging, Charging Schedules* as well as *Charging Modes & Routines,* are features to initiate and plan smart or instant charging.
- *Charging History & Statistics* provide information on previous charging events.

Users can also customise the prototype to their individual needs, which is an additional feature of the prototype:

- *Onboarding & Personalisation* is addressing the requirement of personalisation.

In this first version of the prototype no specific features regarding incentives and rewards or education and privacy were included.

The following section provides an overview of the functional areas and its respective screens (Table 1Table 1). In the description below the screens are shown in German (the way they were tested), but we provide a detailed description of each screen's most important features in English for the reader.

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Table 1: Overview of Screens.

Functional area	No	Description	Screen	No	Description	Screen
Onboarding & Personalisation	1	Onboarding and Personalisation				
Main Screen	2.1	Main Screen (vehicle not being charged)		2.2	Main Screen (vehicle being charged)	
Spontaneous Charging	3.1	Instant Charging (*"Sofort Laden"*)		3.2	Charging Boost (*"Ladeboost"*)	
	3.3	Spontaneous Trip (*"Spontanfahrt"*)				
Charging Schedules	4.1	Charging Schedules (*"Zeitpläne"*)		4.2	Configuration Charging Schedule (*"Zeitplan hinzufügen"*)	
Charging Modes & Routines	5.1	Charging Modes (*"Lademodus"*)		5.2	Configuration of Charging Mode (*"Lademodus bearbeiten"*)	

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Functional area	No	Description	Screen	No	Description	Screen
	5.3	Routines – Locations (*“Routinen – Standorte”*)		5.4	Add Locations (“*Standort hinzufügen*”)	
Charging History & Statistics	6.1	Charging History (“*Ladehistorie*”)		6.2	Filter (Charging History) (“*Nach Zeitraum filtern*”)	
	6.3	Details Charging History		6.4	Charging Statistics – Charging Behavior (“*Ladestatistik – Ladeverhalten”)*	
	6.5	Charging Statistics – CO_2-Emissions (“*Ladestatistik – CO_2-Emissionen*”)				

The *Onboarding & Personalisation* section (Figure 3) focuses on the initial launch and customisation settings. It allows users to set up their preferences and personalise the app according to their specific interests and needs. This approach aims at catering to the individual interests and needs of each user and ensuring enhanced user experience and user acceptance from the beginning.

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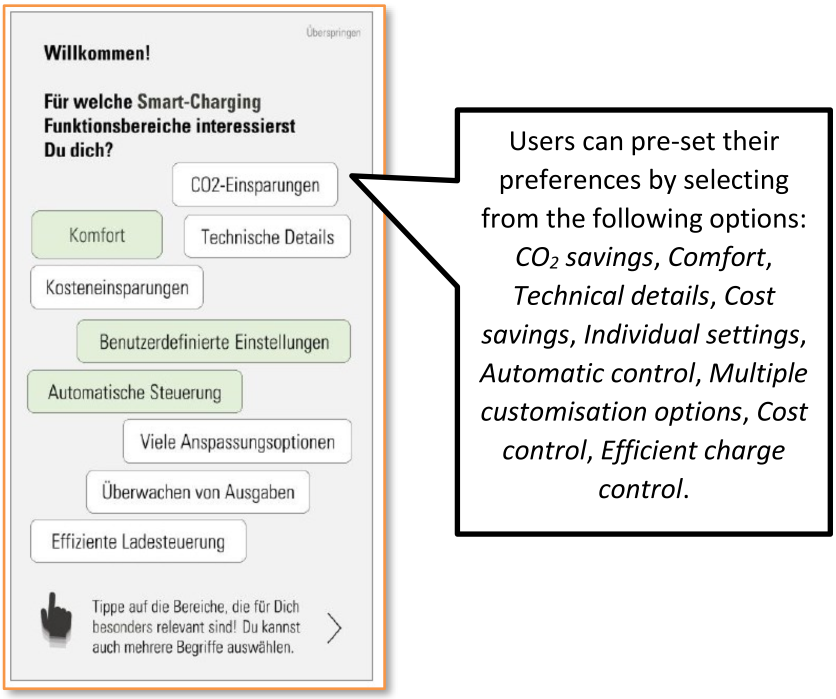

Figure 3: On-Boarding and Personalisation (Screen 1).

The *Main Screen* (Figure 4Figure 4) is the key interface of the app and includes various functions that allow users to access information about their vehicle and its charging status with a clear indication whether the vehicle is currently being charged (Screen 2.2: *Your Hyundai Ioniq 5 is charging. "Dein Hyundai Ioniq 5 wird geladen*.") or not (Screen 2.1: *Your Hyundai Ioniq 5 is not charging. "Dein Hyundai Ioniq 5 wird nicht geladen*."). The screen is divided into two sections: The information in the top section is predefined and fixed whereas the bottom section can be customised with individual interests, functions and information. This customisation option aims to cater to the different user groups identified in the previous literature research (such as a tech-savvy user, a CO_2- or cost-saver, PV system owner etc.). The upper section of the screen allows access to the most important planning and monitoring functions and provides users with comprehensive control over the SOC and enables efficient management of charging schedules. It displays the current SOC in both percentage and distance (in km) through a charging indicator. Additionally, the screen shows information about the activated charging schedules or the estimated start of charging allowing users to schedule charging sessions in advance, ensuring that the vehicle is charged when needed. The screen includes direct access to the functions *Spontaneous Trip* ("*Spontanfahrt*") and *Charging Boost* ("*Ladeboost*") as well as the function *Instant Charging* (*"Sofort Laden"*).

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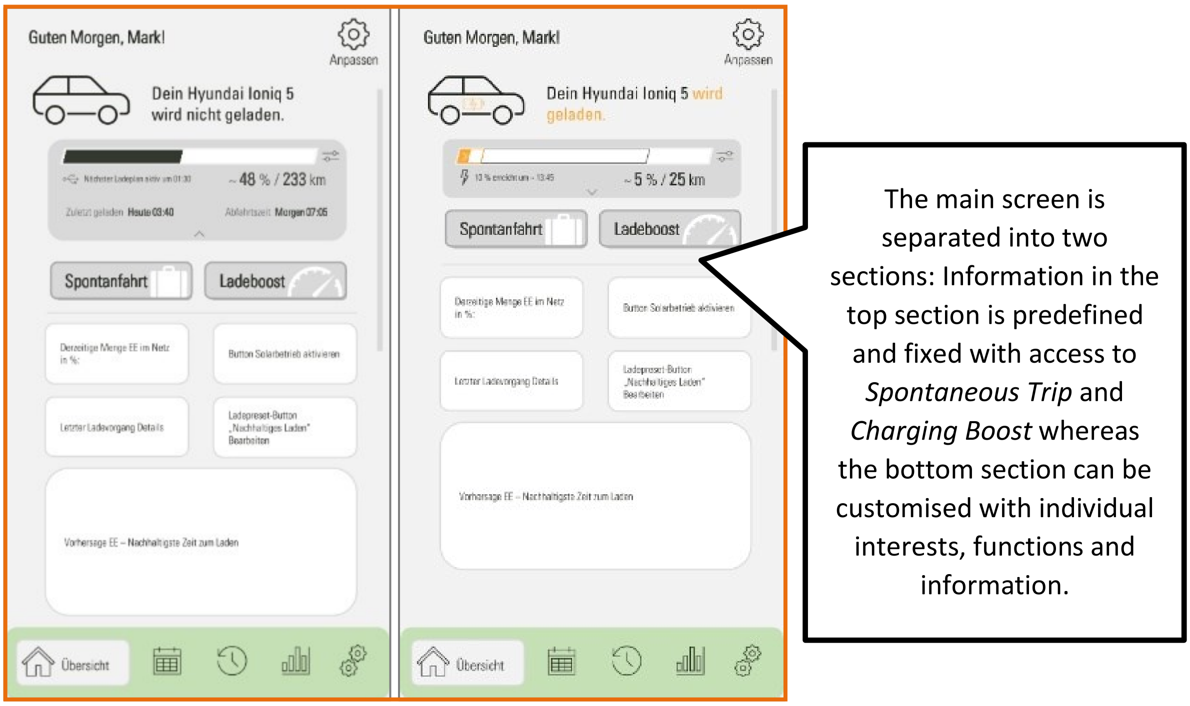

Figure 4: Main Screen with vehicle not being charged (left, Screen 2.1) and vehicle being charged (right, Screen 2.2).

