User acceptability of V2G – An empirical investigation

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Nora Baumgartner (M.Sc.)

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Korreferent:	Prof. Dr. Ulf J. J. Hahnel

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Abstract

Growing climate concerns push policymakers to enact laws to reach national climate goals. In Germany, the "Energiewende" fosters the expansion of renewable energy sources (RES), and simultaneously pursues to reduce the dependency on fossil fuels. In the transport sector, the German Government, among others, aims to shift from internal combustion engine vehicles to electric vehicles (EVs). The widespread adoption of EVs, however, will result in additional electricity demand. Yet, integrating the EV's battery via a bidirectional power flow into the grid could provide short-term flexibility options for the electricity system. Hence, vehicle-to-grid (V2G) enables a smoother and more efficient integration of large EV numbers and a higher potential of integrating RES into the grid.

The adoption of this technology takes place at the local or household level, which, inevitably, assigns the EV owner a key role in the whole V2G system. Achieving system benefits is thus dependent on the user's acceptance of this technology, highlighting the multilevel and multifaceted character of V2G. This dissertation focuses on the user's perspective, analyzing different user motivations to adopt V2G technology. To this end, this work first provides a systematic overview of scientific studies in the field of smart charging, assessing how the user is integrated into state-of-the-art research. Secondly, developing three empirical studies, this thesis builds upon several theories, e.g., value belief norm theory, evaluating economic, environmental, technical, and social motives to adopt V2G, using statistical methods, such as mediation analysis and multi-group structural equation modeling. Additionally, the thesis provides comparisons between sub-groups, i.e., countries (Germany, France, Switzerland, UK), EV experience levels, and between energy initiative members and non-members. Understanding the acceptability of V2G and its underlying motives for different sub-groups is at the core of this thesis.

The systematic literature review confirms the existence of typical patterns of how the user is integrated into the different research streams and highlights the need for more in-depth analysis of the user motivations, while calling for integrative research, accounting for the inherent complexity more holistically. The empirical studies analyze user requirements and motivations to adopt a V2G charging tariff, extending current research by using and developing direct rating methods to capture users' interest in V2G tariff schemes. Results demonstrate, that user requirements about minimum range and monetary compensation are high. Yet, environmental and economic motives positively influence users' range requirements, and willingness to participate in a V2G charging tariff, raising higher flexibility potentials. Importantly, this especially holds for EV owners. Moreover, battery degradation is perceived as a relevant barrier to V2G, increasing users' monetary compensation requirements. Next to environmental and economic motives, community factors can act as drivers of adoption interest, too. Specifically, community factors are uniquely related to adoption interest and, furthermore, influence the adoption interest of V2G via personal norms, indirectly. Finally, while motives seem to be similar between the studied countries, EV knowledge levels, and initiative membership have an impact on how V2G is evaluated and which requirements are applied.

Contents

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List of abbreviations

BEV	Battery electric vehicles
CFA	Confirmatory factor analysis
CH	Switzerland
CI	Confidence interval
CSEM	Community sustainable energy motivation
DE	Germany
DOI	Diffusion of innovation
DSO	Distribution system operators
DWLS	Diagonally weighted least squares
EEG	Erneuerbare-Energien-Gesetz
EnWG	Gesetz über die Elektrizitäts- und Gasversorgung
EV	Electric vehicles
FCR	Frequency containment reserve
FR	France
ICEV	Internal combustion engine vehicles
IDP	Indifference price point
MDP	Point of marginal expensiveness
MGP	Point of marginal cheapness
MiD	Mobilität in Deutschland
ML	Maximum likelihood
OPP	Optimal price point
PSM	Price sensitivity meter
PV	Photovoltaic system
RES	Renewable energy sources
SEM	Structural equation model
SoC	State of charge
StromStG	Stromsteuergesetz
TAM	Technology Acceptance Model
TPB	Theory of planned behavior
TSO	Transmission system operators
UK	United Kingdom
VBN	Value-belief-norm theory
VGI	Vehicle-grid-integration
V2B	Vehicle-to-business
V2G	Vehicle-to-grid
V2H	Vehicle-to-home
V2X	Vehicle-to-x

List of appended research papers

Paper A

Baumgartner, N., Weyer, K., Eckmann, L., Fichtner, W. (2023), How to integrate users into smart charging – a critical and systematic review, *Energy Research and Social Science.*

Paper B

Baumgartner, N., Klumpp, N., Signer, T., Wadud, Z., Fichtner, W. (2024), Users‘ willingness to accept V2G – A comparison between German and UK households, *EEM Conference 2024.*

Paper C

Baumgartner, N., Kellerer, F., Ruppert, M., Hirsch, S., Mang, S., Fichtner, W. (2022), Does experience matter? Assessing user motivations to accept a V2G charging tariff, *Transportation Research Part D.*

Paper D

Baumgartner, N., Sloot, D., Günther, A., Hahnel, U. J. J. (2025), Development and test of a dual pathway model of personal and community factors driving new energy technology adoption - The case of V2G in three European countries, *Ecological Economics.*

Part I

Overview

Chapter 1

1 Introduction

1.1 Motivation

The world is under stress due to climate change, and mankind is beginning to witness its severe effects. Heat waves, forest fires, and floods, just to name a few, happen in regions and in seasons where these heavy weather conditions were not common before. To limit the consequences, a majority of countries worldwide have agreed in the Paris Agreement to reduce their greenhouse gas emissions significantly to hold the increase in global warming below 2°C, compared to pre-industrial levels (UNFCCC, 2015). To this end, governments develop strategies and enact laws to carry out appropriate measures. In Germany, the climate protection law, the "Klimaschutzgesetz" (Bundesministerium für Wirtschaft und Klimaschutz) which was in force in its previous version until June 2024, earmarked reduction goals for greenhouse gases that have to be achieved by the six sectors[1]: energy economy, industry, building, transport, agriculture and waste, and others. Yet, the transport sector missed its targets for several years in a row (Agora Verkehrswende, 2023). The share of transport in total emissions has risen from around 13% in 1990 to almost 20% in 2022 (UBA, 2024).

To decrease CO_2 emissions in the transport sector, the German Government is promoting electric vehicles (EVs) with several measures[2] to reach the aim of 15 million electric vehicles by 2030, as stated in the coalition agreement of the 2021-elected German Government (SPD, Bündnis 90/Die Grünen and FDP, 2021). In 2024, there were ~1.4 Mio EVs on Germany's roads (Kraftfahrtbundesamt, 2024). When charged with 100% renewable energy sources (RES), the operation of an EV produces less CO_2 emissions than internal combustion engine vehicles (ICEVs), and furthermore reduces the dependency on fossil fuels. Thus, EVs are currently the most economical and energy-efficient solution of the currently available reduction options in the transport sector (Wietschel et al., 2022).

The market ramp-up of EVs will result in additional electricity demand. According to a study by Prognos (Kemmler et al., 2021) the additional gross electricity consumption will rise from 2018

1 The climate protection law is the core of the German climate policy. It defines, that Germany has to reduce its greenhouse gas emissions by at least 88 % by 2040 and become climate-neutral by 2045 (Die Bundesregierung, 2024). Various changes were made to the law and it was criticized in particular for softening the greenhouse gas emission reduction targets per sector (Tagesschau, 2024). Compared to the previous frame, sectors are no longer strictly bound to achieve their goals, but the reduction over all sectors is the baseline for success 2045 (Die Bundesregierung, 2024).

2 The so-called „Masterplan Ladeinfrastruktur II" is the basis for the targeted market ramp-up of EVs in Germany. It includes several measures, among others promoting the expansion of public and private (particularly for businesses) fast-charging stations for EVs and trucks, and fostering electricity from PV for EV charging. (BMDV, 2024).

to 2030 by 68 TWh only due to electromobility. With this, electromobility will be one of the main drivers of increasing electricity demand in the future. Additionally, in light of expansion targets for RES in Germany (Bundesministerium für Wirtschaft und Klimaschutz, 2023), and further electrification, for example in the heating sector, the electricity system changes from once unidirectional and centralized to a bidirectional decentralized system. With this, the energy system undergoes a radical transformation, where flexibility options are becoming increasingly important to uphold the system’s stability. Short-term battery storage is one substantive pillar in this system transformation, as it provides geographic and temporal distributed flexibility (Knezovic et al., 2017). In this context, the EV’s battery can make a substantial contribution to the ambitious Government targets, given the potential storage capacities. Using the EV’s battery as a distributed short-term flexibility could provide flexibility options for the electricity system and thus enable a smoother and more efficient integration of these large EV numbers and consequently, higher potential of integrating RES into the grid. Enabling a bidirectional power flow of the EV’s battery while optimizing the charging process towards one or multiple goals and reaching a desired state of charge (SoC) is called vehicle-to-grid (V2G) (Huber et al., 2019; Sovacool et al., 2017).

Besides the technological and regulatory challenges which are associated with V2G, new technologies have to be integrated into user practices, organizations, and routines to be successful. Therefore, it is important to understand how people form an opinion on V2G and why people take action in favor or against it (Huijts et al., 2012). This is especially important as V2G is adopted on a household level, which makes the owner of the EV a key stakeholder in the whole V2G system. System benefits can thus only be achieved when users accept and adopt this technology. Consequently, it is necessary to analyze and understand user motivations to adopt V2G technology.

1.2 Scope and research objective

This work aims to derive an improved understanding of the user’s role in a V2G system. To this end, it is necessary to unfold how the user is characterized and integrated into the V2G system. Moreover, going one step further, it is essential to examine the factors and their role in influencing the user acceptability of V2G technology. Specifically, as the study’s object is a technology that is not yet market-ready, the thesis’ focus is on acceptability, a concept describing the user’s intention to use and engage with the technology in question, in this sense, a pre-condition for adoption (Schade and Schlag, 2003). To gain a more holistic understanding of V2G acceptability, it is vital to consider a variety of motives. Four different factor dimensions are taken into account. Technical factors relate to the technology’s benefits for grid stability and the technological barriers arising from using the technology, such as increased battery degradation. Economic factors play a key role as participating in V2G is, on the one hand, associated with additional investments and, on the other, bears the promise to generate revenue. In contrast, environmental motives focus on the technology’s benefits for the environment, particularly the potential of increasing the share of RES in the grid. Yet, these motives are often in conflict with economic motives. While economic motives reflect individual interests and focus on a shorter time horizon, strong environmental motives tend to reflect collective interests that include concern for future generations. Finally, individuals don’t act in a vacuum but are influenced by their social environment, which is why it is important to also consider social factors as an essential aspect of V2G acceptability from the user's perspective. As the perception of technical, economic, environmental, and social motives may be substantially different between sub-groups, this work offers group comparisons as well. Particularly, this work compares V2G case studies based on EV knowledge, membership in an energy initiative, and the country context. Pursuing an analysis for specific sub-groups allows to draw targeted recommendations for these sub-groups and increases the generalizability of results (Figure 1). Understanding the acceptability of V2G and its underlying motives for different

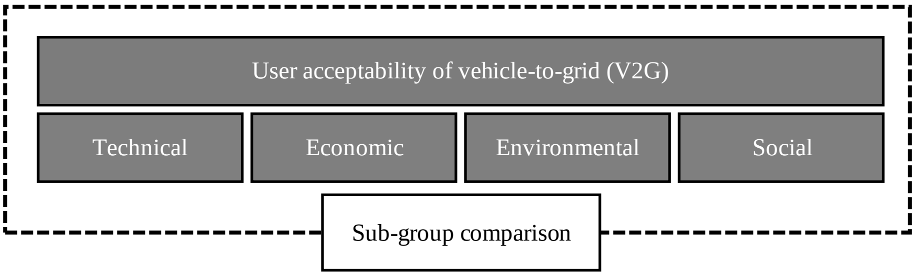


Figure 1: V2G acceptability dimensions, own illustration.

sub-groups is at the core of this thesis. Specifically, the thesis addresses three empirical research questions, which can be categorized into two complementary parts.

The first part provides a systematic overview of the current state of research on smart charging (including both uni- and bidirectional charging), investigating disciplines and methods that are used in this research field, and identifying stakeholders and dominating research topics throughout the various disciplines. Furthermore, this part scrutinizes how the human factor of smart charging is approached by predominating topics and disciplines and provides examples of research topics and the way in which the user characteristics are typically integrated. The first part thereby addresses the following research question:

i. How is the user represented and characterized in current research on smart charging and how do disciplinary approaches differ?

Since the research landscape investigating user motivations to participate in V2G is still underdeveloped, and comparisons across countries and different stakeholder groups are scarce, the second part builds upon the first one by focusing on different factors and their impact on V2G acceptability. Importantly, the thesis does not only focus on one specific motivation but stands out by conflating a diverse set of user motivations analyzing them against the background of different country settings. Conceptually, this thesis develops different approaches to operationalizing V2G acceptability. The focus is on framing V2G charging tariffs and asking for users' willingness to pay (WTP), willingness to accept (WTA), and willingness to participate, using direct approaches. Methodologically, different statistical methods are used to analyze the relationships between V2G acceptability and its predictors, among others, structural equation modeling and mediation modeling. Finally, the thesis undertook considerable efforts to carry out different approaches to analyze different V2G case studies for different sub-groups, firstly by comparing groups of distinguishable EV knowledge levels, second by comparing energy community members with non-members, and finally by comparing different countries. Thus, the second part addresses two research questions:

i. To what extent do technical, economic, environmental, and social factors explain V2G acceptability?
ii. How does the analysis of sub-groups add to and extend the understanding of technical, economic, environmental, and social acceptability factors of V2G?

This thesis proposes that, though there seems to be a general willingness to participate, the perceived barriers arising from the technological peculiarities are evident and are reflected in high user requirements to participate in V2G, particularly high expectations toward compensation and high minimum range requirements. Yet, offering EV owners to charge particularly climate-friendly or in a cost-minimizing way, leads to lower range requirements, providing the aggregator with greater amounts of flexibility. Moreover, the thesis illustrates the importance of considering sub-groups. Specifically, group membership, and EV knowledge level matter and significantly impact V2G adoption interest. In particular, these characteristics influence V2G adoption interest directly and indirectly, highlighting the important role of knowledge and energy initiative membership in creating interest in novel energy technologies. Finally, this thesis shows that country differences seem less relevant in the context of V2G adoption interest.

The cumulative dissertation consists of two parts. Its structure is illustrated in Figure 2. Part I contains this introduction (Chapter 1). The thesis at hand focuses on an innovative technology, that is on the one hand relevant to the energy system by providing flexibility, but, on the other, will be adopted on the household level. Hence, this thesis continues by outlining the technology's fundamentals in the context of the German electricity market, thereby focusing on the relevance for energy economics, and its technical and regulatory barriers (Chapter 2). Chapter 3 focuses on the human dimension of V2G, describing the theoretical fundamentals and concepts, relevant to explain V2G acceptability. Besides the theoretical part, this chapter also includes a review of empirical studies on V2G acceptability, deriving and structuring the most important factors predicting V2G acceptability. Chapter 4 builds upon the previous chapters, outlining the research design of this thesis and how it was implemented in the appended research papers. Thereby, Chapter 4 puts a particular focus on how V2G acceptability was operationalized and how the group analysis was performed within the scientific papers. Hereafter, Chapter 5 provides a synthesis of the four research papers. Next, this thesis summarizes the most important finding and derives political and theoretical implications (Chapter 6) and finally, concludes with a critical reflection and recommendations for future research (Chapter 7).

Part II consists of the interconnected scientific papers A-D:

Paper A The objective of Paper A is to systematically analyze the current state-of-the-art research on smart charging (including V2G) of EVs with a specific focus on the question of how different disciplines integrate the user into their research, which variables and methods are used, and which research areas are being studied. The literature review provides examples of the different disciplines, identifies best practices, and provides recommendations for future research. Paper A is a systematic literature review and was published in 2023 in the journal Energy Research & Social Science (Baumgartner et al., 2023).

Paper B This proceeding article follows three objectives. First, to assess the expected user compensation requirements for participating in V2G charging when informing them about the necessary additional investments and the issue of battery degradation. Second, to evaluate different predictors of users' willingness to participate in V2G charging. And last, to compare the results between a German and a United Kingdom sample. To this end, a survey was developed, which asks for users' compensation requirements. Furthermore, a hierarchical multi-regression model was developed to analyze users' willingness to participate in V2G and its predictors. This proceeding article was presented at the EEM conference in June 2024 and was published in the IEEE (Baumgartner et al., 2024).

Paper C Paper C focuses on user requirements with regard to the minimum range requirements and WTP for a V2G charging tariff for EVs. Moreover, it analyses the extent to which different charging strategies affect the requirements of people with different EV experience levels. Based on a unique data set including a high share of people owning an EV and having experience with EVs, minimum range requirements and users' WTP for a two-level charging tariff are calculated. For calculating users' WTP, the price sensitivity meter by van Westendorp was applied. Furthermore, in this paper three distinct charging strategies are developed – climate-neutral, cost-minimizing, and grid-beneficial charging – and integrated as mediators into a mediation model with categorical predictors. This scientific paper was published in 2022 in the journal Transportation Research Part D (Baumgartner et al., 2022).

Paper D This paper develops a new theoretical model considering personal and community factors as potential drivers of energy technology adoption, with V2G being the test case. To test this model, an empirical study was conducted based on nationally representative panel data collected in three European countries (Germany, France, and Switzerland). The model was analyzed using structural equation modeling. Furthermore, a grouping variable (country) was introduced in a second step to test the model for the three European countries. The objective of this study is to explain whether membership in a community energy initiative increases the likelihood of engaging in additional energy transition practices. This paper was published in 2025 in a special issue of the journal Ecological Economics (Baumgartner et al., 2025).

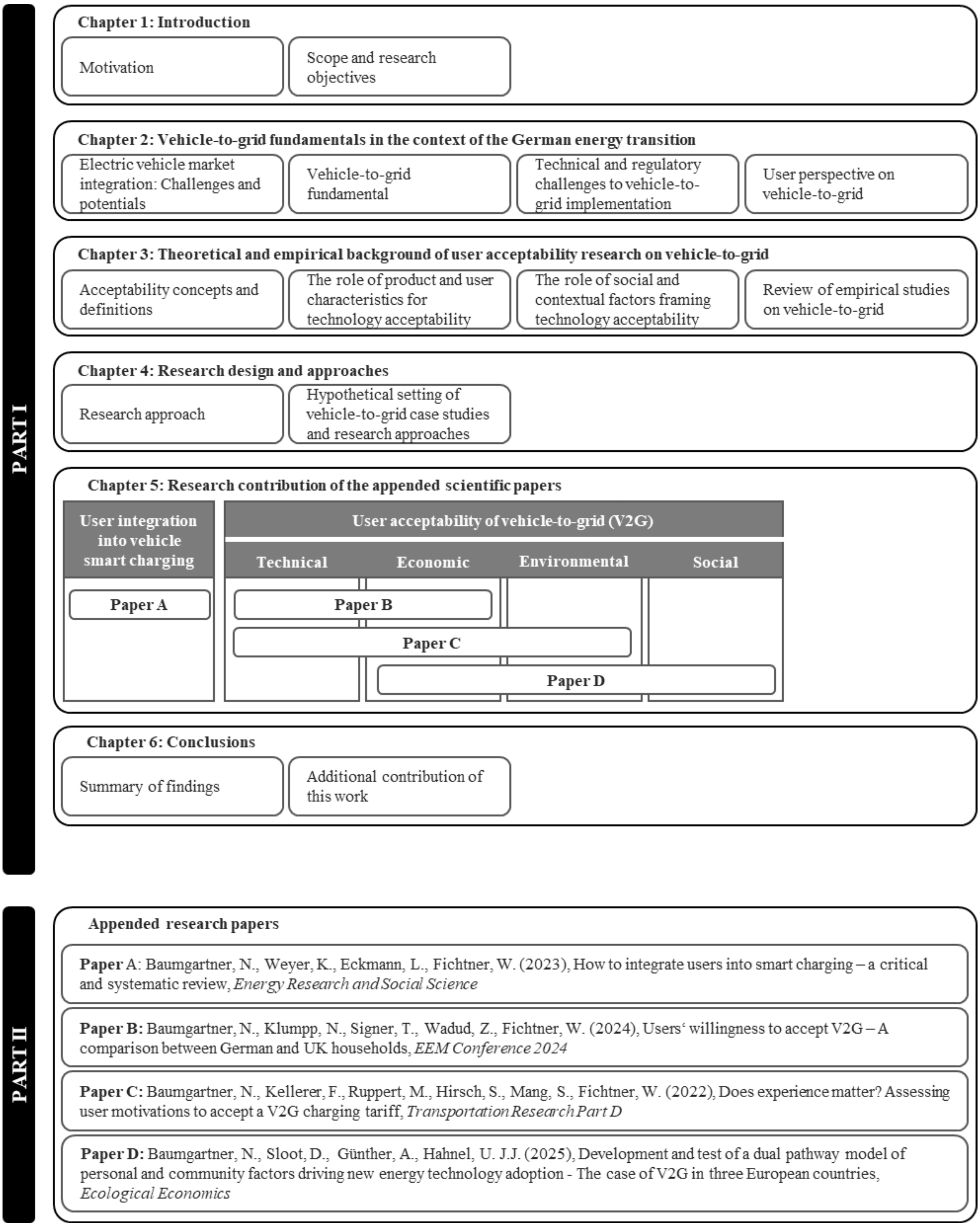


Figure 2: Structure of the thesis, based on Ilg (2024).

Chapter 2

2 Vehicle-to-grid fundamentals in the context of the German energy transition

New technologies, actors, and roles will shape the future energy system that is envisaged by political strategies. This system is characterized by decentralized and renewable energy-based production, and bidirectional power flows. Importantly, scholars have identified the need for flexibility as an integral part of the new energy system design. Energy storage, as well as customer engagement in the frame of demand response programs or dynamic tariffs, are thereby two major bottlenecks in matching intermittent renewable energy supply with electricity demand (Hampton et al., 2022; Heilmann and Friedl, 2021). Moreover, to reach a climate-neutral future, RES are at the beginning of nearly every supply chain, replacing fossil fuels either directly through the electrification of processes and sectors, such as the transport or heating sector, or indirectly through hydrogen or synthetic carriers. Ultimately, this gives rise to new technologies and contributes to sector coupling. In Germany, four technologies have been identified as the main drivers of sector coupling – heat pumps, EVs, power-to-heat and district heat, and electrolysis (Agora Energiewende, 2022; Übertragungsnetzbetreiber CC-BY-4.0, 2023), whereby EVs and the possibility of utilizing their battery as decentralized storage, is the main focus of this thesis.

This chapter provides an overview of the theoretical foundations of V2G from a technical and economic viewpoint. The purpose of this section is

i. to highlight the role of V2G in the energy transformation
ii. to provide an overview of the V2G system and its applications
iii. to describe the existing challenges
iv. to introduce the user role.

Chapter 2 aims to give an overview of the fundamentals of V2G, starting by introducing the technology's role and relevance for a future energy system (Section 2.1). Section 2.2 provides an overview of the V2G fundamentals, including a definition and demarcation to other forms of smart charging, an introduction to the primary and secondary actors of a V2G system, and applications. Section 2.3 highlights the major technical and regulatory challenges that persist, hindering, up to now, a complete market introduction of V2G. The chapter closes with an introduction of the user role in a V2G system, focusing on the conflict between mobility needs and flexibility provision (Section 2.3.2).

2.1 Electric vehicle market integration: Challenges and potentials

As of 2024, there are just over 1 million EVs on Germany's roads (Kraftfahrtbundesamt, 2024). The German government aims to increase this number to 15 million in 2030[3] (SPD, Bündnis 90/Die Grünen and FDP, 2021), while the grid development plan predicts 31 million EVs by 2037 and 37 million EVs by 2045 in its scenarios B (decarbonization through intensive electrification) and C (decarbonization despite low efficiency) (Übertragungsnetzbetreiber CC-BY-4.0, 2023). This would mean an enormous additional electricity demand of up to 90 TWh in 2045, when assuming a net electricity consumption of 2.4 MWh per year and vehicle (Figure 3). To put this into context: in 2023, the net energy consumption in Germany amounted to 467 TWh (BDEW, 2024a). Thus, 15 million EV is equivalent to 20% of today's energy demand.

Another challenge that arises with the ramp-up of EVs is that the load profiles of EVs add to the residual load, which runs counter to the power from RES (especially solar energy). The residual load can be defined as the total grid load that is independent of the volatile renewable energy carriers – the residual electricity demand, of which the majority is covered by conventional sources (Next Kraftwerke). Prospectively, fluctuations in electricity generation will become stronger and more frequent (Brunner et al., 2020), highlighting the demand for increased flexibility and renewable energy production at the same time. These fluctuations can be observed in

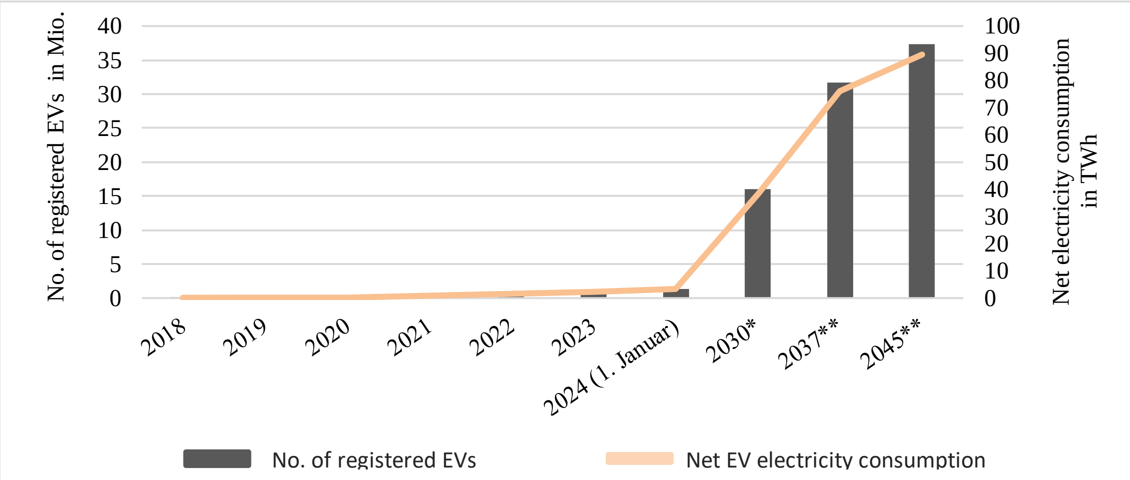


Figure 3: Registered EVs and net EV electricity consumption in Germany, own illustration based on Kraftfahrtbundesamt (2024), * Kemmler et al. (2021) ** Übertragungsnetzbetreiber CC-BY-4.0 (2023).

Note: The net EV electricity consumption is calculated assuming a net electricity consumption of 2.4 MWh per year and vehicle (Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit).

[3] Given the necessary reductions of greenhouse gas emissions to reach climate goals, ambitious targets in the transport sector were formulated in the coalition agreement (2022-2025). Yet, several projections certify that these goals will not be reached. For example, based on the current registrations and (political) incentives, the Expertenbeirat Klimaschutz in der Mobilität (2023) forecast a total of 10.5 million battery electric vehicles (BEVs) by 2030, while the Umweltbundesamt (UBA) (Harthan et al., 2023) forecasts a total of 8.2 million BEVs.

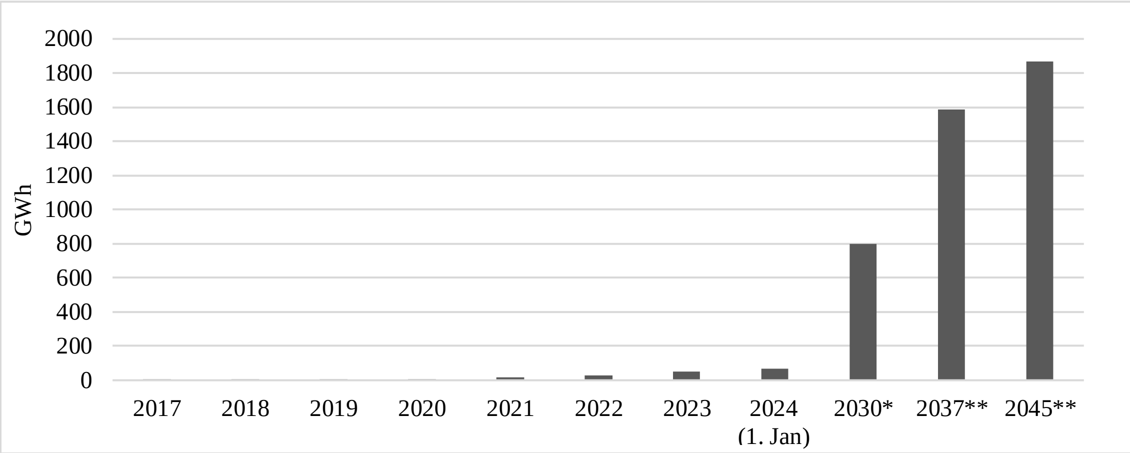


Figure 4: Potential storage capacity of EVs in GWh in Germany, own illustration based on Kraftfahrtbundesamt (2024), * Kemmler et al. (2021) ** Übertragungsnetzbetreiber CC-BY-4.0 (2023).

Note: The potential EV storage capacity is calculated assuming an average battery capacity of 50 kWh.

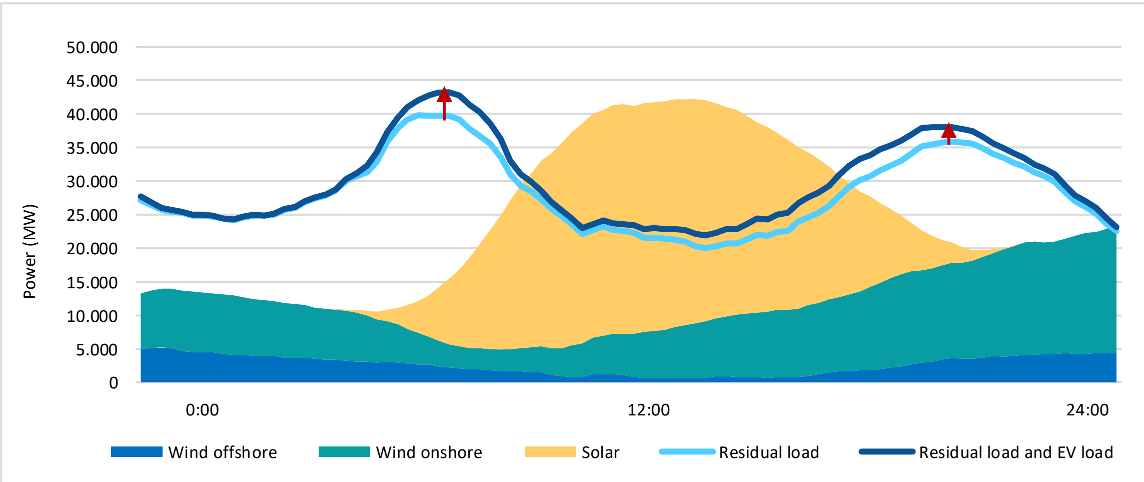


Figure 5: Net renewable electricity production, 10th of June, 2024 and residual load profiles in Germany, own illustration based on Nobis and Kuhnimhof (2018), Fraunhofer ISE (2024).

Note: Residual load and EV load is based on ∑ residual load + EV load of 15 Mio EVs in 2030.

Figure 5, resembled in the peak during midday. Moreover, Figure 5 depicts the residual load in contrast to the electricity production by wind (offshore and onshore) and photovoltaic systems PV. Moreover, it highlights how the residual load would change when adding the electricity demand of 15 million EVs. Ultimately, it can be observed that the more EVs add to the residual load, the more power generation is necessary to cover the additional demand.

This illustrates the need for new innovative ideas and strategies for successful system integration. One way to enable a smoother integration of large EV fleets into the energy system is to use the battery of the EV as a flexible prosumer. By doing so, additional short-term flexibility could be provided. Scholars point to the potential benefits of providing additional decentralized flexibility to the electricity system, particularly the integration of higher shares of RES and more efficient system operation (Blumberg et al., 2022; Kempton and Letendre, 1997; Kempton and Tomić, 2005). This potential becomes apparent when calculating the potential storage capacity of the EV fleet in Germany. Assuming a battery capacity of 50 kWh and a target fleet of 15 Mio EVs in 2030, this would sum up to 800 GWh storage capacity (Figure 4). To compare, the capacity of the pumped-storage power plants in Germany to date is ˜50 GWh (Statista, 2023). Thus, there is great potential in the EVs capacity, that could be raised and employed for system services.

2.2 Vehicle-to-grid fundamentals

Recent developments in EV sales and the ambitious political EV targets worldwide highlight the necessity for strategies and concepts to handle the concomitant increasing electricity demand. In this context, the concept of using the EV's battery as a power source has gained increasing recognition, which is reflected in an increase in the scientific literature (Baumgartner et al., 2023), by first market-ready bidirectional-enabled EVs[4], and by (political) strategies and frameworks to put this concept into practice (NOW, 2024). Using the EV's battery as a power source is suitable for three main reasons: First of all, vehicles spend approximately 97% of their lifetime unused in a private parking lot, of which 84% park at home and 7% at the workplace (Nobis and Kuhnimhof, 2018). Second, vehicles are spatially distributed, and third, they have a quick response time (Englberger et al., 2021). This makes EVs valuable assets in a decentralized and bottom-up energy system.

2.2.1 Defining vehicle-to-grid

In the literature, differing technical concepts exist, describing the integration of large amounts of EVs into the electricity system by intelligently steering the charging process. These charging concepts can be differentiated by their power flow direction, namely uni- or bidirectional power flows. From a technical perspective, these concepts are very different (Yilmaz and Krein, 2013). Unidirectional charging intelligently delays the charging process in response to a steering signal and can be defined "as an information system that optimizes the charging process toward one or multiple objectives besides reaching a desired SoC within a given time frame" (Huber et al., 2019, p. 2). In contrast, the bidirectional chargeable EV serves as a power source during idle times, with the ability to store and discharge electricity when needed or desired (Jansen et al., 2024; Sovacool et al., 2020; Sovacool et al., 2017; Sovacool and Hirsh, 2009). With this, EVs become decentralized power sources and open up a wide range of possibilities for diverse stakeholders in terms of applications, and business models. Different denominations exist. For example, V2G emphasizes the services that can be provided by the vehicle's battery to the power grid (Pearre and Ribberink, 2019; Sovacool et al., 2020), while vehicle-to-home (V2H) or vehicle-to-business (V2B) focus

[4] For example, the Kia EV9 from Hyundai Motors or the Nissan LEAF are already equipped with V2G technology, while other automotive companies announced the introduction of a series of V2G-enabled vehicles, such as BMW, Tesla or Mercedes-Benz (Schmidt et al., 2023).

on services that can be provided to a single building or entity, i.e., a commercial or non-commercial house or building (Pearre and Ribberink, 2019). Vehicle-to-x (V2X) or vehicle-grid-integration (VGI), thereby serve as umbrella terms. Importantly, these differentiations refer to the entity, that benefits from the dispatched energy from the vehicle, with numerous application opportunities arising therefrom (Section 2.2.3). However, these terms have in common that they require a certain level of control over the charging process (Will and Schuller, 2016). This can include the coordination of the charging process of EVs and the provision of ancillary services from the vehicle to the grid (Kempton and Letendre, 1997). In the following thesis, I will use the term V2G, referring to the bidirectional power flow between the EV and the electricity grid.

2.2.2 Actors in a vehicle-to-grid system

A V2G system encompasses a rich collection of actors on different scales. Noel et al. (2019b) categorize those actors into primary and secondary actors. Primary actors play a pertinent role, while secondary actors are located at the periphery of the system. Figure 6 depicts a V2G system, with some of its most important primary and secondary actors[5]. This figure depicts the V2G system in a very simplified way and does not make any claims of completeness or generalizability. Indeed, a V2G system is very complex by nature, involving different scales, actors, and sectors, depending on the application that is pursued.