The *Instant Charging* feature provides users with a sense of control, ensuring they always have a certain level of battery charge available (Screen 3.1, Figure 5). With Smart Charging, the vehicle otherwise attempts to shift charging to specific times of the day, such as when there is a high proportion of renewable energy in the power grid or when electricity prices are low. As vehicle owners often require a minimum level of battery charge immediately, without having to wait for a specific moment, the *Instant Charging* feature ensures that individuals are prepared for unforeseen trips or emergencies. The minimum charge level can be adjusted based on the user's need.

The *Spontaneous Trip* (*"Spontanfahrt"*) and *Charging Boost* (*"Ladeboost"*) features can be accessed through the main interface (Screen 3.2 & 3.3, Figure 5). The features address the dynamic nature of electric vehicle usage. The *Spontaneous Trip* is an advanced planning function and enables users to schedule one-time trips outside of their regular charging schedules. This feature is particularly useful for planning trips that require a higher range than usual. Users can specify the date, departure time, and required range for these trips. This flexibility enables users to easily accommodate special travel needs. The *Charging Boost* allows users to quickly charge a specific amount of energy, enabling them to meet immediate energy demands without altering their regular charging schedules. Users can specify the amount of energy they require in percentage increments of 5%, and the app provides feedback in the form of additional range in kilometres and estimated charging time. This function enables users to plan the precise amount of energy required to charge their vehicle's battery, without charging more than required for the current trip. This feature can help users save both time and money, as they only pay for the exact amount of energy they need for the current trip.

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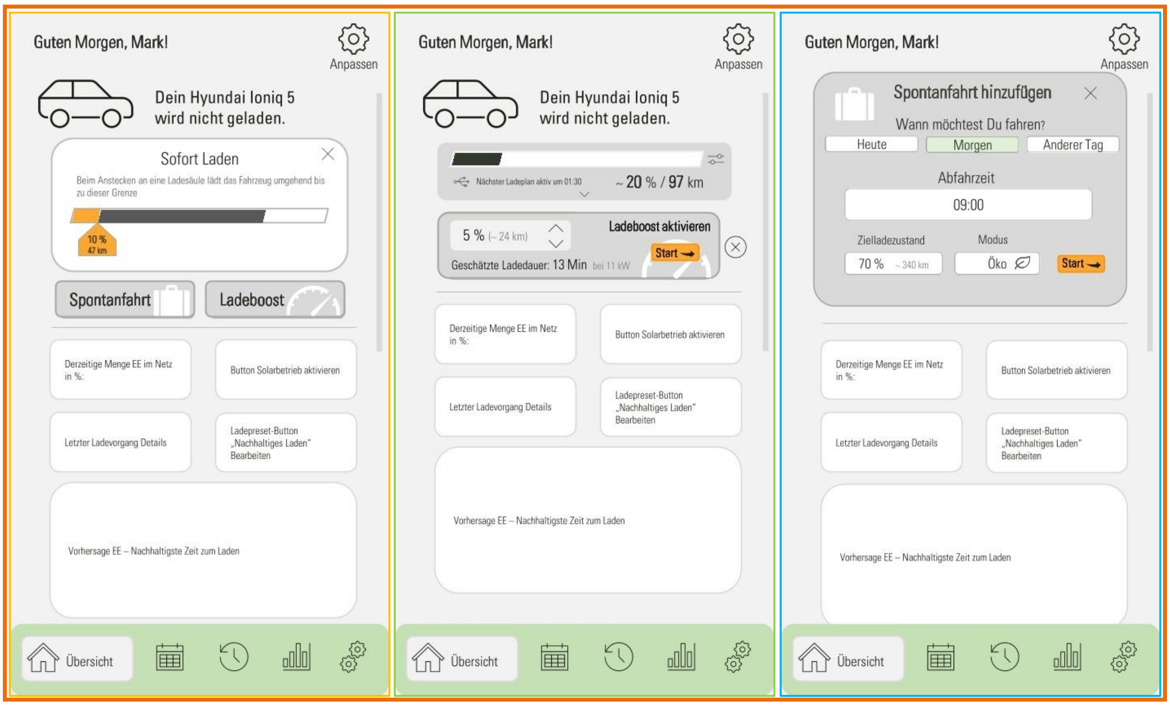

Figure 5: Smart Charging Functions with Instant Charging (left, Screen 3.1), Charging Boost (middle, Screen 3.2), and Spontaneous Trip (right, Screen 3.3).

Users can set up routines as *Charging Schedules* (*"Zeitpläne"*) and modify the charging schedules to suit their daily routines and usage patterns. By allowing users to set up regular charging schedules, this feature promotes efficient energy management and ensures a seamless charging experience. Users can customise each charging schedule with a label, specific days of the week, departure time as well as charging mode and can easily activate or deactivate the schedules (Screen 4.1 & 4.2, Figure 6).

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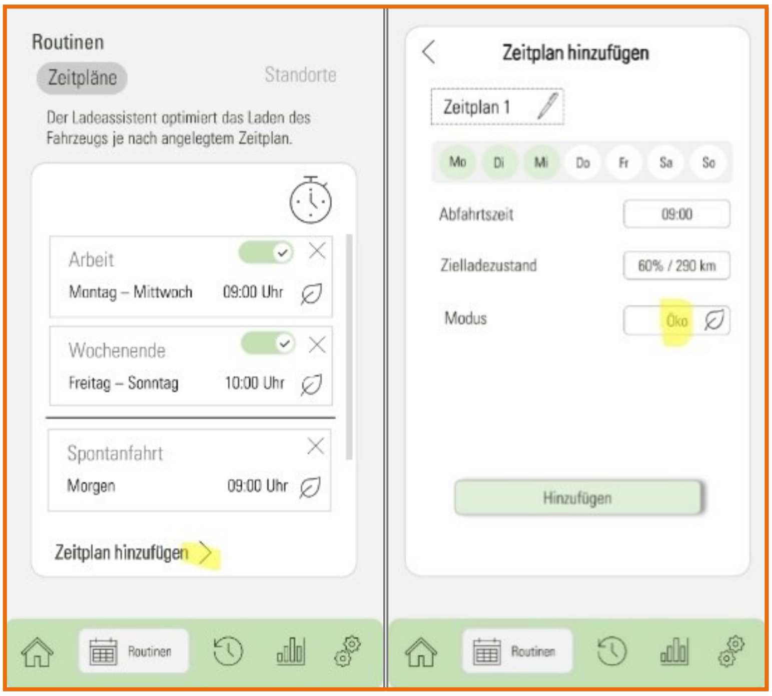

Figure 6: Charging Schedules (left, Screen 4.1) and configuration screen for adding a schedule (right, Screen 4.2).

There are three available charging modes to choose from: *Eco Mode (“Öko”)*, *Savings Mode (“Sparen”)*, *Self-Supply Mode (“Eigene Einspeisung”)* (Screen 5.1, Figure 7). The Eco Mode focuses on sustainable charging by utilising a high percentage of renewable energy sources. The Savings Mode emphasises cost-effective charging. The Self-Supply Mode enables users to charge their vehicle using their own energy sources, such as a solar PV system. Additionally, users can set a *maximum charging limit* (“*Maximale Ladegrenze*”, Screen 5.2, Figure 7) to protect the battery, even under favourable conditions. This helps to prevent overcharging and prolong the battery’s lifespan. Users can also determine the minimum percentage of renewable energy in the electricity mix to be charged up to the *maximum limit* (“*Mindestanteil Erneuerbare Energien im Strommix*”, Screen 5.2, Figure 7).

In addition to setting individual charging schedules, users have the option to set *locations* (“*Standorte*”), and *add locations (“Standorte hinzufügen”*) for their regular routes (Screens 5.3 and 5.4, Figure 7). The app will then provide location-based charging recommendations that optimise charging for those routes. This feature helps users to make informed decisions about when and where to charge their vehicles, taking into account factors such as the current battery level and the planned route to determine if charging is necessary and where it would be most advantageous.

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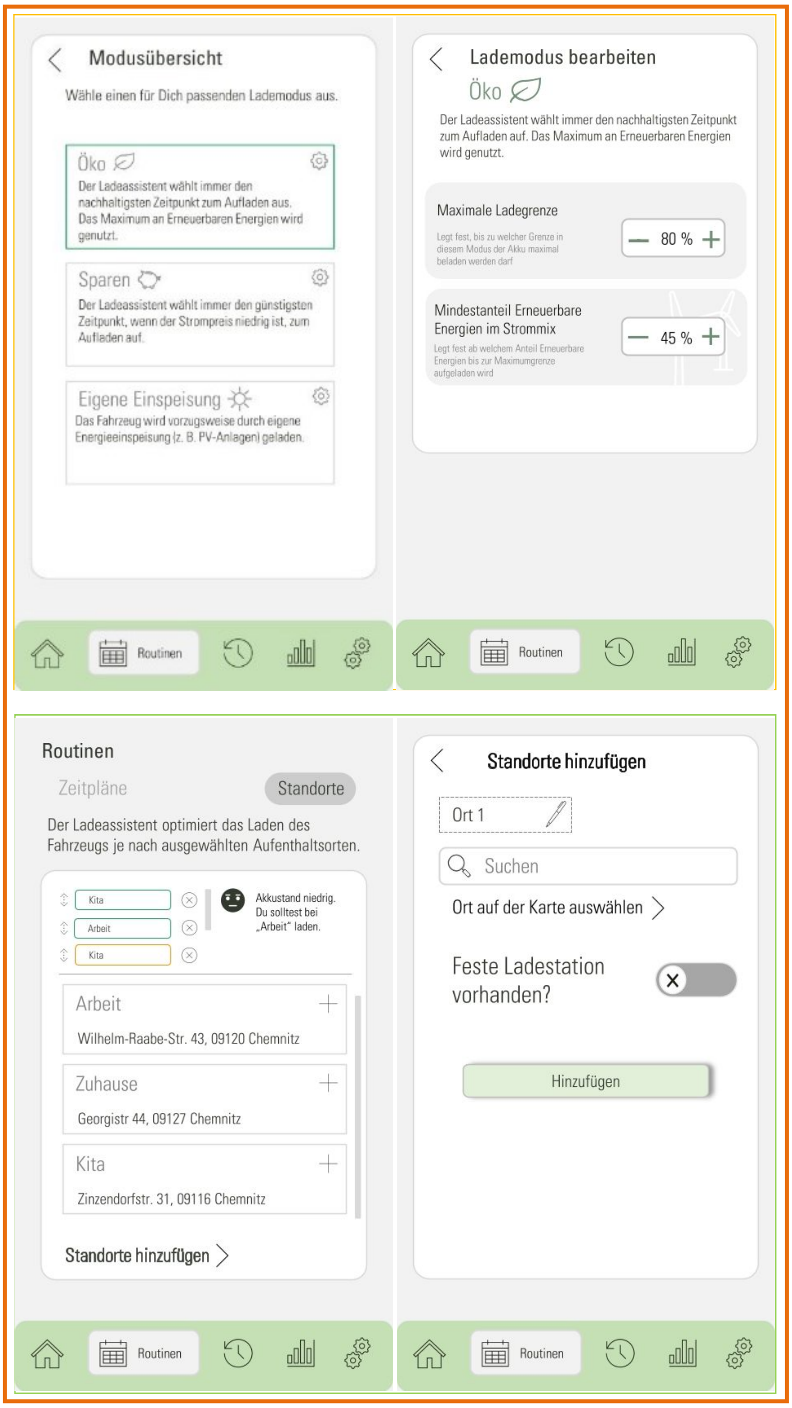

Figure 7: Charging modes (left, Screen 5.1 & 5.2) and adding locations to set up routines (right, Screen 5.3 & 5.4).

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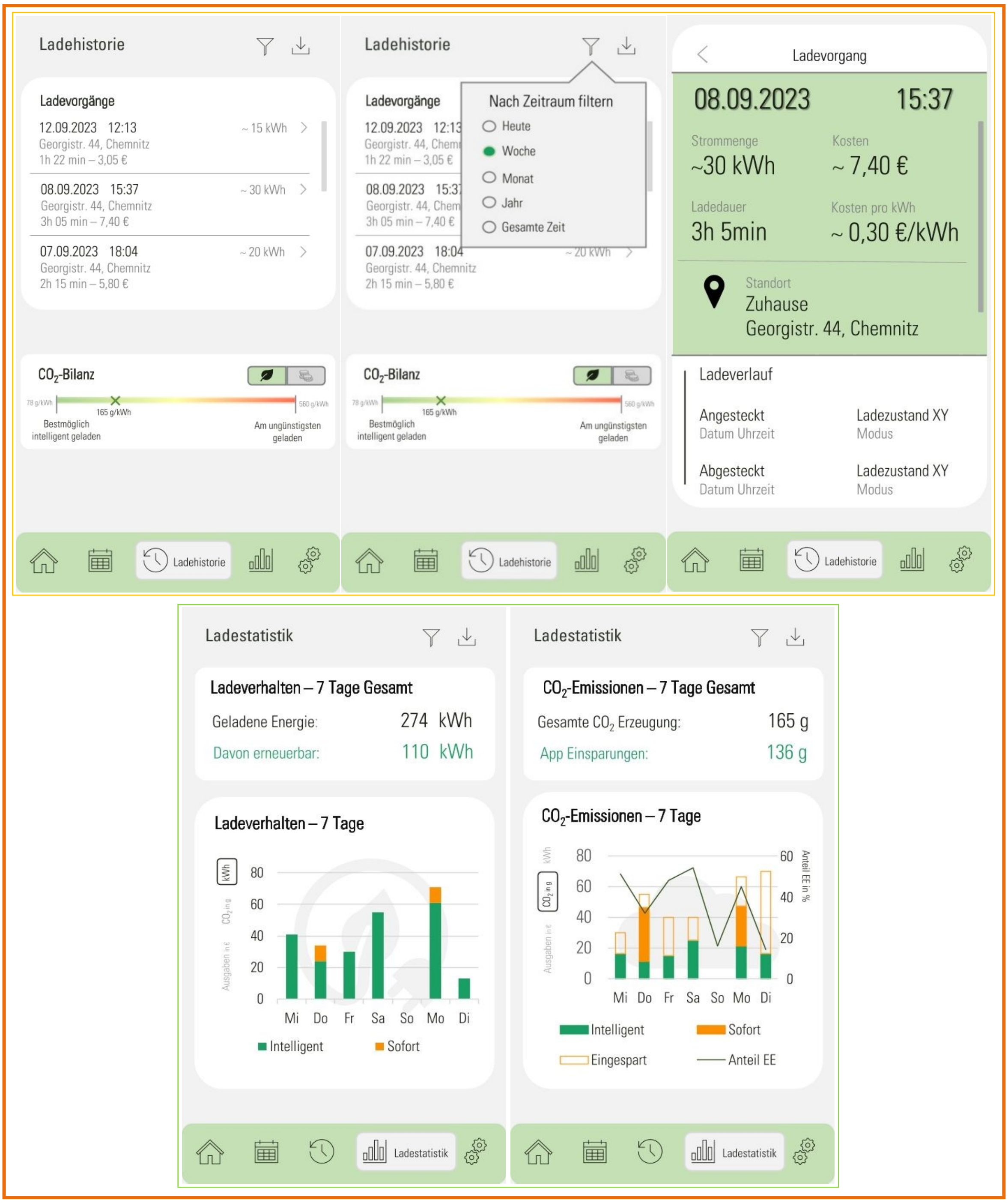

Figure 8: Charging History (Screen 6.1), Filter Charging History (Screen 6.2), Details Charging History (Screen 6.3), Charging Statistics Charging Behaviour (Screen 6.4), and Charging Statistics CO2-Emissions (Screen 6.5).