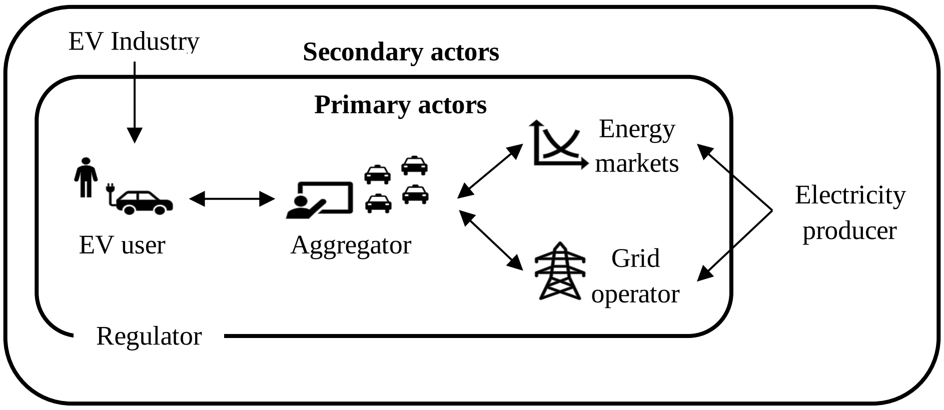


Figure 6: Primary and secondary actors in a V2G system, own illustration based on FfE (2022), Noel et al., (2019b), Sovacool et al., (2020).

There are four main actors in a V2G system, the EV owner, the aggregator, the grid operator, and the market operator. The EV owner is located at the beginning of the chain, having a simple, but decisive role. This actor decides upon the available power capacity and the duration of its availability (Noel et al., 2019b). The aggregator is the connecting link between the EV owner and

5 Secondary actors operate in the periphery of a V2G system, “creating the space to allow V2G to contribute to the grid, as well as potentially increase its value” (Noel et al., 2019b, p. 24). Secondary actors include most importantly, the government, the EV industry, and electricity producers (Noel et al., 2019b). Beyond secondary actors, a variety of further actors come into play depending on the application. Examples are mobility-as-a-service (MaaS) providers, public transit operators, and secondhand markets (see Sovacool et al., (2020) for an overview). However, due to their limited role, they are no further described.

the grid, being responsible for gathering "information about the market situation, schedule (…) [charge and discharge] (…) according to the bargained rules and expected revenues" (Geske and Schumann, 2018, p. 392). Importantly, this actor aggregates individual EVs to a fleet, enabling the participation in electricity markets and providing complex electricity grid services (Das et al., 2020; Noel et al., 2021; Noel et al., 2019b). This is essential, as especially ancillary services, require the participant to provide a minimum power capacity, which is challenging to achieve at the early up-take phase of V2G (Gschwendtner et al., 2021; Sovacool et al., 2020). In Germany, the minimum power capacity is 0.1 MWh for spot markets and 1 MWh for future markets (DIHK, 2020; EPEX SPOT, 2022). Thus, pooling EVs opens more economically efficient means to pursue a variety of V2G applications with differing value streams (Section 2.2.3) (Sovacool et al., 2020). The electricity grid operator is the third actor within this group, interacting directly with the aggregator. For both, TSO and distribution system operators (DSO), EVs are valuable assets to guarantee ancillary services. While the TSO is responsible for transmitting large-scale electricity production through extra high-voltage lines over large areas, the DSO is responsible for distributing the electricity from the transmission system to the end-user (Noel et al., 2019b). Both actors are responsible for a resilient and secured distribution and transmission system (Das et al., 2020). Finally, electricity markets provide a (communication) platform to either trade electricity or provide ancillary services (Heilmann and Friedl, 2021; Signer et al., 2024). To this end, market operators are responsible for carrying out the given market procedures from the various markets, wherein market participants can participate (Tsaousoglou et al., 2022).

2.2.3 Vehicle-to-grid applications

V2G holds many benefits and opens up a variety of applications to different stakeholders. Essentially, the commodity that is central to all these applications is the geographically distributed and temporal flexibility that can be provided by battery storage capacities of aggregated and available EVs. Importantly, with respect to V2G, its value, and cost-effectiveness lies primarily in providing power capacity, which would be provided otherwise by backup and other storage systems (Sovacool et al., 2017). In this sense, the EVs' flexibility as a service can be defined as a 'power adjustment maintained from a particular moment for a certain duration at a specific location' (Knezović et al., 2017).

Clearly, with V2G, different objectives can be pursued, the constraints being determined by the EV owner's mobility needs and preferences. Direct beneficiaries are grid operators, companies, governments, and EV owners, just to name the most important ones. The objectives are of a technical, economic, and environmental nature (Huber et al., 2019), while at the same time being interrelated. In this context, scholars discuss different V2G applications, culminating in a variety of customer services and products. One benefit that is inherent to all V2G applications, and that is also seen as one of the major benefits of V2G, is its capacity to provide flexibility to exploit the full electricity production from fluctuating and distributed RES. V2G can have a significant impact in leveling out fluctuations in renewable electricity generation (Kempton and Tomić, 2005; Sovacool et al., 2017), avoiding congestion (Heilmann and Friedl, 2021), and mitigating expensive redispatch measures (Englberger et al., 2021). With this, V2G can increase the share of intermittent RES into the electricity grid and, consequently, contribute to reducing carbon emissions of energy generation (Huber et al., 2019; Lund and Kempton, 2008). The following provides a synthesis of major V2G applications.

V2G applications can be subsumed into two overarching categories – market applications and ancillary services, including system, and grid applications – whereby a clear distinction is often not possible. Flexibility, which is provided to electricity markets, pursues the goal of optimizing electricity purchase costs or generating revenues by taking advantage of price spreads (Müller et al., 2023; Signer et al., 2024). One example of a V2G market application is spot market trading, which is solely performed to achieve monetary benefits (Heilmann and Friedl, 2021). The spot market includes the intraday and the day-ahead market. In both markets, EVs can profit by capitalizing on the short-lived price differentials – also called arbitrage trading (Englberger et al., 2021; Signer et al., 2024) This can be achieved by shifting the charging process to hours of low electricity prices, and feeding electricity back when electricity prices are high. By doing so, they can either generate economic benefits or mitigate charging costs (Brinkel et al., 2023; Englberger et al., 2021; Heilmann and Friedl, 2021). Yet, the magnitude of generating economic benefit is rather low as the costs may easily exceed the available revenue (Heilmann and Friedl, 2021). Moreover, recent studies also call attention to the associated risks that come along with avalanche effects (Signer et al., 2024).

In contrast, system and grid applications serve to stabilize the grid or to avoid critical network situations. §13 EnWG obligates system operators to carry out measures that stabilize the grid. Thus, making use of the EVs flexibility lies within the responsibility of the grid operator. Particularly, in the framework of system applications, these measures include frequency regulation, load control, grid operation, and grid balancing (Müller et al., 2023). For example, frequency regulation and load control contribute to stabilizing the grid by balancing supply and demand at all times (Heilmann and Friedl, 2021). With an increase in fluctuating RES and the phasing out of traditional electricity-generating power plants, the reliability and operation of the power system become non-trivial (Knezović et al., 2017). Specifically, in this context, the frequency containment reserve (FCR) is increasing. Yet, providing this service necessitates short reaction times and high-power rates within short time periods (Englberger et al., 2021), both of which can be provided by EVs with a V2G function (Martinenas et al., 2017). By participating in the frequency control market, V2G enables the balancing of frequency fluctuations through coordinated charging and discharging in the short-term (Heilmann and Friedl, 2021). In the long-term, infrastructure expansion could be reduced. Yet, at one point, a saturation effect will occur, and the remuneration for this service will decrease accordingly (Englberger et al., 2021; Gschwendtner et al., 2021).

Another future application which can be subsumed under ancillary services and which is particularly relevant for big commercial players is peak reduction. Although there is currently no market for peak shaving and no product available, this application could offer benefits to the grid operator, and big consumers. Specifically, peak shaving is interesting to big consumers due to economic reasons, while it is a promising tool for grid operators to reduce the maximum occurring demand and, as a result, enhance the reliability of the electricity system (Ostermann et al., 2022). Currently, many commercial players consume significant amounts of electricity. When consuming above 100 MWh, commercial players are not only charged for what they consume but also for their peak power demand (Englberger et al., 2021). Hereby, the highest power consumption in the billing period is the basis for the electricity grid surcharge. The more uniform the electricity consumption, the lower the electricity prices of the electricity grid surcharge (Next Kraftwerke, 2024). Subsequently, peak shaving is a major concern for large consumers as it can result in a significant reduction of grid tariffs (ACER, 2021; Brinkel et al., 2023). Consequently, using V2G as a means to reduce large power spikes, brings cost reduction to the affected commercial players, while at the same time contributing to reduced stress in the grid. Moreover, it has been suggested that V2G can bring further benefits by avoiding or decelerating grid reinforcement measures (Englberger et al., 2021; Kucevic et al., 2021). On the downside, this use case is very energy-intensive and bears the risk of excessive discharging of the battery and subsequently increased battery degradation (Englberger et al., 2021).

These applications offer the possibility to a multitude of actors to profit monetarily. Yet, economic profitability varies widely between studies (for a review see Englberger et al., 2021; Sovacool et al., 2017), its viability being dependent on different factors such as market conditions and structures, technological conditions, and business models (Englberger et al., 2021; Heilmann and Friedl, 2021). Moreover, it has been shown that by applying V2G's potential not only to a single-use case but to a multitude, synergies can be raised, utilization increased, and the share of idle times reduced (Englberger et al., 2021; Kern et al., 2022). On the other side, these applications enable multi-use cases and involve many stakeholders, which make these applications structurally very complex and, therefore, difficult to govern. Naturally, there is also a temporal dynamic to technological innovations such as V2G, resulting in shifting costs and benefits over time (Sovacool et al., 2020). While V2G use-cases, particularly grid-scale use-cases, will evolve in the long term as, for example, market structures or regulatory frameworks need to be developed and technological improvements need to be achieved, the implementation of V2H applications is more realistic in the near term, specifically the increase of self-consumption with V2H (Weiller and Neely, 2014). This use-case profits from falling PV and EV prices. Subsidies further foster this trend. Particularly, this is interesting for private and commercial buildings for several reasons: First of all, EVs increase the electricity demand tremendously, for a privately owned house, this often means a doubling of electricity costs (BMUB). Additionally, the typical EV charging pattern is contrary to PV production curves. While PV systems produce during the day, EVs typically charge in the morning and evening peak, which makes the imbalance of supply and demand evident (van der Kam and van Sark, 2015). Using the synergies of a PV system with a V2G-enabled EV can thus be beneficial in economic and environmental terms, as electricity costs and carbon emissions can be reduced (Weiller and Neely, 2014). The economic benefits are especially evident in countries with high electricity prices (Englberger et al., 2021), which is the case for Germany. Furthermore, as already noted above, some business models are prone to market saturation, while others will stay relevant even with high adoption rates.

2.3 Technical and regulatory challenges to vehicle-to-grid implementation

While V2G is ready for the market from a technical point of view and only requires further technological optimization, a number of challenges for V2G commercialization persist. These challenges span technical but mainly social and regulatory aspects. Particularly, the most important ones include battery degradation, costs, unsuitable market conditions, range anxiety, knowledge, regulations and standards (Signer et al., 2023).

2.3.1 Technical aspects

From a technical perspective, V2G has been validated, and first V2G-enabled vehicles can be purchased on European markets (Gschwendtner et al., 2021; Schmidt et al., 2023). Yet, two major overarching issues persist that are directly related to V2G technology. Firstly, even though the technology itself has reached a high level of maturity, issues persist, such as the impact of V2G on battery degradation. Furthermore, and related therewith, hardware costs are high and are seen as a major barrier to a successful market ramp-up. Second, issues arise in connection with integrating the EV into the electricity system. These market-related issues span topics such as standards and operationalization as well as questions on market frameworks and conditions. While the basic functionality is guaranteed and is not affected by either of these challenges, they are substantial to exploit the economic advantages (Noel et al., 2019c). What follows is a brief description of these challenges[6].

Battery technology and costs

- Battery degradation is an issue for V2G implementation, as it is associated with additional costs. Hereby, it is important to distinguish between calendar aging, caused by time, and cyclic aging, which occurs due to charging and discharging (Noel et al., 2019c). In the context of V2G, cyclic aging becomes important, as increased numbers of charging and discharging cycles used for providing V2G services put additional stress on the EV’s battery (Baumgartner et al., 2024). Additionally, battery type, temperature, driving, and charging behavior affect battery degradation (Gschwendtner et al., 2021). Yet, it can be assumed that battery degradation will decrease in relevance in the near future, particularly due to technological development (Signer et al., 2024).
- Implementation costs: Compared to EVs without V2G functionality, V2G technology requires more complex and costly bidirectional chargers and communication systems, which result in higher initial and operational costs (IRENA, 2023). Yet, technological advancements promise a decrease in these costs in the near future (Müller et al., 2023).

Market integration

- Standards and interoperability: There are three types of standards – EV charging component standards, EV grid integration standards, and safety standards (Das et al., 2020) – with the first and second being of primary interest for V2G implementation. Currently, a wide range of standards exist (Noel et al., 2019b), yet they do not enable the interconnection between the vehicle and the grid, and neither do they guarantee the interoperability of V2G equipment. To this end, unified communication, and interconnection standards are essential (Gschwendtner et al., 2021).

[6] The list below captures only some of the major challenges and has no claim to completeness.

- Market conditions: Next to these technology-related standards, further barriers exist that complicate the participation of EVs in electricity markets and the provision of ancillary services. One of the major barriers that are primarily relevant in the early adoption phase is that particularly anciallary services require a minimum bid size, which cannot be offered by single EVs. Therefore, large-scale aggregation is needed, which, on the downside, multiplies the costs of the verification process. Moreover, until now, it is difficult to distinguish between the electricity that is charged for providing a service and the electricity that is charged for mobility purposes. (Gschwendtner et al., 2021).

2.3.2 Regulatory aspects

Several regulatory frameworks[7] exist in Germany, regulating the electricity market and the integration of RES. Particularly, the Gesetz über die Elektrizitäts- und Gasversorgung (Energiewirtschaftsgesetz - EnWG) is the main framework regulating network operation and competition between energy producers. Thus, the EnWG affects the way in which bidirectional EV fleets are integrated into the electricity market[8], potentially impeding the economic implementation of V2G applications and business models. Until recently, no unified definition for energy storage technologies existed on a German and European level. Consequently, storage technologies that intermediately stored energy were considered end-consumer and thus burdened with double-taxation (Burger et al., 2022; Gschwendtner et al., 2021; Hildermeier et al., 2023; Schmidt et al., 2023; Signer et al., 2024). Energy storages were thus taxed twice, for drawing electricity (to store), and for feeding it back into the grid. In Germany, this regulation had particular economically impairing effects, as the electricity price consists of several components – the wholesale price, taxes, fees, and surcharges – where the share of taxes, fees, and surcharges sum up to over 60% of the household electricity price (BDEW, 2024b). Therefore, the electricity price is a decisive factor for the economic success of storage technologies and V2G in particular.

Recently, legal changes have come into force, first, on a European level, which were translated into German law. As a result, a definition of energy storage was included in §3 No. 15d, EnWG, recognizing the independent function of battery storages in the energy system[9] (BVES - Bundesverband Energiespeicher Systeme e. V., 2023). As a result, the previously existing impediment of double taxation was resolved, paving the way for electricity storages to benefit from tax and surcharge exemptions, in particular, grid surcharges and energy taxes. Yet, the term “energy storage” has so far only been consistently applied in a few regulations of energy law. For example, the Stromsteuergesetz (StromStG) provides a definition for stationary storage systems, which is

[7] The dynamics of the energy market, i.e., the introduction of new technologies, put constant pressure on legislation, leading to permanent modifications of the law. This is why the challenges described in this section picture the status quo until the first half of 2024. Revisions beyond July 2024 are not taken into account. Furthermore, the described challenges refer to German law.

[8] These challenges refer to the market integrations of EVs. The applications V2H and V2B are already feasible from a regulatory point of view (Schmidt et al., 2023).

[9] §3 No. 15d EnWG defines energy storage systems as follows: „an installation in an electricity network which postpones the final use of electrical energy to a point in time later than its generation or which converts electrical energy into a storable form of energy, stores such energy and subsequently converts it back into electrical energy or uses it as another energy carrier“. (Bundesministerium für Wirtschaft und Klimaschutz).

not consistent with the definition given in the EnWG, explicitly excluding EV batteries (§ 2, No. 9 Bundeministerium der Finanzen). Thus, some barriers still persist, impeding the integration of storage technologies, and bidirectional EVs in particular, in an economic way:

- Exemptions were recently introduced for stationary storage systems regarding electricity grid surcharges. According to § 14a EnWG, the law earmarks a reduction of these surcharges of 60%, when dimming the load of the charging process. Furthermore, new storage systems profit from complete exemptions from electricity grid surcharges (§ 118 Abs. 6 EnWG). This, however, only applies when the electricity is fed into the same grid as it was withdrawn. (Schmidt et al., 2023).
- Exemptions regarding electricity taxes are granted for renewable energy systems that feed electricity back into the electricity grid or use the electricity for self-consumption (§ 5 Abs. 4 StromStG). The temporary storing of electricity in EVs, however, is not recognized by this law. As a result, both the purchase and the supply of electricity by EVs are taxed (§ 9 Abs. 1a StromStG) – leading to double taxation. Additionally, exemptions are granted for electricity from renewable energy systems producing up to 2 MW, when this electricity is either used for self-consumption (§ 9 Abs. 1 Nr. 1 StromStG) or reused for electricity production (§ 9 Abs. 1 Nr. 2 StromStG). Electricity, that is withdrawn for feed-in, is taxed according to StromStG § 9 Abs. 1a. (Schmidt et al., 2023).

Although these barriers evidently hinder a successful market ramp-up, technological advancements are likely to dissolve some of the problems. Moreover, as political strategies have recognized the importance of decentralized flexibility potential as a pillar of the energy transition, current laws are under review and reconsidered, as evidenced by the recent amendments (i.e., §3 No. 15d, EnWG).