Lastly, the *Charging History* (“*Ladehistorie*”, Screen 6.1, Figure 8) and the *Statistics* (“*Ladestatistik*”, Screen 6.4, Figure 8) functions offer users a comprehensive overview of their past charging events in both a summary and a detailed view. The app also offers filter options to sort charging sessions based

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on different time periods ("*Nach Zeitraum filtern*", Screen 6.2, Figure 8). The summary view presents an overview of the date, time, location, charging duration, price, and energy consumption for each charging session. The detailed view provides more in-depth information, including the charging mode, start and end battery levels, charging speed, and the time when the vehicle was plugged and unplugged. In addition to displaying the charging history, the app also presents a CO_2- and price balance for a selected period of time (Screen 6.3, Figure 8). This balance assists users in monitoring their sustainability and cost-saving efforts, with a range from "most efficiently charged" to "least efficiently charged". The app thereby provides the users with feedback on their charging behaviour and motivates to optimise their charging habit. The app provides a set of charts and graphs in the *Charging Statistics* section ("*Ladestatistik*", Screens 6.4 & 6.5, Figure 8). The upper section of the screen summarises the total energy consumed ("*Ladeverhalten*", Screen 6.4, Figure 8), CO_2 emissions, and costs incurred during a selected period of time. It also includes information about the savings regarding costs and CO_2 emissions ("CO_2-*Emissionen, App Einsparungen"*, Screen 6.5, Figure 8) achieved through intelligent charging practices. The lower section of the screen displays a graphical representation of charging events on a weekly or monthly basis.

3.2.2. Participants

The participant sample consisted of $N = 8$ experts including two EV users, two EV charging experts and four usability experts. This study was conducted in accordance with the European Data Protection Regulation and according to the recommendations, regulations and informed consent of the Ethics Committee of Chemnitz University of Technology. All participants gave written informed consent.

3.2.3. Study design

The expert evaluation started with a pre-test questionnaire that included sociodemographic and EV-usage questions, as well as questions about the experts' work in the usability/charging field. After providing informed consent and an introduction, the experts received an overview of the concept of "smart charging" and an explanation about the goal of a smart charging app. Experts evaluated the respective screens along the prototype's functional areas O*nboarding & Personalisation*, *Main Screen*, planning and initiating charging (including *Spontaneous Charging, Charging schedules* and *Charging Modes & Routines*), and *Charging History & Statistics*. Therefore, they got a comprehensive description of each area and the respective apps screens. After this detailed explanation, the experts were invited to provide their thoughts and feedback on the current solution. This was followed by specific questions about individual screen features and finally, a discussion of potential improvements.

3.3. Results

The experts mentioned both perceived strengths (advantages) and needs for optimisation (disadvantages) of the screens. The results of the expert ratings are shown in Table 2, where '+' indicates perceived strengths and 'x' indicates potential for improvement.

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Table 2: Perceived strengths ("+") and optimisation potentials ("x").

Screen	Category	Comment
Screen 1 (On-Boarding and Personalisation)	Personalisation	+ Personalisation function is positive, informative, user-oriented, and timesaving
		+ Providing information is voluntary
		x Offer a skippable and always accessible tutorial
		x A button should be available to adjust app settings such as font size
		x It should be noted that the selection can be adjusted and changed later on
		x Communicating the importance of personalisation for the ongoing process
	Comprehensibility	+ Appropriate number of tiles and clear representation
		x Unclear representation of the interest cloud, arrangement of terms in groups or in a hierarchical structure (below each other)
		x Providing further information and explanation of individual functional areas
		x Clear indication of functionality, i.e., add a label to the arrow
		x Visually emphasize functionality of symbols (such as the Skip-button)
		x Distinct use of colours
Screen 2.1 & Screen 2.2 (Main Screen with vehicle not being charged and vehicle being charged)	Accessibility	+ Request for additional information in the drop-down menu
		+ Permanent access to functions (e.g., menu bar, charging functions)
		x Move the instant charging function to the charging schedules
	Unambiguity	+ Clear display of whether the vehicle is currently charging through text, icon and colour (colour changes depending on charging status)
	Missing features	x Further information (e.g. SOC at destination and urgency of charging) should be included in the drop-down menu
		x Display percentage or reach in charging bar
		x Integration of multiple vehicles
		+ Display the next charging time
	Personalisation	+ Customisable tile structure provide structure, clarity, and address different interests (e.g., renewable energy prediction)
		+ "Adjust button" (gearwheel) good option for customisation
		+ Customisable charging settings are easily accessible
	Comprehensibility	+ Two-part main screen (structure and content) intuitively understandable, clear and self-explanatory (7)
		+ Clear and organised display of the current charge level
		x Explanation or tutorial for the instant charging function
		x Specify the labels "Spontaneous Trip" and "Charging Boost"
		x Colour representation of the vehicle symbol instead of battery icon
		x Display charging mode in the charging bar
	Distinct icons	x Similar icons should not be used multiple times (i.e., gear icon)
		x Icons for charging statistics and past charging events should be consolidated

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Table 2: Perceived strengths ("+") and optimisation potentials ("x"). *(continuation)*

Screen	Category	Comment
Screen 3.1 (Instant Charging)	Usefulness	+ Idea of an Instant Charge limit: self-explanatory and intuitive
	Comprehensibility	+ Colour design of the loading bar
		+ Indication of percentage and reach
		x Highlight key information (e.g., using colour, colour gradation to visualize charging process)
		x Distinct and appropriate use of colours
		x Visually emphasize the possibility of moving the slider
		x Explanation or tutorial for *Instant Charging* function, i.e., function serves as an emergency backup
		x Reconsider terminology (e.g., *Minimum Battery Level*)
	User Engagement	+ Practical everyday use (provides a sense of security)
		x Integrate push notifications, e.g., when *Instant Charging* target level is reached
Screen 3.2 (Charging Boost)	Usefulness	+ Display of charge level (percentage) and reach (kilometres)
		+ Important function
		+ Short and cost-effective charging
		+ Easy handling
		+ Clear difference between Charging Boost and Instant Charging
		+ Distinct icons and symbols
		+ Display of estimated charging duration
		+ Setting a limit for the Charging Boost function
	Ambiguity	x Terminology is unclear (e.g., Charging Boost, difference between Instant Charging and Spontaneous Trip), need for explanations
Screen 3.3 (Spontaneous Trip)	Usefulness	+ Clear and helpful function that provides autonomy and flexibility
		+ Adjustment of departure time, SOC at destination and mode is helpful
	Additional functions	x Provide recommendations, e.g., about required range for the trip
		x Ask for number of passengers
	Comprehensibility	x Clearly name the function (e.g. one-time trip)
		x Add explanation
		x Add feedback on whether vehicle is plugged in
Screen 4.1 (Charging Schedules)	Usefulness	+ Quick activation and deactivation of schedules (without deleting the)
		+ Display of necessary information only
		+ Distinguish regular charging schedules from spontaneous trips
		+ Importance of function is appreciated
		+ Possibility of generating multiple schedules
		+ Mode display
		+ Fixed schedules provide a sense of security
	Missing Features	x Wish for additional information
		x Integration of push notifications (as reminders)
		x Configuration of spontaneous trips in the schedules instead of on the main page
	Labelling	x Necessity for shorter and more comprehensible explanations of function and terminology
		x Add check marks (similar to the routines menu)
		x Distinct use of icons, e.g., a plus-icon for "*Add Schedule*", a pen-icon for editing schedules
		x Clear and distinct presentation of information

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Table 2: Perceived strengths ("+") and optimisation potentials ("x"). *(continuation)*

Screen	Category	Comment
Screen 4.2 (Configuration of Charging Schedule)	Usefulness	+ Indication of the reach is useful
		+ Function important, frequently usable
		+ Selection of individual weekdays is useful
		+ Show SOC at destination (provides a sense of security)
	Comprehensibility	+ Self-explanatory and clear presentation of information
		+ Easy to understand and operate
		x Concept of SOC at destination (as minimum limit) not intuitively understandable (explanation required, designation as "*Guaranteed Charge*")
	Missing features	x Additional functions: air conditioning, heater, rear window, front window, mirrors
		x Include electricity tariff rates and electricity prices on the stock exchange
	Labelling	x Naming the function as a "*weekly schedule*"
		x Departure time planning in quarter hour increments (not minute increments)
Screen 5.1 (Charging Modes)	Usefulness	+ Functionality is useful
		+ Clear and understandable presentation
		+ Differentiation of modes is useful and understandable
		+ Explanations are understandable and sufficient
		+ Overview is suitable for beginners
	Missing features	x Information about achieving the SOC at destination despite mode function
		x Information button for specific functions and processes
		x Collaboration or integration of modes (e.g. ranking)
		x Display mode on overview page
		x Relationship between different modes (e.g. via examples or recommendations)
		x Consideration of sunrise and sunset times for eco mode
		x Pre-settings of renewable energies to relieve the user
		x Information about type of electricity and extent of charging when minimum share of renewable energies is not reached
Screen 5.2 (Configuration of Charging Mode)	Comprehensibility	+ Functions "maximum limit" and "minimum share" are self-explanatory
		x Maximum charging limit is not intuitively understandable
		x Differentiation and function of the three used limits are not understandable
		x Explanation for the target charging limit is necessary
	Missing features	x Display of minimum and maximum charging limits in the charging bar

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Table 2: Perceived strengths ("+") and optimisation potentials ("x"). *(continuation)*

Screen	Category	Comment
Screen 5.4 (Set up Routines)	Usefulness	+ Function useful when battery is low
	Ambiguity	x Function cumbersome, time-consuming, and unnecessary
		x Too much information density
		x Unclear purpose of the location function
		x Integrate locations into routine schedules
	Missing features	x Charging location recommendations in the vicinity when battery level is low (recommendations with current charging prices and renewable energies; recommendation tiles on overview page)
		x Integration of a map in the location functions
		x Provide more intelligent functions, e.g., consideration of contextual conditions such as number of passengers, additional luggage, traffic
Screen 6.1 (Charging History)	Accessibility	+ Display of the most interesting information (accessible at first glance)
		+ Expandable menu with additional information
		x Feedback should be accessible but does not need to be displayed permanently
	Missing features	x Display cumulative values
		x Add further information such as price per kWh
	Understandability	+ Use of different colours allows for an intuitive self-assessment
Screen 6.2 & 6.3 (Filtering & Details	Usefulness	+ Detailed information are very useful
		+ Filtering option is appreciated
	Missing features	x Wish for further information, e.g., charging type and current strength
		x Link with additional apps such as Google Maps
Screen 6.4 (Charging Statistics)	Usefulness	+ Good overview (of total values and savings)
		+ Selection of options based on individual interest
		+ Differentiation between functions is useful
		+ Display of most important information, i.e., type of charging and charging quantity
		x Avoid complex figures
	Missing features	x Provide a function for showing or hiding functions
		x Offer the possibility to create own figures

3.4. Conclusion

Overall, the needs and requirements for a smart charging app, as identified in the previous literature review, have been largely confirmed and further specified from an expert perspective. The central needs that have been confirmed and can be inferred from the expert evaluation are as follows:

- A sense of control and autonomy are crucial: Functions such as *Instant Charging* and *Charging Schedules*, which provide users with flexibility and allow them to intervene in the automated smart charging process, are highly valued and considered important. The app's functionality in this regard is positively assessed, and the offered features are deemed relevant.
- The need for clarity amidst complexity: Clarity was one of the most frequently discussed aspects in the expert evaluation. Further improvements are desired, such as the use of

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clearer terminology or the inclusion of additional explanations, including tutorials, to enhance understanding.

- The design, structure, and clarity of symbols contribute to better comprehension when implemented effectively.
- Additionally, personalisation was frequently mentioned: The existing options were appreciated, and they positively contribute to users' sense of autonomy.

The findings presented provide valuable insights for the future development of an optimal smart charging app. In order to ensure that UI solutions meet the needs and expectations of users, while addressing concerns related to control, understanding, and personalisation, it is essential to consider the findings presented in this work.

In the future development of the current interim prototype, there are several key areas of focus. Firstly, there is a need to enhance clarity and understanding within the app. This can be achieved through clearer terminology, additional explanations, and tutorials to help users better comprehend the functionalities and processes. Secondly, it is important to thoughtfully expand and diversify the current range of functionalities. This can involve integrating additional intelligent features. Personalisation options can also be expanded to allow users to customise their charging preferences and schedules. Furthermore, the inclusion of contextual information, such as real-time energy prices or charging station availability, can enhance the overall user experience. Throughout these developments, it is crucial to maintain simplicity, clarity, and comprehensibility. The app should remain user-friendly and intuitive, even as new features and functionalities are introduced. By prioritising these aspects, the aim is to create a smart charging app that not only meets the users' needs but also provides a seamless and enjoyable user experience. In summary, the future development of the smart charging app will focus on enhancing clarity and understanding, expanding the range of functionalities, and maintaining simplicity and user-friendliness. These efforts aim to create an app that not only meets the users' needs but also provides an intuitive and seamless user experience.

4. User Study: Evaluation of Existing UI Solutions

4.1. Aim

This study aims at identifying important features and functions for smart charging interfaces by evaluating usability, acceptance, and trustworthiness of three existing UI solutions *MyBMW* app, *ev.energy* app, and *Jedlix* app. It is important to note that the MyBMW app is not a smart charging app, but rather a charging and vehicle status app. Therefore, the purpose of this study was not to compare the three different apps, but rather to use them as a means to an end in order to identify important functions and features that users want and need in an app interface for smart charging, and to determine how these functions should be implemented. Overall, this study offers valuable insights for future improvements and developments in this field.

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4.2. Methodology

4.2.1. Participants

A total of *N* = 49 participants took part in the study with *n* = 37 identifying as female, *n* = 11 as male, and *n* = 1 as diverse. The sample consisted of students, trainees and interns with a mean age of 21.0 years (*SD* = 4.0) who were rather unexperienced with EVs (69.39% with no experience at all, 23.44% had driven an EV for either a test drive or as a rental). The majority of participants (63.27%) were not previously aware of the concept of smart charging. Of those who were aware of the term, only one individual reported using smart charging.

4.2.2. Material

We used the apps MyBMW (comprehensive vehicle app including charging functions), ev.energy (smart charging app) and Jedlix (smart charging app) to identify the importance of certain features and functions for UI solutions. Additionally, we replicated the screens of the existing apps using a high-fidelity prototyping tool (ProtoPie). This decision was motivated by two key factors. Firstly, certain features of the apps were incompatible with the vehicle available for the study. Secondly and more importantly, the employment of replicated screens allowed for standardised and consistent experimental conditions across participants, including factors such as SOC and charging history. Therefore, depending on the specific use cases, participants interacted with both the original app and the replicated screens.

4.2.3. Measures

We included several questionnaires to assess the constructs of interest (Table 3).

Table 3: Overview of self-report measures.

Construct	Scale	Source
Acceptance	Acceptance Scale	Van der Laan et al. (1997)
Usability	System Usability Scale (SUS)	Brooke (1996)
Usability	Short scale for assessing users' perceived mobile app usability (SmartUse)	Mohr et al. (2024)
User Experience	User Experience Questionnaire (UEQ)	Laugwitz et al. (2008)
Trustworthiness	Facets of System Trustworthiness Scale (FST)	Franke et al. (2015)

In addition to self-reported data, we collected behavioural data in the form of experimenter ratings (Forster et al., 2020). The experimenter rated participants' behaviour on a 5-point rating scale for user interaction success, ranging from "1 = *no problem*" to "5 = *help of experimenter*". We further employed the think-aloud-method during the evaluation of each app in order to capture the mental processes of the participants as they interacted with the apps. We asked the participants to verbalise their thoughts, intentions, and expectations during the interactions.

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4.2.4. Study design

The study was conducted as a laboratory experiment and took place in November and December 2023 in the laboratories of Chemnitz University of Technology. Each participant interacted with all three apps.