2.4 User perspective on vehicle-to-grid

Challenges arising from the implementation of V2G in society are inextricably linked to the EV user. An individual's behavior is complex and multifaceted, which is why its prediction and determination are subject to uncertainty. Consequently, the EV owner's behavior is a great unknown. Hence, there is uncertainty about the actual adoption of V2G, and about the amount of flexibility that users will provide (Jansen et al., 2024). While the significant loads of EVs have great potential to function as flexibility providers they can also contribute ultimately to lower household expenditures. Yet, adoption and the user's interaction with V2G are thereby dependent upon several factors, acting as conditions and fundamentally framing the utilization of the EV for V2G applications, thus directly influencing potential benefits on different levels.

One major conflict arises from the fact that EVs are either owned by private individuals, households, or companies, and their main function is to satisfy mobility needs unconditionally. In contrast, V2G directly involves the EV user, requiring a certain level of user compliance to be successfully implemented (Baumgartner et al., 2022; Bühler et al., 2014). For example, the amount of flexibility that is provided is dependent on the user's charging and mobility behavior but also on the decision to plug in the EV when parked (Bailey and Axsen, 2015). Thus, the plug-in rate has been identified as one of the most sensitive factors when it comes to social aspects affecting

V2G integration. Current research has shown that the plug-in rate of EVs (without V2G capability) lies around 30%, and plugging-in is only perceived as necessary when the SoC is low (Gschwendtner et al., 2021). Due to their primary role, these factors are the most frequently used parameters to integrate user characteristics into energy system modeling approaches (Baumgartner et al., 2023). Relatedly, V2G causes the user to weigh up different (opposing) goals, leading to increased planning and interfering with the user's lifestyle and mobility behavior (Sovacool et al., 2017). As a consequence, the user might feel restricted in his or her flexibility (Franke and Krems, 2013).

Another barrier that scholars identified as a major issue for users, and that is directly linked to the charging and discharging process, is battery degradation (see also Section 2.3.1). This barrier not only holds for EV charging per se but is valid for bidirectional charging as well (Geske and Schumann, 2018; Ghotge et al., 2022). Yet, pursuing a battery-friendly charging strategy can counteract increased battery aging through V2G (Lacey et al., 2017). This strategy would for example charge at lower SoC values and reduce the pressure on the battery by reducing the amount of charging cycles (Lacey et al., 2017). While positively affecting the battery's lifetime, such a strategy might in turn restrict the user's flexibility. In either case, the user is confronted with disadvantages associated with the use of V2G, having financial consequences in terms of monetary losses through increased battery aging or in terms of potentially restricted flexibility to accommodate mobility needs. For users, battery aging is thus mainly perceived as a financial issue and raises the question of product guarantee and compensation (Geske and Schumann, 2018).

Relatedly, range anxiety is another issue associated with EVs, but also relevant in the context of V2G. Range anxiety can be defined as "the psychological anxiety a consumer experiences in response to the limited range of an electric vehicle" (Noel et al., 2019c, p. 96). From the user perspective, range anxiety seems even more important than battery aging (Ghotge et al., 2022). Yet, this anxiety has been shown to be not purely rational, but much of this anxiety is perceived, especially in the frame of daily trips and mobility needs (Noel et al., 2019c). As statistics show, the maximum ranges of EVs, i.e., the maximum technical range of an EV, have significantly increased during the last few years. Yet these advancements seem to have contributed little to accommodate the user's perceived risks (Baumgartner et al., 2019). Also, when looking at the minimum range, i.e., the range that users have at their disposal at any time during the charging process to react to unplanned mobility needs (Ensslen et al., 2018), is still perceived as an important hindrance (Baumgartner et al., 2022; Baumgartner et al., 2019). Thus, in the framework of V2G, both, maximum and minimum range requirements are still important parameters.

The previous explanations illustrate that the usage of the technology itself entails several disadvantages and can furthermore conflict with individual mobility needs. Therefore, emphasizing as well as accommodating user preferences and needs are essential foundations to a successful market ramp-up.

Chapter 3

3 Theoretical and empirical background of user acceptability research on vehicle-to-grid

A growing body of literature is dedicated to assessing the roles and perspectives of individuals on V2G. EV owners are central to the adoption of V2G as they decide whether to provide flexibility and to which extent. Thus, the societal dimension of technology adoption often comes with great challenges and barriers, as behavior is not purely rational, but driven by values, norms, and preferences (Huckebrink and Bertsch, 2021). Therefore, understanding the human dimension of V2G is essential to its successful implementation. The following chapter provides an overview of the fundamentals of user acceptability of vehicle-to-grid. In particular, it seeks to

i. define and delineate the concept of acceptability in relation to the concept of acceptance,
ii. introduce the most important factors explaining technology acceptance,
iii. provide an overview of the empirical research landscape on V2G and smart charging,
iv. derive the most important factors for V2G acceptability.

Section 3.1 gives an overview of existing acceptability and acceptance concepts and definitions, delineating the acceptability concept from the acceptance concept, and providing a definition that is used and referred to throughout this thesis. This section is followed by illuminating the role of product and adopter characteristics (Section 3.2) and the complementary role of contextual factors (Section 3.3) in framing technology acceptability. This chapter closes with a literature review (Section 3.4) of empirical studies deriving the most important factors for V2G acceptability.

3.1 Acceptability concepts and definitions

The energy transition results in an encompassing system transformation, shifting from a formerly unidirectional, centralized energy system toward a bidirectional and decentralized energy system. With the introduction of new energy technologies on a micro level, households become part of the decentralized energy system, resulting in the shifting and creation of new roles, whereby individuals turn from mere consumers to prosumers. To successfully master this transformation, societal acceptance, alongside technological, economic, and regulatory challenges, has gained importance in the context of structural and technological changes (Fournis and Fortin, 2017; Upham et al., 2015). Different research streams exist, with their own definitions and conceptualizations of acceptance. Moesker et al. (2024) provide a literature overview, identifying three major research streams, each having its own understanding of the term:

- Social science studies on the acceptance of energy systems encompass a wide range of understandings and perspectives. These studies are primarily influenced by Wüstenhagen et al. (2007), who introduced the 'triangle of social acceptance'[10]. Acceptance is hereby understood as "the positive response to, or tolerance of a technical or socio-technical transition project by members of a given social unit" (Klok et al., 2023, p. 2). Yet, the understanding in this tradition changed from an outcome-oriented understanding, where acceptance is desired to mark the endpoint of this transition, to a process-oriented understanding, where the focus lies on the transition process while the outcome is open and undefined (Moesker et al., 2024).
- Ethics of technology, highlighting the ethical and normative concerns that come along with technological developments. The main objective is to evaluate the moral desirability and implementation of a specific technology. The concepts of "distributive justice" and "procedural justice" are two major concepts standing in the tradition of ethics of technology. (Moesker et al., 2024).
- Innovation studies are a particular research field of social sciences, with a special focus on technology acceptance and adoption. The diffusion of innovation (DOI) and the Technology Acceptance Model (TAM) are two prominent examples of this research stream. Hereby, acceptance refers to a behavioral response toward an acceptance object and reflects the actual purchase and use. (Moesker et al., 2024).

This latter research stream is thereby closely related to Wüstenhagen et al. (2007) market acceptance, which is based on Rogers (1983) "process of market adoption of an innovation" (Busse and Siebert, 2018; Fournis and Fortin, 2017, p. 3). Market acceptance is characterized by the actual adoption of the technology by the end-user and by investments (Fournis and Fortin, 2017; Wüstenhagen et al., 2007). Importantly, this type of acceptance takes place at the micro- or individual level (Moesker et al., 2024). This is also displayed in the work of Upham et al. (2015), who contextualize the three types of social acceptance based on three levels (general, local, household) and distinguish by the acceptance object (technology, infrastructure, and application). In their framework, the household level displays the acceptance of the end-user and refers to the concept of market acceptance. Additionally, the authors note that this type of acceptance not only becomes visible through technology adoption but also has a psychological, social, and political dimension to it. In aggregated form, individual decisions become a powerful means of social acceptance. (Upham et al., 2015).

Within the process of market adoption, a new technology is introduced to the market and diffuses over time via different communication channels among a variety of actors (Rogers, 1983). The widespread adoption of the technology stands at the end of a successful diffusion process. Yet, the adoption process undergoes different stages, in which the purpose of this technology, its benefits, and risks may be perceived differently by consumers and subsequently may affect the

[10] This concept consists of three dimensions: The socio-political acceptance refers to the most general level of social acceptance and includes key stakeholders and policy actors, shaping the political and regulatory frameworks for steering technological developments and their implementation. By contrast, community acceptance comes into play on the local level when a specific project is to be implemented by local stakeholders, and local authorities. Finally, market acceptance is characterized by the actual adoption of the technology by the end-user and by investments. (Fournis and Fortin, 2017; Wüstenhagen et al., 2007).

evaluation of this innovation. Therefore, following the tradition of innovation studies, it is suggested to distinguish between ‘intention’ and ‘behavior’ as two distinct target outcomes within the adoption process. While adoption intention refers to the state of mind before the actual behavior which is reflected in the actual purchase and use of the product, the intention can be seen as a prerequisite to adoption. (Arts et al., 2011).

This distinction is also reflected in the conceptual differentiation between (technology) ’acceptance’ and ’acceptability’. In innovation studies, acceptance refers to a behavioral response toward an acceptance object and reflects the actual purchase and use. In contrast, acceptability is an attitude toward an object, reflecting an individual’s readiness or willingness to adopt the technology and can, therefore, be regarded as a hypothetical situation with regard to the actual decision. (Emmerich et al., 2020; Huijts et al., 2012; Moesker et al., 2024). While it is desirable to measure acceptance in terms of actual behavior, this is an impossible undertaking with regard to not-yet market-ready technologies. This is why the core of this work is to understand the acceptability of V2G technology, using behavioral intention as an approximation of actual behavior. Indeed, previous studies focusing on technological innovations have considered acceptability as a proxy variable for acceptance (Bamberg and Möser, 2007; Ozaki, 2011; Ozaki and Sevastyanova, 2011; van Zomeren et al., 2008; Wolske et al., 2017), operationalized in terms of consumer readiness and the willingness to adopt an innovation (Arts et al., 2011; Rezvani et al., 2015; Schuitema et al., 2013). In this context, the TPB is a widely applied model to explain pro-environmental behavior and technology adoption. Yet, conceptually, the model stresses that the predictors of a pro-environmental behavior determine behavior only indirectly, via intention to perform that behavior. Attitudes, perceived behavioral control, and social norms thus predict behavior only indirectly via intention. A meta-analysis performed by Bamberg and Möser (2007) provided evidence that intention is indeed highly correlated with behavior and that intention functions as a mediator between all other psycho-social variables and pro-environmental behavior. Importantly, none of the psycho-social variables directly predicted pro-environmental behavior (Bamberg and Möser, 2007). Therefore, it can be concluded that intention is a suitable approximation of behavior.

In this work, the definition of technology acceptability by Huijts et al. (2012) is applied, who define “acceptance as behavior towards energy technologies and acceptability as an attitude (an evaluative judgment) towards new technologies and attitude towards possible behaviors in response to the technology” (see also Schade and Schlag, 2003).

3.2 The role of product and user characteristics for technology acceptability

Studies concerned with energy technologies oftentimes focus on the technical or economic dimension of the technology, assuming a rational user and a high level of technology-smartness (Libertson, 2022a). Yet, scholars increasingly come to the conclusion that technologies must be understood in their societal context to achieve widespread acceptance (Sovacool et al., 2017). This is particularly true for energy technologies, which often do not only satisfy a specific user need but have far-reaching effects on the energy system, society, and the environment as well.

EVs can be classified into this category. Due to their anticipated role in reducing greenhouse gas emissions in the transport sector, EVs symbolize a more environmentally friendly alternative to cars with combustion engines. In this context, EVs have been characterized as an eco-innovation, requiring a high level of consumer involvement during the purchase process. An eco-innovation can be defined as “a new product that avoids or reduces environmental harm” (Jansson et al., 2011, p. 51) (see also Beise and Rennings, 2005; Rezvani et al., 2018), while “high-involvement” is associated with a costly product (such as a house, or EV), where the purchase necessitates a careful evaluation of the product attributes and is therefore not repetitious and carried out on a daily basis (Rezvani et al., 2018). Hence, the evaluation of such technologies is a goal-directed process (Arts et al., 2011).

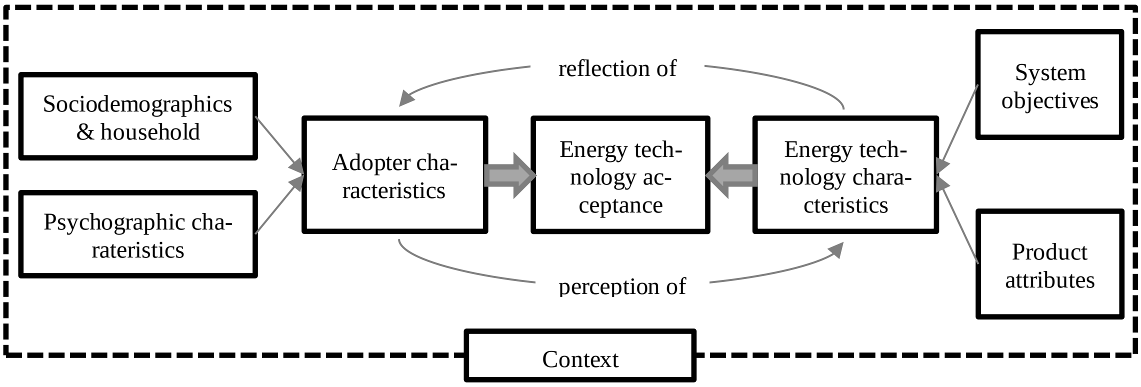


Figure 7: Technology and user characteristics as predictors of energy technology acceptance, own illustration.

Innovation adoption literature posits adopter and product characteristics to be the main factors explaining the adoption of innovations. While adopter characteristics can be described in terms of sociodemographic and psychographic characteristics, innovation characteristics are described in terms of their attributes[11] (Arts et al., 2011). In the specific case of energy technologies that enable individuals and households to become part of the energy system, not only the perceived benefits and costs for the individual may be relevant factors explaining adoption, but also the benefits arising on a system level may be relevant determinants of the technology. Yet, these factors solely explain adoption based on individual perceptions, and values. However, the surrounding context frames and reflects upon the individual’s decisions as well, i.e., how technologies are perceived, and what values are stimulated (Bradley et al., 2024) (see Section 3.3). Thus, technology acceptability depends upon a variety of factors. Following Figure 7, this includes on the product side the objectives on a system level that can be pursued with the technology, and the user’s perception of its attributes. On the adopter side, these factors refer to the user’s sociodemographic and psychographic characteristics, including values, attitudes, and preferences. Last but not least, contextual factors essentially affect acceptability as well, which, in contrast to personal

11 With regard to the perception of product attributes, it is suggested that individuals may evaluate them differently depending on how distant the future behavior is. This implies that behaviors, such as the adoption intention of an innovative product, are guided by more abstract and general considerations as behaviors, that will happen in the near future. Particularly, perceived costs may thus outweigh the perceived benefits, when the behavior is more distant. (Arts et al., 2011).

variables, is outward-looking, focusing on the understanding and interaction of individuals with their various environments (Section 3.3).

Different research streams apply different perspectives to study the acceptance of energy technologies. These research streams have been synthesized by Upham et al. (2015), identifying five major research domains, whereby four of them also apply to empirical studies on EVs and V2G:

- Economics: Studies from this research domain stand in the tradition of choice experiments, explaining technology acceptance based on trade-offs between different product attributes. In this tradition, the individual makes decisions based on economic rationality. Behavioral economics extends the economic rationale by accounting for psychological factors as well.
- Sociology and human geography: This research stream studies technology acceptance in terms of equity issues, habits, sociodemographics, and lifestyles, or takes a policy and institutions perspective. Sociology thus focuses on social factors, determining the interaction with technologies or the processes, by which problems are socially constructed.
- Social psychology: This research tradition aims to explain technology acceptance based on psychological characteristics. Hereby, social psychology applies a wide range of models, i.e., TPB, norm activation model, and factors, such as risk perception, environmental norms, values, and behavior, place identity and attachment, and social representations.
- Frameworks and methods-driven work: These studies do not take an explicit theoretical stance, but are methods-driven and avoid a mono-theoretical subscription.

These research streams take different perspectives, by which technology acceptance is studied. While studies in the tradition of economics focus on the preferences and perceptions of the technology's attributes, sociology puts forward adopter characteristics. Social psychology can be placed in between these two research traditions, focusing on beliefs about technology on the one hand and adopter characteristics on the other. Yet, product attributes mirror the outcomes and use of an energy technology, thus indirectly reflecting upon an individual's values and norms. Thus, many motivational factors go hand in hand with the perceived benefits and associated risks of a technology (Schmalfuß et al., 2015).

Research suggests that attitudes and perceptions may change over time, while values are assumed to be relatively stable (Steg and Groot, 2012). These values influence which information people detect, affecting attitudes, beliefs, and preferences, and finally, the willingness to engage in a specific action. Thus, specific objectives or product attributes can trigger specific values. This suggests that values are independent of the technology, even though the preferences for specific technology attributes are often congruent with the value, providing a stable and general basis for attitudes and preferences. (Steg et al., 2014a; Steg et al., 2014b).