The study procedure began by obtaining informed consent from participants, providing them with written information about the study objectives, including a definition of smart charging, and with participants completing a pre-test questionnaire. The evaluation phase involved assessing the three smart charging apps, with the order of app presentation randomised among participants. First, participants were given approximately three minutes to freely explore and form their initial impression of the original app regarding design and functionality. Next, they were introduced to the replica of the apps for about three minutes. We informed participants of any differences from the original app and asked them to consider those during the evaluation. We recorded first impressions of the app replica. Then, participants interacted with both the original app and the replica, performing real-life use cases (UC) and basic interactions. These app interactions can be categorized into three functional areas: 1) plan and initiate charging, 2) charging monitoring, and 3) charging history & statistics. During these interactions, we asked participants to think aloud. Additionally, the experimenter rated the participants' interaction performance. After interacting with each app, participants evaluated the app using several self-report questionnaires. Due to the considerable number of app interactions, we have elected to present the results in a selective manner, focusing on a few selected interactions. We recorded the entire interaction through audio and video.

After participants interacted with all three apps, we conducted a qualitative final interview. We showed participants three copies with screenshots of the app interfaces and asked them to compare the three apps. In a verbal discussion, participants identified advantages and disadvantages of each app with regards to the requirements of smart charting. We specifically asked participants to provide feedback on the app interfaces, including positive aspects, recommendations, and areas of improvement. To complement the qualitative analysis, we established a quantitative ranking by assigning a rank order to each app, accompanied by justifications based on the evaluation criteria.

4.3. Results

Section 4.3 presents descriptive statistical parameters, including the mean (*M*) and standard deviation (*SD*), as well as the results of inferential statistical analysis based on specific test values. The p-value (*p*) provides information on the probability that a difference observed in the sample is based on chance. The statistical tests were conducted with a significance level (α) of 5%. This implies that p-values below 5% ($p > .05$) indicate a statistically significant difference.

Descriptively, participants rated the first impression of the each app on a German school grading scale, with 1 = *very good*, 2 = *good*, 3 = *satisfactory*, 4 = *sufficient*, 5 = *poor*, 6 = *deficient* (Jedlix: $M = 1.49$, $SD = 0.65$, ev.energy: $M = 1.55$, $SD = 0.61$, MyBMW: $M = 1.92$, $SD = 0.91$). Regarding the app replica, a similar pattern was observed (Jedlix: $M = 2.02$, $SD = 0.83$, ev.energy: $M = 2.02$, $SD = 0.83$, MyBMW: $M = 2.33$, $SD = 0.88$).

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The self-reported data of the User Experience Questionnaire (UEQ) showed no significant differences between the three apps with regard to the Hedonic Quality scales (*Stimulation*, $F(2,96) = 2.95$, $p = .057$, and *Novelty,* $F(2,96) = 0.221$, $p = .803$). In addition, there were no significant differences between the ev.energy and Jedlix app in terms of the Pragmatic Quality scales (*Efficiency*, *Perspicuity*, and *Dependability*) and the Attractiveness scale of the UEQ. However, on the Pragmatic Quality and Attractiveness scales, the ev.energy app and the Jedlix app were each rated significantly higher than the MyBMW app at a significance level of $\alpha = .05$ (Table 4). This pattern was also evident for the Acceptance Scale, the System Usability Scale (SUS), the SmartUse Scale, and the facets of the system trustworthiness scale. There were no significant differences between the ev.energy and the Jedlix app in the four questionnaires mentioned.

The results of behavioural data are in line with the self-reported data: Experimenter ratings showed higher values (representing more difficulties) for MyBMW ($M = 2.24$, $SD = 0.51$) compared to Jedlix ($M = 1.75$, $SD = 0.40$) and ev.energy ($M = 2.04$, $SD = 0.52$). The results indicate that across all app interactions, participants performed best using the Jedlix app (Figure 9).

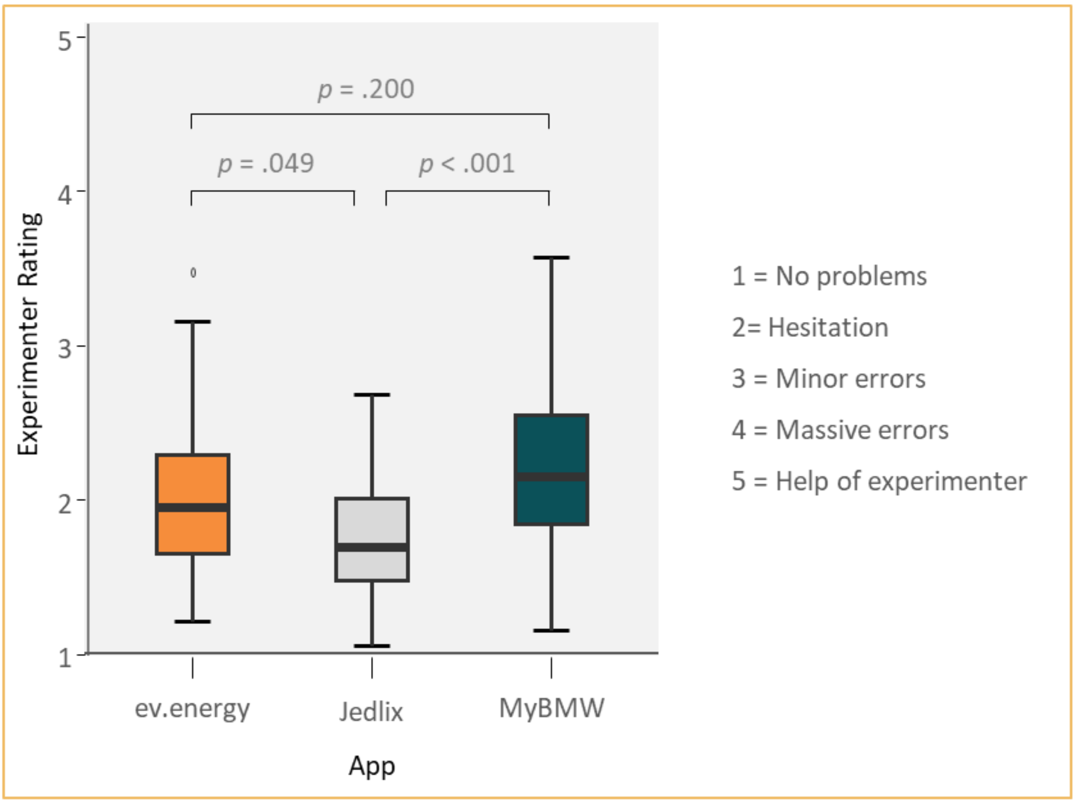

Figure 9: Mean Value of the Ratings of the Individual App Interactions as a Function of the App.

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Table 4: Descriptive and inferential statistics for each questionnaire and each comparison.

Questionnaire and Subscale	App	M	SD	Comparison	Post-hoc pairwise comparisons with p-value adjustment (Bonferroni)				
					estimate	*SE*	*df*	*t-value*	*p*
UEQ-Efficiency	MyBMW	0.20	1.16	ev.energy – MyBMW	1.31	0.17	96	7.89	< .001
	ev.energy	1.51	0.86	ev.energy – Jedlix	-0.27	0.17	96	-1.63	.316
	Jedlix	1.78	0.70	Jedlix – MyBMW	1.58	0.17	96	9.53	< .001
UEQ - Perspicuity	My BMW	-0.30	1.34	ev.energy – MyBMW	1.78	0.20	96	8.95	< .001
	ev.energy	1.47	0.98	ev.energy – Jedlix	-0.42	0.20	96	-2.11	.113
	Jedlix	1.89	0.83	Jedlix – MyBMW	2.19	0.20	96	11.05	< .001
UEQ - Dependability	MyBMW	0.66	1.08	ev.energy – MyBMW	0.93	0.14	96	6.61	< .001
	ev.energy	1.60	0.76	ev.energy – Jedlix	-0.08	0.14	96	-0.58	> .999
	Jedlix	1.68	0.71	Jedlix – MyBMW	1.02	0.14	96	7.19	< .001
UEQ - Attractiveness	MyBMW	0.41	1.29	ev.energy – MyBMW	0.98	0.18	96	5.45	< .001
	ev.energy	1.39	0.80	ev.energy – Jedlix	-0.12	0.18	96	-0.65	> .999
	Jedlix	1.51	0.78	Jedlix – MyBMW	1.09	0.18	96	6.09	< .001
Acceptance Scale - Usefulness	MyBMW	0.79	0.77	ev.energy – MyBMW	0.33	0.11	96	3.10	.008
	ev.energy	1.11	0.52	ev.energy – Jedlix	-0.06	0.11	96	-0.58	> .999
	Jedlix	1.18	0.49	Jedlix – MyBMW	0.39	0.11	96	3.68	.001
Acceptance Scale - Satisfying	MyBMW	0.29	0.92	ev.energy – MyBMW	0.67	0.12	96	5.67	< .001
	ev.energy	0.96	0.62	ev.energy – Jedlix	-0.07	0.12	96	-0.56	> .999
	Jedlix	1.03	0.60	Jedlix – MyBMW	0.74	0.12	96	6.23	< .001
SUS	MyBMW	52.14	19.28	ev.energy – MyBMW	20.92	2.9	96	7.21	< .001
	ev.energy	73.06	15.51	ev.energy – Jedlix	-4.34	2.9	96	-1.49	.416
	Jedlix	77.39	13.75	Jedlix – MyBMW	25.26	2.9	96	8.70	< .001
Smart Use - Usability	MyBMW	4.66	1.04	ev.energy – MyBMW	0.96	0.14	96	6.75	< .001
	ev.energy	5.62	0.79	ev.energy – Jedlix	-0.22	0.14	96	-1.58	.350
	Jedlix	5.84	0.72	Jedlix – MyBMW	1.18	0.14	96	8.33	< .001
Smart Use – Design	MyBMW	4.90	1.00	ev.energy – MyBMW	0.89	0.15	96	5.74	< .001
	ev.energy	5.79	0.82	ev.energy – Jedlix	-0.16	0.15	96	-1.05	.895
	Jedlix	5.95	0.88	Jedlix – MyBMW	1.05	0.15	96	6.79	< .001
FST Scale	MyBMW	4.28	0.88	ev.energy – MyBMW	0.55	0.11	96	4.94	< .001
	ev.energy	4.82	0.68	ev.energy – Jedlix	-0.07	0.11	96	-0.66	> .999
	Jedlix	4.90	0.73	Jedlix – MyBMW	0.62	0.11	96	5.61	< .001

Note: Higher M values indicate superior ratings across all scales, with the following ranges: UEQ Scales (-3 to 3), Acceptance Scales (-2 to 2), SUS (0 to 100), SmartUse (1 to 7) and FST Scale (1 to 6).

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Additionally, experimenters also noted which problems participants encountered when interacting with the apps. Using ev.energy and MyBMW, participants had the most difficulties with setting a charging goal of 30% for conventional charging. When interacting with the MyBMW app, participants found the charging goal slider, but overlooked the fact that they had to change the charging mode to "*Instant charging*" or did not find the charging mode selection. With the ev.energy app, participants struggled most with setting the maximum charge limit for conventional charging to 30%. Participants either deactivated smart charging or set the limit for smart charging (instead of conventional charging) to 30%. Using Jedlix, difficulties arose with the task of checking the connection to a charging station. When the app displayed "*Charging complete*" as SOC, it was not always clear to the participants whether the car was still plugged in or not.

Across all three apps, participants had difficulties looking for the costs of charging and the amount of energy charged over the last two months in order to make a judgement about the increase in cost. These tasks were part of the subordinate category of "Charging History & Statistics". Table 5 shows the mean experimenter ratings and respective problems encountered within this app interaction.

Table 5: Mean Experimenter Rating and Problems with the App Interaction Charging Costs.

App	Experimenter Rating	Problems
MyBMW	2.9	Participants did not use the charged energy amount (only total costs per month)
		There was no monthly average, but some participants were able to use the price per kWh
		Some participants overlooked the change of month
		Some participants used charging times instead of charged energy amount for comparison
Jedlix	3.1	Participants did not use the charged energy amount
		There were no readable statistics for prices per kWh and misinterpretation of the bonus benefits as prices per kWh
		Some participants hoped to find the monthly average in the annual overview
ev.energy	3.9	Participants did not consider the basic cost differences between charging types in history
		Task was not solvable in the statistics because of no access to individual months

Additionally, participants were asked to think aloud during the evaluation of each app. The results of the think-aloud-method are presented in Table 6 as illustrative examples for two app interactions. The two interactions were selected for analysis because they were comparable across all three apps.

As shown in Figure 10 the participants' overall evaluation of the three apps in the final interview revealed that the Jedlix app was most often rated as the best app on a descriptive level.

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Table 6: Results of the Think-Aloud-Method.

Screen	App	Positive Comments	Negative Comments
Main Screen	MyBMW	- Clear visualization of the registered vehicle - Clear visualization of SOC and range (in % and km) - Precise indication of the charging process	- Unclear whether the image of the vehicle on the home screen is updated when the vehicle is unplugged - Participants expected to see the connection status when clicking on "Check status" on the main screen - Menu item "Charging history" relatively at the bottom and hidden in view of its relevance, resulting in problems in menu navigation
	ev.energy	- Clear visualization of the charging status in percent - Clear list of past charging events with the most important information - Simple setting of the charging limit - Boost mode allows quick, temporary overwriting of the smart charging settings without deactivating the charging mode - Clear indication of the charging duration and vehicle plugging status	- Missing indication of the range in km - Text must be read carefully to be able to assign timings, which occasionally led to confusion between departure and charging times - Charging limit for smart charging, but not for boost charging - Charging limit can only be set as a percentage and not in range - No support for setting an appropriate charging limit - Unclear what the charging limit refers to - The charging limit function disappears during boost charging - Meaning of boost mode occasionally unclear - Unclear whether smart charging is activated or not - Redundant information that vehicle is not plugged in - Information text at the top of the main screen is often overlooked when the vehicle is plugged in
	Jedlix	- Clear visualization of the charge level in percent and range - Clear overview of whether smart charging is activated or not - Combination of conventional charging and smart charging is depicted in the charging bar - Separate setting of charging limits for conventional charging and smart charging - Displaying the settings for conventional charging and smart charging side by side improves understanding - Simple setting of charging limits - The departure time setting is easy to find via the main screen - Clear list of departure times for each day of the week	- Option to deactivate smart charging is hidden - No indication of the duration of the charging process until the charging goals are reached - No indication of whether the vehicle is connected to the charging station or not - No support for planning charging goals - Irritation that direct charging is only possible up to 50% - Few setting options for charging times - Lack of transparency about the actual start of charging if charging is postponed - Irritations that the time cannot be adjusted with “Postpone charging" - Setting the same time for all days can be annoying - No creation and activation/deactivation of multiple schedules for different events possible

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Table 6: Results of the Think-Aloud-Method. ***(continuation)***

Screen	App	Positive Comments	Negative Comments
Charging History	MyBMW	- Clear listing of the individual charging processes with the most important information - Clear visualization of extended information for each charging process	- Inconspicuous button for changing the months was occasionally overlooked - No statistical trend information, such as electricity costs per kWh over time - No differentiated information on costs/CO_2 emissions saved through smart charging - No clear subdivision/filtering option by conventional charging or smart charging - Missing information on charging mode - Missing information on CO_2
	ev.energy	- Clear listing of past charging events with extended information in submenus	- No information about the start and end charge status of the last charging process
	Jedlix	- Clear list of past charging events with the most important information - Further, detailed information about the charging events in the submenu	- No statistical trend information, e.g., on electricity costs per kWh over time - No indication of how much electricity was charged via conventional charging and smart charging - Benefits were misunderstood (e.g., as electricity price) - Missing information on CO_2 emissions