Building on the previous argument, these motivations can be conflated into three major goals, encompassing adopter characteristics and perceptions of product attributes and the evaluations of the technology's objectives. According to goal-framing theory, acceptance is motivated by different goals, acting as guiding principles and influencing individuals' decisions and behaviors (Huijts et al., 2012; Lindenberg and Steg, 2007). Goals can be defined as "a mental representation of a desired future state with both cognitive and motivational components" (Lindberg and Steg, 2013, p. 95). This theory posits three goals, *hedonic*, *gain*, and *normative* goals (Lindenberg and

Steg, 2007). Translated to the evaluation of an energy technology, *hedonic* goals stand for emotions, i.e., positive or negative feelings, which are associated with the technology, *gain* goals refer to a rational evaluation of the technology, based on costs, risks, and benefits, and finally, *normative* goals, focusing on moral evaluations, emphasizing the possible environmental and societal consequences, that could result from the technology (Huijts et al., 2012, p. 526). These goals are said to be relatively stable over time (Steg, 2016). Yet, these goals often stand in conflict with each other, reflecting different underlying rationales. While gain goals focus on monetary and economic aspects in the short term, normative goals stand for collective interests in the long-term, leading to a "social dilemma" (Steg et al., 2014a).

Furthermore, known theories, such as the theory of planned behavior (TPB) or the value-belief-norm theory (VBN), which are mainly applied in the research streams (behavioral) economics and social psychology, coincide with one of these goals, explaining technology adoption based on a particular rationale (Huijts et al., 2012). Generally, pro-environmental behavior is said to be comprised of a mixture of these rationales, self-interest, and concern for other people, species, and the ecosystem (Bamberg and Möser, 2007). Depending on which rationale is emphasized, either the TPB or the VBN are applied. For example, the TPB has been widely used to understand decision-making processes within an environmental context (Azjen, 1991), emphasizing rational choices. It has been introduced as an expectancy-value model of attitude-behavior relationships (Conner and Armitage, 1998). The model explains behavior indirectly through intention, which is mainly determined by attitudes, perceived behavioral control, and social norms and was adapted and applied to various contexts, for example, to explain EV adoption (Haustein et al., 2021; Lee et al., 2023), V2G acceptability (van Heuveln et al., 2021) or engagement in environmental activism (Fielding et al., 2008a). While this theory remains grounded in rational choices and self-interest, others argue that sustainable behavior is not purely rational but influenced by intrinsic motivations such as values and norms, which is given more weight in the VBN theory developed by Stern et al. (1999). This theoretical strand argues that acting pro-environmentally is primarily rooted in altruism, directed at humans and other species (Dietz, 2015; Jackson, 2005; Wolske et al., 2017). It posits a causal chain where relatively stable and general factors, such as values affect behavior-specific variables such as problem awareness, outcome efficacy, and personal norm (van der Werff and Steg, 2016; Wolske et al., 2017). Pro-environmental behavior is thus rooted in a moral obligation (van der Werff and Steg, 2016).

3.3 The role of social and contextual factors framing technology acceptability

Despite the important role of individual factors affecting technology acceptability, individuals do not act in a vacuum, but their decisions and behaviors are influenced by the context in which a person resides and acts (Barth et al., 2016; Bradley et al., 2024). Hence, scholars have argued that factors on a personal level and the social context are equally relevant in explaining environmental behavior, and can be seen as complementary and interdependent. While personal factors focus on the self, social context factors are outward-looking, considering the context within the decision-making process. (Bradley et al., 2024). These contexts and social affiliations frame perceptions, attitudes, and behaviors (Barth et al., 2016). Though these factors are often correlated, they are yet distinctive. Social context factors have been considered in previous studies on technology acceptance or environmental behavior, but their understandings of the "social context" differ (Bradley et al., 2024). Based on the literature, Bradley et al. (2024) identify five different understandings of the term "social context":

(1) the geographical, climatic, or cultural contexts (e.g., Gifford and Nilsson, 2014; Kollmuss and Agyeman, 2002)
(2) the sociodemographic, and socioeconomic characteristics of the geographic surrounding (e.g., Axsen et al., 2016; Chadwick et al., 2022)
(3) the structural and institutional characteristics of the geographic surroundings (e.g., Kramer and Petzoldt, 2022; Perlaviciute and Steg, 2014; Steg et al., 2015)
(4) individual's membership in a social entity or group, shaping social identities (e.g., Barth et al., 2016; Fielding and Hornsey, 2016; Fritsche et al., 2018)
(5) the characteristics of social situations and momentary circumstances triggering behavior (e.g., Houser et al., 2022).

What these understandings have in common is that they either facilitate or hinder a specific behavior. Yet, these understandings are distinctive in the way, in which they emphasize either the "social" or the "context". While (3) explicitly stresses the "context" by highlighting the geographical conditions and realities, (4) and (5) put more emphasis on the "social" aspects, referring to groups to which individuals feel a sense of belonging and thereby influence an individual's behavior. (1) and (2) can be filed in between, emphasizing peoples' affiliations while at the same time factoring in given structures and geographies. Specifically in the context of crises, such as climate change, each understanding has its own relevance. Hereby, it can be argued, that considering the social context is essential as it facilitates or impedes individual pro-environmental behavior, be it in terms of infrastructure, policies, or social norms (Bamberg et al., 2015).

When applying an understanding in terms of geographical, structural, or socioeconomic features, the social context can be defined as the "availability of products [or structures] that hinder or promote a specific behavior or acceptance" (Kramer and Petzoldt, 2022, p. 2). Thus, the context defines the costs and benefits of a behavior and makes some behaviors even impossible (Steg et al., 2015). Additionally, geographical contexts can also influence behavior not only via infrastructure but also through targeted policies to pursue a specific goal. For example, taxes and subsidies have a steering effect that can promote a specific technology or make its use less attractive. This way, the national context can influence the decision-making of individuals more directly. Geographies can also act in a more subtle way. Following a specific national target, such as climate neutrality, may also create different cultural norms and attitudes (Chard et al., 2024). Consequently, the existence or non-existence of structures, such as infrastructure and institutions or geographies and culture can be the reason for the adoption or rejection of a specific technology (Chadwick et al., 2022).

Yet, applying the understanding of social identities is distinctive, in that it functions on a more abstract level. Herby, individuals oftentimes experience themselves as part of a group, framing one's identity. Social identity theory posits that an identity comprises personal and social identities. The social identity thereby develops through the process of categorization, by accentuating similarities with the group and dissimilarities with the outgroup. As a result, the norms, attitudes, and beliefs of the salient social group become internalized, leading individuals to act in accordance with them (Barth et al., 2016; Fielding and Hornsey, 2016). Group norms are thus assumed to affect individual decision-making via the internalization of what relevant social groups stand for in terms of their goals and values. Norms, in the tradition of social identity, can be characterized as injunctive and descriptive norms. Injunctive norms influence behavior through the belief in the existence of certain group expectations, while descriptive norms refer to the belief in what distinguishes the behavior of other group members (Barth et al., 2016). It can thus be argued that the norms of a specific group will influence the behavior rather than the expectations of others that do not belong to the same group – the norms of the group will act as a guide for appropriate behavior (Barth et al., 2021; Fielding et al., 2008b; Fielding and Hornsey, 2016).

In this context, scholars have shown that pro-environmental norms of a group explain pro-environmental behavior on a personal level, even when considering social norms (Fritsche and Masson, 2021). Beyond that, pro-environmental behavior may also be fostered simply because individuals care about being involved with a relevant social group (Sloot et al., 2019). Thus, the norms of the group decisively determine individuals' pro-environmental actions (Barth et al., 2021; Fielding and Hornsey, 2016). Moreover, group membership might not only influence individual behavior but enable collective action and bring about social change as well (Barth et al., 2016). This is specifically relevant, as many existing crises result from collective behavior (Barth et al., 2021). Research has thus highlighted the importance of social identities for sustainable energy behavior (Fielding and Hornsey, 2016; Fritsche et al., 2018), emphasizing the role of groups and identities in fostering a sustainable energy transition in a more indirect way by creating involvement in the system transformation. A prominent example of such a group is an energy initiative, playing a significant and influencing role in decentralizing and transforming the energy system over the past decades. Their success lies mainly in their bottom-up approach, their regional rootedness, allowing individuals to play an active role in this transition, creating awareness and acceptance towards energy technologies, and motivating individual and collective sustainable energy behavior (Bauwens et al., 2016; Devine-Wright, 2008; Koirala et al., 2018). These initiatives are an example of how collective efforts can drive system transformation.

Importantly, in this work, the author differentiates between "social" and "contextual" factors. While social factors refer to the understanding of the internalization of social identities, contextual factors include factors, that shape individuals' physical environment, such as countries, and institutions or infrastructure.

3.4 Review of empirical studies on vehicle-to-grid

Having provided an overview of acceptability concepts and technology acceptability in particular, as well as factors explaining technology acceptability, this section presents empirical studies that were conducted on V2G and smart charging. The focus of the literature research is on V2G *and* smart charging, as the terms are often used synonymously in empirical studies. It is often unclear, which form of controlled charging is referred to. Furthermore, both forms imply an active role of the EV user, though the applicability differs from a system perspective (Section 2.2.3). The literature is systematically narrowed down to i. empirical studies, which ii. specifically focus on V2G acceptability, iii. focus on the individual level, iv. were published between 2015-2024[12], and v. in peer-reviewed journals. In total 22 studies meet the above criteria. Table 1 presents an overview of the included studies. Importantly, the studies are presented according to the following categories:

- Type of charging: specifying the charging concept in focus.
- Country/-ies: specifying the country/-ies, in which the study was conducted.
- Target group/-s: specifying the group of people that were surveyed or interviewed.
- Operationalization of acceptability: specifying how acceptability was framed and measured.
- Methodology: specifying, which data collection methods were used.

It can be observed from Table 1, that most studies have their theoretical origin in (behavioral) economics, focusing on preferences for specific product attributes. Some studies come from social psychology, applying a specific theoretical model to explain V2G acceptability and only one study can be categorized as a sociological study. Finally, three studies fall into the category framework and method-driven, meaning they are not explicitly theory-driven. Interestingly, some studies use the more general term “smart charging”, while only a few studies directly focus on the V2G[13] use case. Moreover, the majority of studies are conducted in a single Western country’s context, including European countries, the United States, and Canada, and only the minority are conducted in Asian or developing countries. Moreover, the studies focus on a single group of people, mainly early adopters or the general population. Consequently, there are few comparative analyses. Importantly, V2G acceptability is operationalized in different ways, which can be clustered into four categories: (i) The most common approach is to operationalize V2G acceptability in terms of user’s WTP for different tariff and service attributes. (ii) Conversely, several studies operationalize V2G acceptability in terms of users’ WTA. (iii) Closely related, some studies approach V2G acceptability by assessing preferences for V2G services and tariffs. (iv) Finally, some studies operationalize V2G acceptability in terms of interest or intention to use V2G. Interestingly, there is a bandwidth of data collection methods. Although most studies collected their data using surveys, some studies applied qualitative methods such as focus groups and interviews, and some applied a mixed methods approach.

[12] The literature review was conducted in August 2024. Therefore, only literature that was published until August 2024 is included in this section.

[13] For reasons of simplification and consistency, henceforth, the term “V2G” will be used solely. This also includes studies that use other terms, such as “smart charging”, or “utility-controlled charging”.

Table 1: Empirical studies on vehicle-to-grid between 2015-2024.

Authors	Research stream	Type of charging	Country/-ies	Target group/-s	Operationalization of acceptability	Methodology
Axsen et al., 2017	(behavioral) Economics	Utility controlled charging (UCC)	CAN	Mainstream vehicle buyers	-	Interviews
Bailey and Axsen, 2015	(behavioral) Economics	Utility controlled charging (UCC)	CAN	Early mainstream PEV buyers	Enrollment in a UCC program and WTP for product features	Mixed-mode survey
Daziano, 2022	(behavioral) Economics	Coordinated EV charging	USA	EV owners, lessees	WTP for a service	Online survey
Dean and Kockelman, 2024	(behavioral) Economics	Supplier-managed charging	USA	General population	Preference for a charging program and WTP	Online survey
Delmonte et al., 2020	(behavioral) Economics	Smart charging	UK	Actual *vs.* potential PEV users	Participants' willingness to participate	Interviews
Geske and Schumann, 2018018	(behavioral) Economics	V2G	DE	Vehicle users	Willingness to participate	online survey
Helferich et al., 2024	(behavioral) Economics	Smart charging	DE	BEV users	Smart charging tariffs	online survey
Henriksen et al., 2021	Sociology & human geography	Smart charging	NO	Pilot participants		Interviews
Huang et al., 2021	(behavioral) Economics	V2G	NL	EV users	V2G contract	Online survey
Huber et al., 2019	Frameworks & methods-driven	Smart charging	-	Experts	-	Expert survey
Kester et al., 2019	Frameworks & methods-driven	V2G	ICLD, SWE, DK FIN, NO	General population	-	Focus groups
Khezri et al., 2024	Frameworks & methods-driven	V2G and V2H	SWE	EV users	Interest in V2G / V2H	Online survey
Kubli, 2022	(behavioral) Economics	Smart charging	CH	Potential EV users	Willingness to accept (WTA)	Online survey
Kubli et al., 2018	(behavioral) Economics	Flexibility co-creation	CH	Early adopters	Power contract	Online survey
Lagomarsino et al., 2022	(behavioral) Economics	Smart charging	-	Early adopters	Interest in charging choice scenarios	Online survey

Table 1 (continued): Empirical studies on vehicle-to-grid between 2015-2024.

Authors	Research stream	Type of charging	Country/-ies	Target group/-s	Operationalization of acceptability	Methodology

Lee et al., 2020	(behavioral) Economics	V2G	KR	General population	Monthly Willingness to accept (WTA) for a V2G service	Online survey
Libertson, 2022b	(behavioral) Economics	Smart charging	SWE	Pilot participants, BEV and PHEV users	Willingness to participate, duration of smart charging session	Mixed-methods
Mehdizadeh et al., 2024	Social psychology	V2G	NO	EV and non-EV users	Intention to use V2G (Theory of planned behavior)	Online survey
Schmalfuß et al., 2015	Social psychology	Smart charging	DE	Pilot participants	Acceptability, Willingness to use	Mixed-methods
van Heuveln et al., 2021	Social psychology	V2G	NL	EV users	Consumer acceptance	Interviews
Will and Schuller, 2016	Social psychology	Smart charging	DE	Early adopters	Usefulness of and satisfaction with smart charging	Online survey
Wong et al., 2023	(behavioral) Economics	Smart charging	USA	EV users *vs*. EV interested buyers *vs*. general population	Willingness to sign up for a smart charging program	Online survey

3.4.1 Vehicle-to-grid acceptability factors

The following provides a detailed analysis of the literature review, including 22 empirical studies on V2G and smart charging, synthesizing the most important factors explaining V2G acceptability. These factors are a conglomerate of product and adopter characteristics as shown in Figure 7 in section 3.2 – starting with V2G objectives, followed by product attributes, adopter characteristics, and social context factors.

3.4.1.1 Objectives from a user perspective

Objectives ultimately influence an individual's behavior. This is particularly relevant in the context of energy technology adoption as a prerequisite for a successful energy transformation. In the context of V2G, different objectives exist that can potentially shape a user's decision to adopt V2G and incentivize them to provide higher levels of flexibility to the grid. These objectives partially overlap with the applications described in Section 2.2.3. The acceptance of V2G thus depends, among others, on the objective that can be pursued by adopting and using the technology (Geske and Schumann, 2018; Huber et al., 2019).

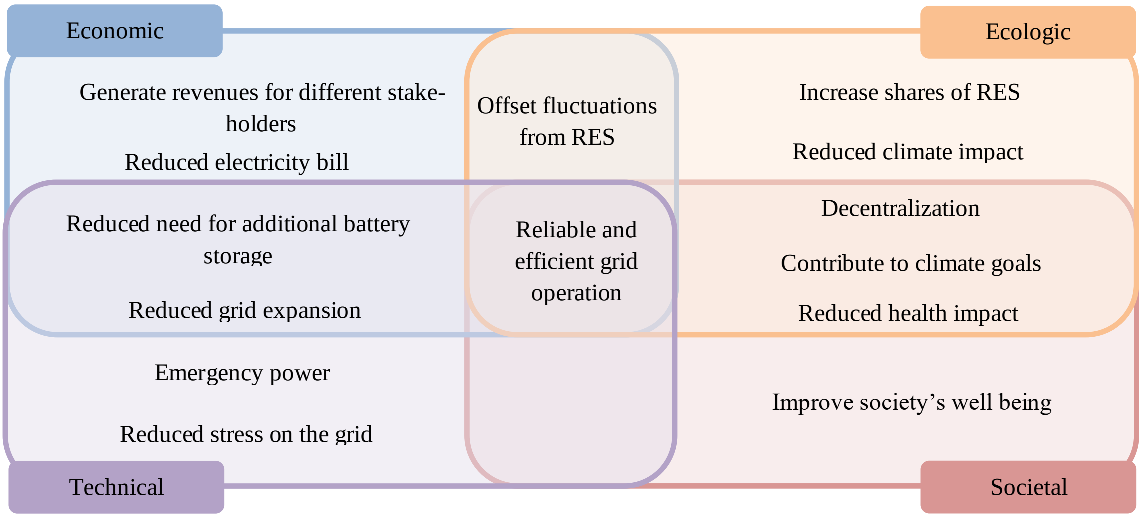


Figure 8: V2G objectives from a user perspective, own illustration.

Figure 8 summarizes the most important objectives from a user perspective. The categorization is based on Huber et al. (2019), who cluster smart charging objectives into three categories: technical, economic, and socio-environmental. The categorization at hand, however, differentiates between social and environmental as well, considering social and environmental factors as independent dimensions. Importantly, these categories are not distinctive but fluid and intersect. The following analyses of the various approaches of this review follow this categorization. Obviously, most objectives center around economic and ecological objectives. While economic objectives are mainly based on an individual level and include savings in terms of reduced electricity costs (e.g., Dean and Kockelman, 2024; Geske and Schumann, 2018; Helferich et al., 2024), ecological objectives are based on a system level and capture overarching societal objectives, such as increasing the share of RES (e.g., Dean and Kockelman, 2024; Lagomarsino et al., 2022; Will and

Schuller, 2016) and contributing to the decentralization of the energy system in order to contribute to the energy transition and subsequently climate goals (Geske and Schumann, 2018). These goals are particularly intuitive and easy to understand for potential users, which might be the reason why these objectives have been shown to be relevant to users' acceptability toward V2G (Huber et al., 2019; Will and Schuller, 2016). Yet, also technical objectives are relevant in framing a user's decision to adopt and use V2G technology, though they are less intuitive and require some basic knowledge of the electricity system (Huber et al., 2019). Just like ecological objectives, technological objectives are based on a broader system-level, targeting grid reliability (e.g., Libertson, 2022b; Will and Schuller, 2016), reduced stress on the grid (e.g., Lagomarsino et al., 2022), or avoiding grid expansion (e.g., Helferich et al., 2024), and investment in additional battery storages (e.g., Dean and Kockelman, 2024; Geske and Schumann, 2018). These objectives cannot directly be influenced by a single user providing flexibility, but they can ultimately support these objectives in aggregation. Finally, societal objectives are less prominently represented in literature, as they are more difficult to grasp. However, these objectives are implicitly reflected in the ecological, economic, and technical objectives, such as reducing CO_2 emissions or contributing to grid stability (van Heuveln et al., 2021).