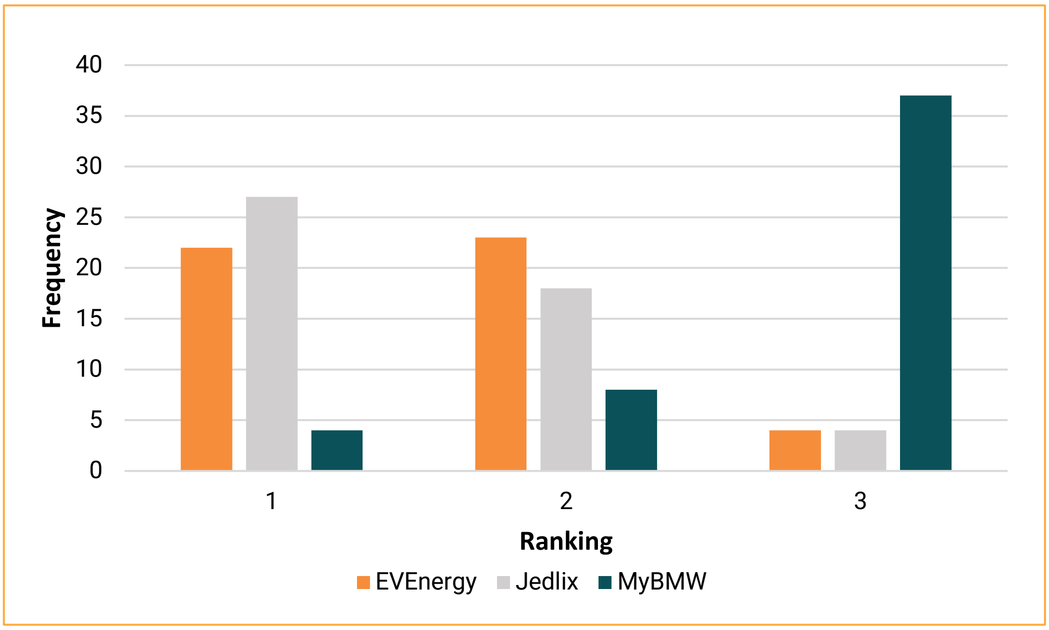

Figure 10: Participants' overall evaluation of the three apps in the form of a ranking (1 = best app).

The positive and negative remarks made by the participants during the final interview about the three apps are listed in Table 7.

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Table 7: Participants' remarks during the final interview.

Category	App	Positive Comments	Negative Comments
Clarity	MyBMW	- Clear charging history - Charging schedule is clear and understandable - Comprehensive overview that provides information regarding the status of the vehicle's connection to the charging port, the level of its charge (including distance in kilometres), and the duration of the charging process	- Unclear and confusing menu navigation - Too many nested submenus hide important functions and make settings more difficult - Setting a charging time period for setting the departure time appears very confusing and complicated - Unclear if the charging time is important when the departure time is already known
	ev.enery	- Clear menus, not too many submenus - Colours support clarity - Clear charging history - Charging schedule and charging status easily visible - Clear distinction of charging modes in the statistics - Compact and clear smart time schedule - Clear/organized statistics with graphs and mean values	- The term "boost charging" is initially incomprehensible for inexperienced users
	Jedlix	- Clear menus - Clear visualization of costs and savings - Logical structure of charging history	- Uncertainty regarding the functioning of dual charging goals - Uncertainty about the function of "boost charging"
Settings	MyBMW	- Many configuration options, not just for charging	- Long latency when saving the settings - Changing the charging mode is complicated
	ev.energy		- Charging time cannot be manually set

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Table 7: Participants' remarks during the final interview. ***(continuation)***

Category	App	Positive Comments	Negative Comments
Design/ Usability	MyBMW	- Modern, luxurious design - Intuitive navigation to the charging schedule by tapping on the charging status	- Unintuitive, complicated operation - Overloaded app (too many features, information; too much at once, too much "bells and whistles") - Very confusing because smart charging features are integrated into a general vehicle app - Less aesthetically and creatively designed compared to the other two apps - Some settings (e.g., charging within a time frame and pre-conditioning for departure) should be separated spatially because they overload the menus - Insufficient/absence of use of symbols for important functions (e.g., charging mode), which leads to them being easily overlooked - Lack of transparency regarding the selected charging mode (smart charging or conventional charging) - No bar charts in the charging history and thus less visually appealing
	ev.energy	- Intuitive operation - Appealing design	- Charging history and statistics should not be presented separately - Less information on main screen - Low transparency regarding whether smart or normal charging is being used - Bar charts are difficult to read - As the central charging display attracts a lot of attention, it should show more information (e.g., range) - Design is too colourful
	Jedlix	- Intuitive and easy operation - Appealing design - Colour differentiation between regular charging goal and smart charging goal	- Boring design - Hidden functions, i.e., charging boost in pop-up on the top right of the home screen

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Table 7: Participants' remarks during the final interview. ***(continuation)***

Category	App	Positive Comments	Negative Comments
Functionality	MyBMW	- All vehicle functions in one app	- Yearly overview as well as financial and CO_2 savings are missing in the charging history
	ev.energy	- Boost mode directly on the home screen - CO_2 balance and CO_2 statistics - Good amount of information and features - Low tariff mode activated with a single button press - Solar option for smart charging - Diagrams in the statistics provide an overview of the charging progress for specific time periods	- No indication of range in km - No filtering by months in the statistics
	Jedlix	- Direct access to most important settings immediately on main screen - Display of SOC and on main screen - Showing necessary functions only - Charging history encompasses most important information	- Limited functionality - No feedback on duration of charging process - The time for shifting the charging should be adjustable - Missing statistics on CO_2 emissions - Charging history without price per kWh

4.4. Conclusion

In conclusion, participants placed particular emphasis on an intuitive and clear presentation of content. Participants also appreciated the integration of all vehicle functions in a single app. The results indicate that a combined app that incorporates both conventional vehicle functions and smart charging functions may be a promising avenue for further exploration. Participants expressed positive views regarding the function of setting a charging limit. However, they also criticised when it is possible to set this limit for one charging type only. According to the participants, the ability to set a departure time is a crucial feature for smart charging. They appreciated a direct access to departure time settings through the home screen and a clear display of departure times for each day of the week. A significant shortcoming was the lack of clear visibility regarding cost savings through smart charging. Participants expressed a clear desire for information on how much money they had saved through smart charging. Additionally, participants expressed a clear desire for information on CO_2-savings (CO_2-balance and statistics).

It is important to acknowledge certain limitations in this study. The comparability of the apps is not guaranteed as not all three apps are pure smart charging apps. Therefore, a direct comparison of user interactions may not be meaningful in this context. Additionally, the study aimed to explore and learn from best practice examples and UI features that are relevant to Smart Charging. The identification of such examples and features was based on the available apps and may not capture the full spectrum of possibilities.

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5. Summary

The objectives of this work were to

- provide an overview of the state of the art in research and development of user-centred smart charging concepts and HMI solutions,
- design and test innovative smart charging app features and,
- identify key user requirements for (smart) charging apps to improve user satisfaction.

Therefore, desk research was conducted, which included national and international research projects, an extensive literature review and the investigation of current developments in the industry. Based on the findings, a prototype smart charging app was developed and evaluated. In addition, a laboratory study was conducted to evaluate existing smart charging UIs.

Results show that there is a need to develop apps that offer a wide range of smart charging features for both public and private charging. Smart charging apps should meet the following user requirements:

- Give users control and autonomy: Features such as instant or immediate charging and charging schedules allow users to intervene in the automated smart charging process. The ability to set a departure time and charging limit allows users to take control of the charging process.
- Create clarity in complexity: Apps should be clear in design, structure and icons to be intuitive and easy to use.
- Provide transparency about the charging process itself, as well as financial aspects (pricing and cost savings) and environmental aspects (CO_2 savings).
- Allow personalisation, such as customisation of charging preferences and schedules.
- Consider integrating all vehicle functions (beyond smart charging functions) into a single app to enhance convenience for users.

D2.3 thus presents an overview of the main requirements for smart charging applications in general. The upcoming deliverable D2.4 will then provide specific recommendations for user interfaces in the testbeds and demos (WP6 and WP7).

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