3.4.1.2 Product attributes

Evaluating a new product, that is not widely established on the market is a challenging task for potential users. Therefore, using product attributes to make the product and its characteristics more tangible, is a common approach to capture the user's perceptions and evaluation of the product as a whole. A widely used framework to cluster attributes of sustainable innovations is proposed by Axsen and Kurani (2012), defining three categories based on which potential adopters form their opinion - instrumental, symbolic, and environmental attributes (Axsen and Kurani, 2012; Noppers et al., 2014). Instrumental attributes reflect the functional outcomes of a product, while environmental attributes emphasize the effects on the environment. Symbolic attributes refer to the symbolic value (e.g., social status) that the product may bring to the owner. While functional attributes may inhibit the adoption, environmental and symbolic values may rather promote the adoption of sustainable innovations (Noppers et al., 2014). In this context, previous studies have provided evidence that people with strong environmental values are more likely to adopt sustainable products (e.g., van der Werff et al., 2013).

Table 2: V2G product attributes.

Attribute category	Example attributes
Functional (technical)	Guaranteed battery level, control over the charging process, average daily plug-in time, charging mode, discharge cycles, charging duration, user interface, handling
Functional (economic)	Charging/service price, pricing scheme, remuneration, penalty, contract duration
Environmental	Power mix, use RES for charging, emission reduction
Symbolic	Brand of the charging service

With respect to V2G, these categories are also evident in the literature at hand applying choice experiments to study the user's perception and evaluation of a V2G charging service. Table 2 provides a synthesis of the product attributes in empirical studies on V2G. Strikingly, the majority of studies focus on functional attributes. Yet, these attributes are either technical or economic by nature. Economic attributes include the charging or service price (Bailey and Axsen, 2015; Daziano, 2022; Kubli, 2022; Kubli et al., 2018), the pricing scheme (Helferich et al., 2024) or the remuneration (Daziano, 2022; Helferich et al., 2024; Huang et al., 2021; Kester et al., 2019; Lagomarsino et al., 2022; Wong et al., 2023) that is paid to the EV owner, compensating for providing flexibility. Finally, there are two studies including the contract duration (Huang et al., 2021; Kubli et al., 2018) as an additional attribute. Most studies contain technical attributes, although, interestingly, the amount does not signify variety. Most technical attributes focus on the perceived technical barriers that are inherently connected to V2G. Hence, there are few studies including the guaranteed battery level or SoC (Bailey and Axsen, 2015; Lagomarsino et al., 2022; Wong et al., 2023) into their experiment, while the majority of studies consider attributes referring to the charging process. For example, this is operationalized in terms of hours, the user or the utility has control over the charging process (Daziano, 2022; Khezri et al., 2024), the average daily plug-in time (Huang et al., 2021), the charging mode (Helferich et al., 2024), or discharge cycles (Huang et al., 2021), and the charging duration (Huang et al., 2021; Lagomarsino et al., 2022). In contrast, environmental attributes are operationalized in terms of the power mix (Kubli et al., 2018), or refer to emission reduction (Daziano, 2022), and increasing the share of RES (Bailey and Axsen, 2015; Lagomarsino et al., 2022). Symbolic attributes play only a role in terms of the brand of the charging service (Daziano, 2022), and in what regard the flexibility is used (Kubli et al., 2018).

3.4.1.3 Sociodemographic and psychological factors

Adopter characteristics can be studied in terms of sociodemographic and psychographic factors. Psychographic characteristics thereby include attitudes, perceptions, and values. These factors condition and drive technology acceptability in a positive or negative way (Busse and Siebert, 2018). While sociodemographic and household characteristics are suitable to describe individuals from a social or economic viewpoint[14], psychographic characteristics reveal their attitudes, values, and perceptions. Empirical studies on V2G make use of both factor types, yet, primarily psychographic factors are used to explain V2G acceptability. Perceptions and attitudes are directed toward the technology at hand and its technical, environmental, economic, and social implications, such as the state of charge, its implications for reducing CO_2 emission, its trustworthiness, and the perceived control over the charging process. While attitudes and perceptions may change over time, values are said to be relatively stable (Steg and Groot, 2012). Thus, values are also independent from the technology, yet the objectives of the technology are reflected herein, and can trigger specific values. Thus, values and beliefs play an important role as well when determining an individual's acceptance of the technology.

Empirical studies on V2G assess both, sociodemographic and household characteristics, and psychographic characteristics. While most studies collect data on e.g., age, gender, and household characteristics, the landscape of psychographic characteristics is more diverse. Noticeably, while

[14] Studies in consumer research have shown that sociodemographic characteristics play a subordinate role compared to psychographic characteristics in predicting sustainable behavior (Jansson et al., 2011).

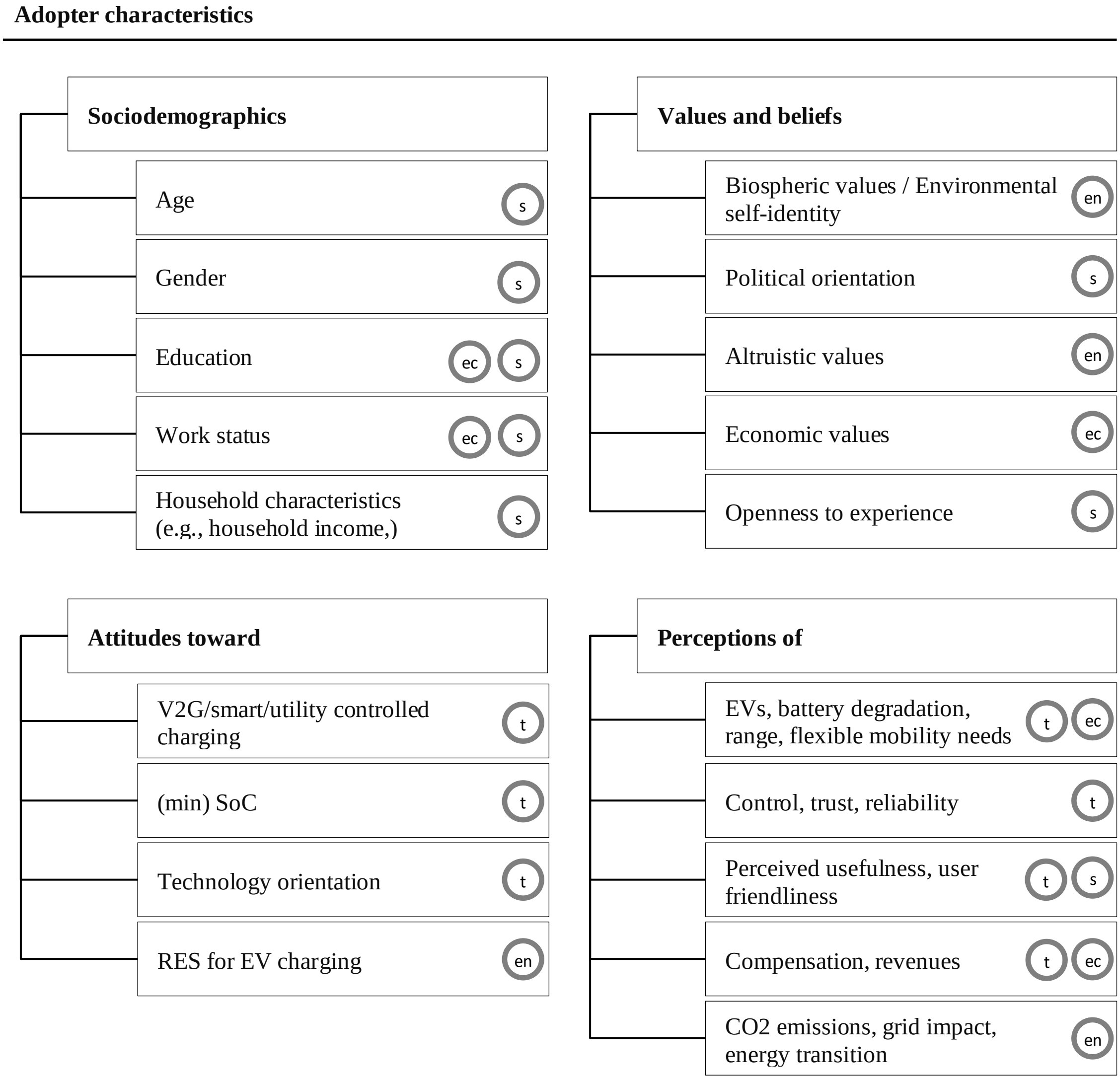


Figure 9: Psychographic factors affecting the V2G acceptability, own illustration.

Note: t= technical, ec= economic, en= environment, s= social.

the majority of studies focus on perceptions, followed by attitudes, only few studies assess values and beliefs. Figure 9 provides a synthesis of the most important sociodemographic, and psychographic factors that are used to explain V2G acceptability, integrating a categorization based on the four major categories – technical, economic, social, and environmental – as described in Section 3.4.1.1. It has to be noted, once again, that these categories are not distinctive but are fluid and overlap.

Economic factors mainly concentrate on the monetary costs and benefits that are associated with V2G and which can thus frame the perceptions and attitudes toward the technology. Three types of costs can be distinguished that are important to EV owners. The first category refers to the initial investments in the V2G-enabled EV and the associated charging infrastructure. The second category refers to operational costs, including maintenance and battery degradation (see also

Section 2.3.1) (Geske and Schumann, 2018). Empirical studies hereby, mainly focus on perceptions of the perceived costs that come along with additional battery degradation (Mehdizadeh et al., 2024). Yet, participating in a V2G charging scheme also enables the user to earn revenues by providing flexibility (Libertson, 2022b) and is therefore recognized as an important incentive for EV users to participate in these services. Technological factors mainly assess users' perceptions and attitudes toward the technical peculiarities of the technology, such as (reduced) range compared to an ICEV (Libertson, 2022b), or operational reliability (van Heuveln et al., 2021). Moreover, V2G necessitates the sharing of sensitive data, which is another issue influencing the potential adopter's perceptions (e.g., Bailey and Axsen, 2015; Dean and Kockelman, 2024). Finally, attitudes with regard to V2G are oftentimes assessed in terms of people's technology orientation (e.g., Helferich et al., 2024; Henriksen et al., 2021), assuming that a high technology affinity is related to a higher interest in V2G.

While economic and technical factors trigger both negative and positive associations with V2G, environmental factors have a mainly positive impact on people's perceptions and attitudes toward V2G. Hereby, the positive effects of V2G are stressed, namely, using RES to charge the EV (Bailey and Axsen, 2015), reducing CO2 emissions, and contributing to the energy transition (Kubli, 2022). Noticeably, in this context, environmental values are also assessed (e.g., van Heuveln et al., 2021; Will and Schuller, 2016). Finally, there are a few social factors that are studied with regard to V2G. Directly related to the technology, the perceived usefulness as well as the user-friendliness, in terms of handling the technology, seem important. Finally, beliefs play an important role as well, assessed in terms of individuals' political orientation (Lagomarsino et al., 2022) and openness to experience (Helferich et al., 2024).

3.4.1.4 Social and contextual factors

Social and contextual factors have been shown to evidently influence technology adoption on an individual level by framing perceptions, attitudes, and behaviors (Barth et al., 2016) or by facilitating or hindering a specific behavior (Steg et al., 2015). In V2G literature, these factors are present, though less eminent (Table 3). Indeed, social and contextual factors play a rather subordinate role in empirical studies on V2G, with a focus on either (1) geographical or cultural contexts, (2) structural and institutional characteristics, and (3) individual membership in a social entity or group, shaping social identities.

Table 3: Social and contextual factors in empirical studies on V2G.

Type of social and contextual understanding	Examples
(1) Geographical, or cultural contexts	Place of residence, country, region, race
(2) Structural and institutional characteristics of the geographic surrounding	Commuting distance, dependency on/availability of public charging stations
(3) Individual's membership in a social entity or group, shaping social identities	Subjective norm

Category (1) and (2) are similar in the sense, that both underline the context's ability to create a sense of belonging and affiliation. Yet, they are distinctive in that the first category is more abstract, by stressing the geographical dimension in terms of the country (Kester et al., 2019), region

(Lee et al., 2020), or place of residence (e.g., urban, suburban, rural) (Dean and Kockelman, 2024; Kubli, 2022; Will and Schuller, 2016), and the cultural dimension in terms of race (Dean and Kockelman, 2024; Wong et al., 2023). In contrast, the second category puts emphasis on the structural characteristics of the surrounding and is presented in the literature in terms of the commuting distance (e.g., Lagomarsino et al., 2022; Wong et al., 2023), and the availability of charging stations (e.g., Kubli, 2022; Libertson, 2022b). Particularly, the factors of the latter are important in determining whether V2G charging is feasible on a household level and whether the infrastructure would allow for such technology adoption.

The last category emphasizes the social dimension more specifically, e.g., by factoring in subjective norms (Mehdizadeh et al., 2024; van Heuveln et al., 2021). This category is thereby less tangible but equally important. In this sense, Mehdizadeh et al. (2024) note in their study, that peoples' attitudes toward V2G are also influenced by the expectations of others, for example their beliefs about the technology's trustworthiness.

3.4.2 Summary and research avenue

The literature review provided an overview of the current research landscape on empirical studies on V2G acceptability. Essentially, it mapped the most important factors employed to explain V2G acceptability. The analysis thereby followed the concepts outlined in Section 3.4.1.1. Importantly, it showed that empirical studies on V2G exist, deploying a broad spectrum of factors, that can be categorized into technical, economic, social, and environmental factors. Yet, this comprehensive overview also points out the research gaps that this thesis aims to fill.

The majority of studies concentrate on one specific dimension, with the vast majority focusing on economic and technical factors, explaining V2G acceptability. Moreover, most studies put their research focus on product attributes. Therefore, this work concentrates on user characteristics and seeks to provide a holistic understanding of V2G acceptability, focusing on different factors, combined, covering the four relevant V2G acceptability dimensions technical, economic, environmental, and social factors. Moreover, what is particularly striking is that most studies do not consider social or contextualual factors, which are equally important in explaining interest in and acceptability of innovative technologies, such as V2G. Importantly, social and contextual factors enable to study sub-groups and thus allow to transfer results to similar groups and contexts. Last but not least, it is apparent that most studies focus on one country. Studies, that do focus on different countries only strive for a qualitative comparison. Yet, nearly no studies are available exploring, whether these contexts influence the user's motive to participate in V2G. To this end, the thesis at hand also aims to close this gap by providing three empirical studies, each of which focuses on different sub-groups. The following chapter outlines the research design of this thesis.

Chapter 4

4 Research design and approaches

The previous chapters outlined the fundamentals and the theoretical underpinnings with respect to V2G and the user acceptability of the technology in focus. The following chapter introduces the methodological choices and research approaches undertaken to study the research questions described in Section 1.2. In particular, this section seeks to

i. provide an overview of the overall research approach,
ii. outline how acceptability was operationalized in the framework of this thesis,
iii. outline the approaches for the sub-group analysis in the empirical studies.

This chapter first provides an overview of the overall research approach including the four scientific papers (Paper A - D) in Section 4.1. As V2G is a technology that has, until now, only been introduced in the framework of pilot studies to customers, particularly the hypothetical character is a decisive challenge, associated with questioning individuals with regard to their acceptability toward this technology (Section 4.2). Therefore, the way in which V2G acceptability is framed is critical to deal with the bias. Furthermore, analyzing the research case for different sub-groups, is another means to improve the findings' reliability and generalizability as well. Specifically, the cases are analyzed for i. groups with differing EV knowledge and experience and ii. energy initiative members and non-members. This is why Sections 4.2.1 and 4.2.2 concretely outline the operationalization and multi-group analysis of user acceptability of V2G and dive into the methodological approaches to analyze the research cases.

4.1 Research approach

A wide range of approaches exist to elicit user acceptability of innovative energy technologies. Two major approaches are available, the first one focusing on the preferences for different product attributes or the objectives that can be pursued by applying the technology, and the second by studying user characteristics in terms of their sociodemographic characteristics, values, and attitudes. Supplementary, the social context spans both approaches and can be used to form sub-groups to analyze the research case (Figure 7 in Section 3.2).

Table 4 depicts the research designs of the scientific papers appended to this thesis. While Paper A provides a systematic literature review on how the user is integrated into current research on V2G, Papers B - D develop an empirical research case and focus on different factors affecting user acceptability of V2G. The systematic literature review serves as a basis for the empirical studies, pointing to the need for further research directed at the user motivations to participate in V2G and contributing to a more in-depth understanding. To this end, in Paper A, we applied a systematic approach, which primarily aims to introduce transparency through their systematic and reproducible process. The overarching objective of this systematic literature review is to shed light on and create transparency on how the user is characterized in different research streams and how different disciplines deal with and consider the user in their research. By doing so, this literature review scrutinizes how the human factor of smart charging is approached by predominating topics and disciplines and provides examples of research topics and the way in which the user characteristics are typically integrated. It furthermore lays the basis for the following three empirical research papers. Specifically, it identifies a lack of research conducted in social science, with the majority of studies being conducted in "technical" research fields, such as engineering, economics, and computer science. Essentially, these studies integrate user characteristics into their modeling approaches only to a limited extent in a very simplified way, using easy-to-integrate parameters, neglecting the complex nature of human behavior. Hence, the human dimension of V2G, the complexity of behavior is largely neglected. This calls for the need for empirical studies elaborating on specific factors driving user motivations to accept and ultimately, to use the technology in question. Moreover, Paper A points out that particularly mobility and charging-related behavior variables, as well as preferences, are widely used in research to characterize the user of V2G, while factors, such as values are not prevalent in previous studies.

Building upon the systematic literature review, the empirical research papers address complementary research questions, displaying different factors relevant to explaining user acceptability of V2G. Noticeably, as it is the objective of this thesis to analyze different, but complementary viewpoints on users' acceptability of V2G, the research contributions of the empirical studies essentially focus on the different dimensions of V2G, which are based on the framework of Huber et al. (2019) (Section 3.4.1.1). Particularly, the empirical studies can be categorized into one or several of the four dimensions – technical, economic, environmental, and social – representing the user motivations that are focal for the empirical study.

Paper B focuses on the technical and economic factors relevant to explaining user acceptability of V2G, by assessing user perceptions with regard to battery degradation, and investments for a V2G-enabled wallbox, all factors explaining acceptability in economic and technical terms. Paper C extends this view by also considering environmental factors. Specifically, Paper C develops three charging strategies – cost-minimized charging, climate-neutral charging, and grid-beneficial charging – implicitly reflecting V2G objectives and the respective user motivations. The study assesses, to which extent these charging strategies mediate users' minimum range requirements and WTP. Finally, Paper D has the primary focus on social factors and, less prominently, on environmental and economic motives, predicting V2G adoption interest. Hereby, social factors refer to community factors, while environmental and economic factors are included in terms of personal values.

The following provides a detailed synthesis of the research approaches of the three empirical papers. Starting with describing the challenges arising from the hypothetical character of the studies' research cases for the research designs, the section dives into the empirical research Papers B-D, with a particular focus on the operationalization of V2G acceptability and the sub-group analysis of the research cases.

Table 4: Research designs of the scientific papers.

		Paper A	Paper B	Paper C	Paper D
Type of study	Literature	✓	×	×	×
	Empirical	×	✓	✓	✓
V2G dimensions	Economic	✓	✓	✓	✓
	Technical	✓	✓	✓	×
	Environmental	✓	×	✓	✓
	Social	✓	×	×	✓
Sample	Year of data collection	2020-2021	2021	2023	2023
	Sampling strategy	Systematic literature review	Randomized*	Randomized* and purposive	Randomized* and purposive
	Size[b]	183	1334	1196	979
	Representativeness[c]	×	A, G, F	A, G, F	A, G
Sub-groups	Target groups	×	People with a driving license	People with a driving license, EV-experienced people	Homeowners, energy initiative members
	Countries	Global	DE, UK	DE	DE, FR, CH
Operationalization[a]	Scenario experiment	×	×	×	✓
	Willingness to pay	×	✓	✓	×
	Willingness to participate	×	✓	×	×
Factors[a]	V2G objectives	×	×	✓	×
	V2G attributes	×	✓	✓	×
	Psychographics	×	✓	×	✓
	Sociodemographics	×	✓	✓	✓
	Social factors	×	×	×	✓
Methods		Systematic literature review and thematic analysis	Hierarchical multi-regression analysis	Mediation analysis	Structural equation model (SEM)

[a] Included (✓), not included (×)
[b] post data cleaning
[c] Age: A, Gender: G, Federal state/region: F
* The sample was collected with a specialized company. These companies offer already selected samples, which is why it cannot be ensured, that the data contains a truly randomized sample.

4.2 Hypothetical setting of V2G case studies and research approaches

V2G is a technology, that is not yet established on the German market. Indeed, even though few bidirectional EVs can be purchased on the market, the technology cannot unfold its potential under the current regulatory framework (Section 2.3.2). Currently, few research projects pilot the up-scaling of the technology. Yet, these trials take place on a small-scale and within a protected and controlled environment, implying that it is currently only possible to a limited extent to collect behavioral data (i.e., revealed preference data). Data from this context is moreover, highly selective and likely biased. Hence, the majority of studies collect data on intention by putting participants into a hypothetical situation when evaluating the technology without any actual experience (i.e., stated preference data) (Breidert et al., 2006; Jensen et al., 2013). The difference between stated preferences and real-life behavior is known as *hypothetical bias* (see also Lehmann, 2023). As the studies appended to this thesis assess the intention to adopt V2G, this thesis distinguishes between acceptance and acceptability (Section 3.1).

The hypothetical character is particularly critical, as it may limit the validity of studies assessing the acceptability of novel energy technologies. Static characteristics, such as values and more general motivations, are less susceptive toward this bias. Conversely, this bias may be particularly apparent with regard to situations, asking about real-life behavior, for example, the adoption of V2G tariffs. In this case, preferences may diverge from answers based on real-life experiences. Thus, the respondents's answers do not reflect opinions based on real-life experience, but only momentary stated preferences. Scholars provided evidence, that people with real-life experience evaluate specific energy technologies, and connected attributes differently than people who have not gained experience yet. For example, in an EV field trial, participants evaluated the EV's range differently than before the testing (Jensen et al., 2013). Likewise, respondents living close to a biogas plant demanded smaller distances to the sites than the general public (Schumacher, 2019), showing that experience with a specific technology crucially determines its evaluation. Other sources for hypothetical bias are the survey design, and the personalities of respondents (Lehmann et al., 2019; see also e.g., Reed Johnson et al., 2013).

Relatedly, this bias of evaluating a novel energy technology may become even more critical, as the technology's properties, i.e., the associated benefits and risks, present a very ambiguous picture to the user. This ambiguity of properties is also known as the *paradox of technology* (Johnson et al., 2008). Concretely, while V2G promises revenues to the end user and benefits the grid and the environment, the purchase of the technology comes with additional costs and may harm the battery lifetime. To this end, scholars provided evidence that this ambiguity of novel technologies has rather negative, than positive effects on the user's evaluation, also called *negativity bias* (Rozin and Royzman, 2001), and outperforms positive valence in user adoption intentions (Frank et al., 2023). Building on this argument, it is suggested that individuals may evaluate the product attributes differently depending on how distant the future behavior is. This implies that behaviors, such as the adoption intention of an innovative product, are guided by more abstract and general considerations as behaviors, that will happen in the near future. Particularly, perceived costs may thus outweigh the perceived benefits, when the behavior is more distant. (Arts et al., 2011).

Capturing people's behavioral intentions can be performed using either direct or indirect approaches. As the literature review in Section 3.4 illustrates, most studies use online surveys to collect data. These surveys can be categorized into direct and indirect surveys. While indirect surveys include conjoint analysis, discrete choice analysis, or best-worst methods providing insights into structures of consumer preferences for product attributes (Breidert et al., 2006; Lehmann, 2023), they do not reveal underlying reasons and motivations for accepting the product or service (van Heuveln et al., 2021). In contrast to indirect surveys focusing on product characteristics, direct methods focus more strongly on user characteristics by applying either expert judgments or customer surveys (Lehmann, 2023). Particularly, direct surveys are used in environmental psychology to explain behavior of individuals or groups based on a behavioral theory. To explain a specific behavior, these models use observable and unobservable user characteristics.

Thereby, unobservable characteristics are created by aggregating multiple indicators, i.e., Likert scale questions to a latent variable (Lehmann 2023). Interestingly, most empirical V2G studies that were identified in Section 3.4 (Table 1), perform indirect approaches, to assess users' WTP for V2G functionalities or attributes, users' willingness to accept or preferences with regard to V2G contracts and services. In contrast, fewer studies apply direct approaches and focus on users' general willingness, interest, or intention to participate. The schematic categorization displayed in Figure 10 is based on the results of the literature review presented in Section 3.4. To the author's knowledge, there are, until now, no studies using direct approaches to assess users' willingness to participate in V2G contracts and services. The empirical Papers B – D appended to this thesis, therefore, put the focus on this gap.

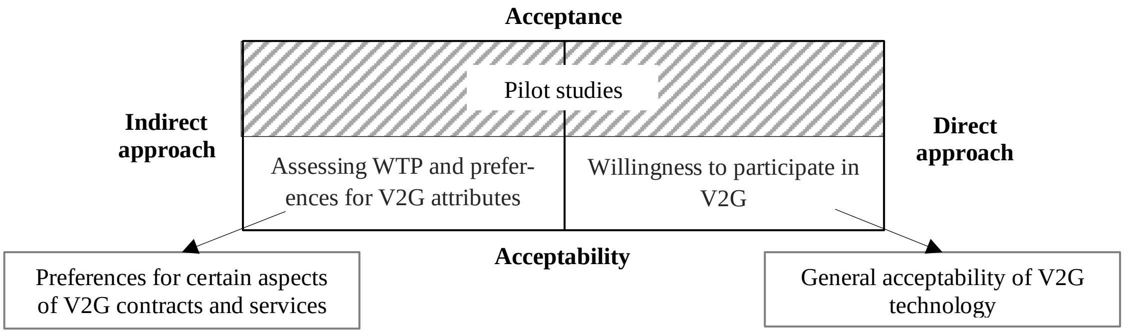


Figure 10: Operationalization of V2G acceptability in direct and indirect approaches, own illustration.

All empirical papers (B – D) are based on data collected via online surveys, including questions on sociodemographic and household characteristics, questions reflecting a theoretical model (Paper D), and direct approaches (rating-based approaches) to query user acceptability of V2G. Particularly, as stated above, the hypothetical setting posed several challenges to the research design. Therefore, each empirical study put emphasis on the way in which V2G acceptability was operationalized. The concrete procedures are described in detail in the following sections.

4.2.1 Operationalization of vehicle-to-grid acceptability

This thesis operationalizes V2G acceptability using direct approaches. A direct approach refers to rating-based approaches, i.e., Likert scales, where respondents directly rate the extent to which they agree or disagree with the statement of the Likert scale item. With regard to V2G, Kubli (2022) highlights three main situations in which V2G can be initiated, serving as anchor points to assess users' acceptability towards this technology – the EV purchase decision, through contracts, and at the charging event. Papers B - D operationalize V2G acceptability in terms of a V2G charging contract or tariff, with a specific focus on the charging conditions. A V2G contract constitutes the interface between the user of the bidirectional EV and the power system, i.e., the aggregator. They define, under which conditions the charging process takes place. Importantly, depending on the contract conditions, these contracts can incentivize a specific charging behavior and thus enable the operator to raise flexibility potentials (Emodi et al., 2022). Moreover, as V2G bears the promise to be economically profitable to a variety of actors, the price level essentially determines whether users will participate, and, when mirroring them with the market perspective, it can be assessed whether these values can be realistically yielded (Baumgartner et al., 2022; Lee et al., 2020). In this context, Papers B and C determine the monetary value people assign to a V2G charging tariff using direct measurement methods.

Determining the value a customer assigns to a product is an essential step in the pricing process when introducing a new product or service (Miller et al., 2011). Two common approaches are to assess users' WTP or users' WTA. While WTP assesses the amount needed to acquire a product or service, WTA is determined by the amount an individual wishes to receive for giving it up (Georgantzís and Navarro-Martínez, 2010; Horowitz and McConnell, 2002). In theory, WTA and WTP values should be equivalent when assuming the same levels of a given product (Contu and Mourato, 2020). Yet, previous research illustrates that the WTA is usually higher than the WTP (Georgantzís and Navarro-Martínez, 2010; Horowitz and McConnell, 2002). This asymmetry is often explained by the perceived loss of the product, arguing that losses weigh stronger than gains (Anderson et al., 2000; Kahneman et al., 1990). Moreover, research suggests that this discrepancy is even higher for products the less the product is like an "ordinary market good" (Horowitz and McConnell, 2002), which is especially relevant for innovative products and services. Research also suggests that this discrepancy can further be explained by affect or moral considerations (Biel et al., 2011), or by different personality profiles (Georgantzís and Navarro-Martínez, 2010).

WTP and WTA are oftentimes the results of choice experiments, where respondents repeatedly rate multiple alternatives to elicit the importance of different product attributes. In the context of V2G studies, both WTP as well as WTA approaches are used to place a monetary value on users' acceptance of V2G. While WTP is used in the context of V2G contracts and services, evaluating different product features, WTA is used with regard to the potential of earning revenues by providing flexibility to the market and with regard to potential barriers, such as required plug-in times (Lee et al., 2020). Moreover, WTA approaches can be used to provide insights into the evaluation of trade-offs between different attributes (Kubli, 2022).

In contrast, when using direct methods, respondents are queried to directly state how much they would be willing to pay / would be willing to accept for a product or service (Breidert et al., 2006). The primary advantage of this method is that the focus is set on the price of a product and not on its attributes. Regarding WTP, the method is based on the assumption that a price range exists, which is bounded by the maximum and minimum that users are willing to pay (Larson et al., 2014). Since its first application by Stoetzel (1954), the direct approach has been continuously developed. A known advancement of the direct WTP measurement approach is the price sensitivity meter (PSM) by van Westendorp (1976), which includes four questions, asking not only for the maximum and minimum price but also for a reasonable, cheap, and expensive price. This method is still applied in commercial settings (Breidert et al., 2006). Yet, this method was criticized, mainly for the following reasons: First, and foremost, the focus is set on the price and a precise evaluation may be difficult, due to the lack of knowledge or prestige effects, in which customers purposively state higher or lower prices. Particularly with respect to unfamiliar and complex products, such as a V2G charging tariff, knowledge gaps might lead to over- or underestimation of prices. Finally, these direct approaches have been said to not be stable over time and not automatically translate into behavior (Breidert et al., 2006; Hofstetter and Miller, 2009).

Paper B follows a WTA approach, assessing the minimum monthly compensation for providing flexibility deemed necessary by participants after having a proper overview of the technology with its risks and costs. The description of the technology followed the introduction from Paper D. As the focus was on the economic aspects of V2G, we provided the participant with the necessary information and queried their perceptions with regard to cost-relevant aspects, such as battery degradation and wall box costs, which are assumed to exceed the costs of a "normal" wall box. We ensured that the participants made informed decisions by providing the respondents with information about the service, and the product's costs and benefits.

In contrast, Paper C applies the van Westendorp PSM, to assess users' WTP for a V2G charging tariff. The charging tariff is thereby comprised of two levels (Table 5) – in the first level, the EV is instantly charged until reaching the minimum range before switching to the second level, where the EV is charged bidirectionally until reaching the desired SoC. The design of the charging tariff follows the criteria of being simple, transparent, and predictable (Dütschke and Paetz, 2013). The tariff scheme is inspired by an EV-specific controlled charging tariff developed by Ensslen et al. (2018).

Table 5: Two-level charging tariff design (Baumgartner et al., 2022).

Charging level	**Charging mode**	**Definition**
1st tariff level	Uni-directional charging	Instant charging until the individually chosen SoC_{Min} is reached. The price for this mode is €5.20 / 100 km.
2nd tariff level	Bi-directional (V2G) charging	Charging in the bidirectional charging mode until the individually chosen maximum range is reached.

Following the PSM approach, respondents were asked to state their WTP for the second charging level, in four open-ended questions[15] as follows: *At what average price per 100 km of range would you consider V2G charging...*

a) …too expensive, i.e., you would definitely look for a cheaper tariff?
b) …expensive, i.e., you would only conclude the contract after careful consideration?
c) …cheap, i.e., the tariff would be a bargain?
d) …too cheap, i.e., you have doubts about the seriousness of the tariff?

Aggregating the answers leads to four curves. The intercepts between the different curves determine the different price points – indifference price point (IDP), optimal price point (OPP), point of marginal cheapness (MGP), and point of marginal expensiveness (MDP), as well as the upper and lower bounds of the acceptable price range.

[15] It is important to note, that while the question was an open-ended question, we still defined an upper bound, which equaled the reference price of 5.20 €/100 km, assuming that participants' WTP would be lower than the given reference price, as the second charging level comes with disadvantages for the user. Thus, the difference between the reference price and the WTP for the second charging level defines the saving for the user.

Paper D operationalizes user acceptability in terms of a V2G charging service as well, yet, it develops direct rating-based scenarios that vary along three attributes, each consisting of two levels (2^3 = 8 unique charging tariffs). This approach also falls under a direct approach, as participants rated their interest in V2G based on the eight tariffs sequentially on a scale from 1 (not interested at all) to 7 (very interested). Hence, participants repeatedly rated the scenarios, reflecting their overall propensity to participate in the V2G contract. For our analysis, we created a compound variable from all ratings based on the mean values. The attributes were not analyzed any further, as it would have answered another research question, going beyond the scope of the study. The attributes and levels were derived from Gschwendtner et al. (2023). The scenario included an introductory text describing a V2G contract to the respondents. The full scenario text was as follows:

Scenario introduction

{constantly shown above every scenario; use CHF for Swiss version}

Imagine you own a bidirectional electric car with a range of 350 km. To be able to charge your electric car bidirectionally, you sign a contract with a service provider. The contract allows you to charge your electric car bidirectionally at home, at your workplace and at public charging stations. Assume, the charging infrastructure is available. Additionally, you have the possibility to flexibly pause the contract.

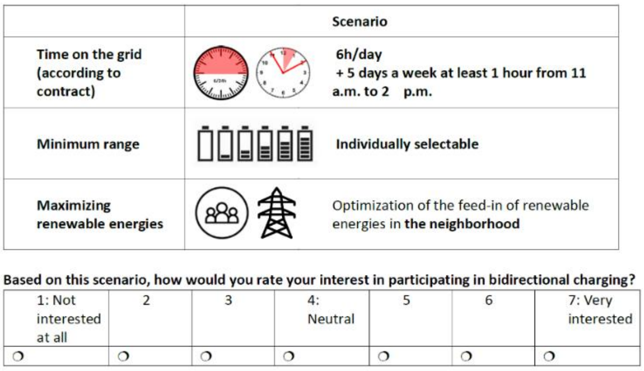
As soon as you plug in your electric car, it is initially charged to a minimum range without interruption. The minimum range corresponds to the range that is always available for unplanned shorter trips and should therefore also be understood as a safety reserve. Once the minimum range is reached, the bidirectional charging phase begins. In an app, you can set your planned departure times and the desired destination range at departure. In addition, your system has an opt-out function that allows you to cancel the bidirectional charging mode and charge your vehicle directly. You will receive a monthly compensation of 50€ for providing your battery. Below we present eight different contract conditions. The introductory text remains the same. We ask you to read the contract conditions carefully and then evaluate them. There is no right or wrong answer. Your opinion alone counts.

The attributes and levels were defined as displayed in Table 6.

Table 6: Scenario attributes and levels (Baumgartner et al., 2025).

Attributes	Level 1	Level 2
Time on the grid	The vehicle has to be connected to the grid for a total of 6h/day, but the time of connection is freely selectable	The vehicle has to be connected to the grid for a total of 6h/day for five days a week and at least for one hour between 11 a.m. to 2 p.m.
Minimum range	The minimum range is individually selectable	The minimum range is 30% / 100km
Maximization of renewable energies	Optimization of the feed-in of renewable energy sources into the entire energy system	Optimization of the feed-in of renewable energy sources into the local grid of the neighborhood

Finally, Figure 11 displays an example of how the scenarios were presented.



	Scenario
Time on the grid (according to contract)	6h/day + 5 days a week at least 1 hour from 11 a.m. to 2 p.m.
Minimum range	Individually selectable
Maximizing renewable energies	Optimization of the feed-in of renewable energies in **the neighborhood**

Based on this scenario, how would you rate your interest in participating in bidirectional charging?

1: Not interested at all	2	3	4: Neutral	5	6	7: Very interested
○	○	○	○	○	○	○

Figure 11: Example of one of the eight V2G tariff options (Baumgartner et al., 2025).

By providing the participants with information about the product, including the different product attributes and attribute levels, this method ensured that participants made informed decisions based on detailed information about the technology. This approach is expected to reduce the likelihood that participants unfamiliar with this new technology would make decisions that do not align with their actual preferences and assumes that there is an underlying level of general interest to participate regardless of specific tariff design options (Sloot et al., 2022).

4.2.2 Sub-group analysis

Specifically, in the context of innovative technologies, the need for in-depth and group-specific analyses is evident. In this work, group-specific analyses are performed by

i. contextualization of the research case,
ii. segmentation of the sample based on social factors,
iii. segmentation of the sample based on specific user characteristics.

While the latter recognizes specific user characteristics to be important determinants of V2G acceptability, contextualization, and social factors acknowledge that people do not act in a vacuum; rather, they are influenced by various contextual factors, e.g., infrastructure and political agendas. In contrast, social factors are less tangible, including the interaction with the social environment or the feeling of belonging, shaping identities (Section 3.3). These factors are important determinants to understanding, whether adoption is likely to happen or not.

Using the categories as an anchor point, Paper B incorporates contextual factors following the understanding of (i) and Paper D (i) and (ii). In contrast, Paper C builds sub-groups based on user characteristics, i.e., knowledge and experience levels with regard to EVs (iii). Importantly, the scientific studies (B-D) use these factors and characteristics to study and compare antecedents of V2G acceptability between groups. Methodologically, in this way, contextualization and segmentation support the reliability of results for specific groups and furthermore enable the transferability of results to similar contexts and groups. Specifically, two major types of comparisons are realized. First, Papers B and D compare different countries, and second, Papers C and D compare groups of people, based on their EV knowledge and membership in energy initiatives.

The countries at the center of this thesis are Germany, the United Kingdom (UK), France (FR), and Switzerland (CH) (Table 4). Studying V2G adoption in different country settings is important, as even within Europe, countries follow different trajectories regarding their energy transition, with likely impacts on the decision-making of individuals in these countries, either more directly through targeted policies, such as subsidies, or indirectly, via norms, culture, and education (Chard et al., 2024). For example, France and the UK rely on nuclear power plants as a core pillar of the energy transition strategy (HM Government, 2021; Vernay et al., 2023). Particularly in France, this strategy supports a system that is (historically) more centralized, with only a few main energy actors (Vernay et al., 2023). In contrast, Germany relies on RES and hydrogen, and already phased out nuclear power plants, and Switzerland prohibits the construction of new nuclear plants. To this end, comparing countries is of great interest, as the strategies and understandings of the energy transition differ, even within Europe, likely influencing peoples' views.

Another way of group comparison is carried out by segmenting the sample into sub-samples, based on specific user characteristics. Sub-groups were built based on i) the level of knowledge and experience respondents of the survey had with EVs and ii) their affiliation and membership in an energy initiative. With regard to i) it is assumed that the knowledge base with regard to V2G technology, differs between people with and without EV experience, and consequently, underlying motives to accept V2G may vary. In addition, and with respect to the associated hypothetical bias of V2G (Section 4.2), results of previous studies suggest that users' experience with EVs represents a critical factor in creating an informed decision about issues in the realm of V2G (Chen et al., 2020; Noel et al., 2019a). Concerning ii) it is assumed that, due to the unique role of energy initiatives in the energy transition, they might not only foster acceptance toward energy technologies but might create interest in and have the potential to motivate the adoption and use of novel technological innovations that have not been widely established yet. In this context, previous research has shown that for the adoption of an innovative technology, social groups are particularly influential in framing individual goals, which is essential in the early stages of an adoption process (Barth et al., 2016; Klöckner, 2014).

Summing up, the empirical studies operationalize these understandings by including them either as variables in the developed models directly or by striving for a comparison across different groups and contexts. Concretely, Paper B builds a hierarchical regression model. The model is set up in three steps, and the variables are entered hierarchically. Model 1 includes the contextual variables. Specifically, we used the following variables: rent vs. ownership, type of region, EV ownership, and commuting. In step 2, we entered two variables capturing battery degradation (battery aging and compensation for battery aging) before entering in step 3 the psychographic variables (environmental self-identity, consumer novelty seeking, and consumer independent judgment making). The model is tested separately for Germany and the UK. This way, Paper B allows to compare the overall model between countries.

Paper C distinguishes between different groups of people, with a specific focus on the knowledge base. Methodologically, Paper C builds a mediation model, which is performed for groups with different levels of EV experience. Specifically, three groups are of interest: (i) people with no EV experience, (ii) people, who have gained experience by driving an EV in solitary events, (iii) individuals owning and regularly using their EV, thus being familiar with the technological peculiarities. The mediation model is tested for the three groups, dummy-coding the categorical variables (n-1), with *no EV experience* being the reference category. By doing so, the model results can be compared between groups with different levels of EV experience.

Another question is which process variables can explain why the acceptability of V2G differs for these sub-groups. Mediation, in its simplest form, is based on three variables – the independent variable *X*, the dependent variable *Y*, and the mediator *M*, channeling the relationship between *X* and *Y* (Meuleman, 2019), reflecting a causal sequence (Field, 2018). Mediation occurs when the effect of the independent variable X on the dependent variable Y is reduced by integrating the mediator variable M (Baron and Kenny, 1986; Dudenhöffer, 2015). Testing for inference, one way is to perform the Sobel test (Hayes and Scharkow, 2013), which is a significance test, rejecting or accepting the null-hypothesis (Tibbe and Montoya, 2022). Another common procedure is to analyze the percentile or bias-corrected bootstrap confidence intervals (CIs) to see whether zero falls outside its confidence limits (Tibbe and Montoya, 2022). In Paper C, we applied the bias-corrected bootstrap CIs (N= 10.000) (Field, 2018; Hayes and Preacher, 2014; Hayes and Scharkow, 2013; Zhao et al., 2010).

The mediation model is based on the equations below.

$$c = c' + ab \tag{1}$$

Equation (1) defines the relative total effect c, which corresponds to the sum of the relative direct effect c' and the product of the coefficients a and b.

$$M = \beta_M + a_1X_1 + a_2X_2 + \varepsilon_M \tag{2}$$
$$Y = \beta_Y' + c_1'X_1 + c_2'X_2 + bM + \varepsilon_Y \tag{3}$$

The indirect effect of X on Y through M is estimated as the product of ab from equations (2) and (3). Equation (2) measurse the effect of X on M. With β_M the standardized (regression) coefficient is included and ε_M defines the error. As the study setup results in a multicategorical predictor (user experience), dummy coding is applied, resulting in two predictor variables a_1 and a_2 in the model. Equation (3) defines the direct effect.

$$Y = \beta_Y + c_1X_1 + c_2X_2 + \varepsilon_Y \tag{4}$$

Finally, equation (4) defines the total effect of X on Y, which is the observed difference of group means on Y. A detailed description of statistical mediation analysis with multicategorical independent variables can be found in Hayes and Preacher (2014).

In Paper D, we developed a theoretical model to assess the role of (i) community energy initiatives in shaping V2G adoption interest of individuals (ii) in a country specific context. To this end, Paper D builds a structural equation model (SEM), and in a second step, tests the model in a multigroup setting. The role of initiative membership is tested by including community motives and initiative membership, next to personal values and norms, into a dual-pathway model. The existence of country differences was tested by adding country as a grouping factor to the model. Thereby, we compared a constrained model in which all regression parameters were set to be equal across countries to an unconstrained model in which all parameters were allowed to vary freely across the three countries. This way, Paper D allows to draw conclusions on the role of initiative membership on adoption interest of V2G, and a comparison of motivation pathways between countries.

Specifically, Paper D employs a SEM, because it allows to estimate and test for interactions between observed (manifest) and nonobservable (latent variables), i.e., a set of indicators defining a construct, which is not possible using, e.g., multivariate regression (Schumacker and Lomax, 2010; Wentura and Pospeschill, 2015). A SEM thereby places a strong "emphasis on evaluating the validity, reliability, and comparability of measurement instruments" (Meuleman, 2019, p. 130).

Essentially, a SEM consists of two components, the measurement model and the structural model, including the associated path parameters, to model the covariance and mean structures of multivariate data (Meuleman, 2019). The measurement model tests the relationships among indicator variables and latent variables, which is quantified by the factor loading (Wentura and Pospeschill, 2015). It can be formally written as (Meuleman, 2019):

$$\gamma_i = \nu + \Lambda_{\eta i} + \varepsilon_i \tag{5}$$

where subscript i refers to the individual cases. Equation (5) displays a vector of observed responses on the indicators γ_i. γ_i are modeled as a function of latent variables η_i, with matrix Λ containing the regression weights. Vector ν contains the intercepts, and ε_i refers to the measurement errors.

In contrast, the structural model defines the relationships between exogenous and endogenous latent variables. The structural model can be formally written as (Meuleman, 2019):

$$\eta_i = \alpha + \mathrm{B}\eta_i + \Gamma\chi_i + \xi_i \tag{6}$$

Equation 6 is composed of a matrix B containing the effects among latent variables, and Γ containing the direct effects of the χ's on the latent variables. α refers to the intercepts and ξ_i to the residuals of the endogenous variables. (Meuleman, 2019)

Common to all SEM methods is that a $p \times p$ covariance matrix **S** (where p is the number of involved variables), obtained from the empirical data is used as an estimator for the covariance matrix $\sum$ of the population. $\sum(0) = \sum$ is the covariance matrix implied by the model (Wentura and Pospeschill, 2015). Pospeschill (2010) formulates the following hypotheses:

H_0: $\sum(0) = \sum$; there is a fit between the covariance matrix $\sum(0)$ implied by the model and the covariance matrix of the population $\sum$.

H_1: $\sum(0) \neq \sum$; there is no fit between the model and data structure.

For estimating the model, a fitting function is used, which aims at reducing the difference between $\sum$ and S. A matrix $\sum$, that equals zero (S - $\sum$ = 0), X^2= 0, displays a perfect model. For estimating the model, different estimation procedures are available. A common estimator is the maximum likelihood (ML) estimator, which, however, can only handle continuous variables. In the specific case of Paper D, we used the diagonally weighted least squares (DWLS) estimator to handle the endogenous categorical variables in our model. There are three ways of testing the model fit. First, model fit indices show, how well the sample data fits the model. Secondly, indices are available that compare the proposed model with a null model, and finally, some indices test for parsimony, providing information on estimated parameters required to increase the level of model fit. (Schumacher, 2019).

Another advantage over multivariate regression approaches is that a SEM allows to build multigroup models by segregating the model based on moderators, i.e., group variables, instead of calculating single interaction effects, which was essential for the research case of Paper D. Multigroup SEM can be described as a technique, that explores the moderating effects of groups on the model (Chard et al., 2024). Thus, it is possible to conclude how the model applies to different groups. The procedure of testing a multigroup model is to compare an unconstrained model, i.e., which allows regression parameters to vary across subgroups, with a model, where the structural weights are constrained, i.e., equal across groups. This procedure allows testing whether the model is variant across groups (Chard et al., 2024). The effect is tested using a Chi-square (X^2) test. To test how well the model fits the data, the same model fit indices as described above can be used. Paper D followed this procedure to integrate and test for multigroup effects.

Chapter 5

5 Research contribution of the appended scientific papers

The preceding chapters of this thesis provided an introduction to the V2G fundamentals (Chapter 2), an overview of the key concepts, and theories, as well as a literature review presenting the most relevant acceptability factors, laying the basis for the following four research papers (Chapter 3), and finally, a methodological and conceptual justification (Chapter 4) for the choices made, in the proceeding research contributions. This chapter summarizes the research contributions, that comprise this thesis. For each paper, the context, methods, and major results are outlined.

5.1 Paper A: How to integrate users into smart charging – a critical and systematic review

5.1.1 Motivation and research objectives

The successful implementation of V2G applications (Section 2.2.3) implies an active role of the EV user and, therefore, hinges on the user's willingness to provide flexibility. As argued by Huckebrink and Bertsch (2021, p. 2), 'adoption rates and market shares are important, [yet] the active use of a technology is what ultimately determines energy demand'. The human dimension, however, is complex in nature and multifaceted. As outlined in Section 3.4.1, various acceptability factors influence a user's decision to partake in V2G. These include behavior, preferences, perceptions, attitudes, and values. Yet, despite the user's primary role, most scientific studies illuminate either technical or economic aspects of V2G, only including a limited set of user characteristics in their research design.

Therefore, *Paper A (Baumgartner et al., 2023)* sheds light on and creates transparency on how the user is characterized in different research streams and how different disciplines deal with and consider the user in their research. Hence, Paper A seeks to make the following contributions to the state of the art:

i. Analyze the current state of research on smart charging[16] by investigating disciplines and methods of smart charging and by identifying stakeholders and dominating research topics throughout the various disciplines;

ii. Investigate how the human factor of smart charging is approached by predominating topics, methods, and disciplines and provide examples of research topics and the way in which the user characteristics are typically integrated.

5.1.2 Procedure

Paper A systematically reviews 183 peer-reviewed journal articles from the past 20 years of research on smart charging. In this case, systematic refers to the procedure of selecting the research papers and the approach, by which the papers were analyzed.

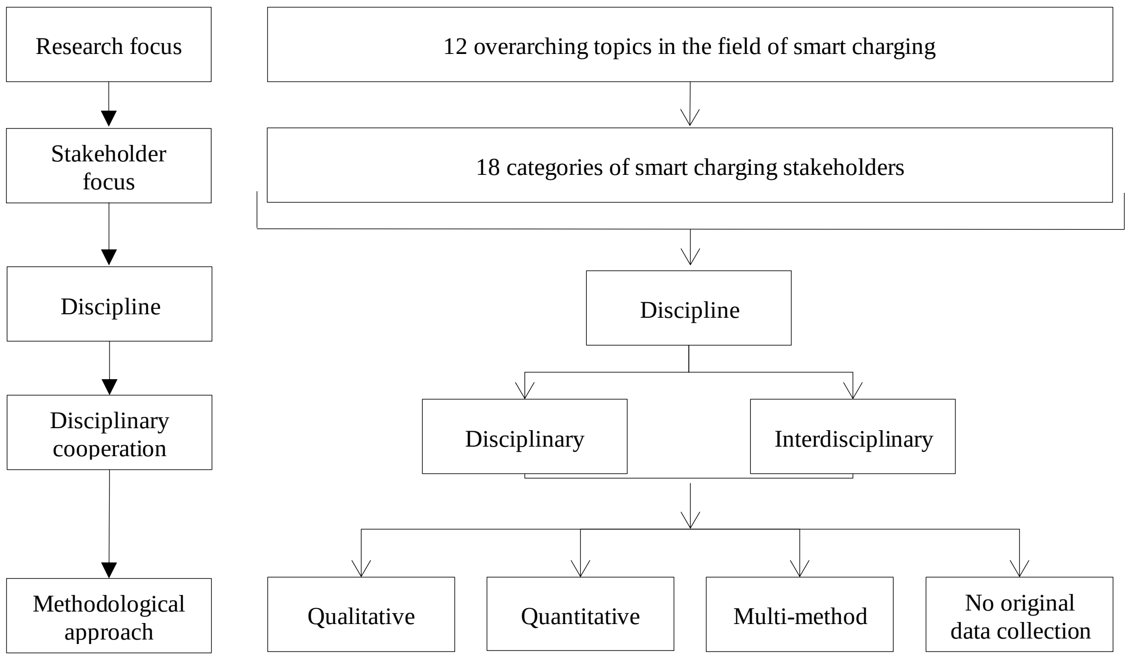


Figure 12: Structuring categories for the analytical framework (Baumgartner et al., 2023).

The stepwise analysis followed an analytical framework which is depicted in Figure 12. This framework consists of several structuring categories, the research topics and stakeholder focus of the study, the disciplinary background of the researchers, and the methodological approach chosen. The identification of research topics largely followed the thematic analysis according to Braun and Clarke (2006), using a data-driven approach which identifies themes based on existing data and not based on a pre-existing coding scheme.

[16] This systematic literature review uses the term “smart charging”. As outlined in section 3.4., empirical studies in this research realm often use the terms smart charging and V2G synonymously. In many cases, it is unclear, which form of controlled charging is referred to. Furthermore, both forms imply an active role of the EV user, though the applicability differs from a system perspective (Section 2.2.3). Due to these reasons, the literature review includes studies on both, uni- and bidirectional charging, whereas in Paper A the term “smart charging” is used.

Hereafter, the data was organized into meaningful groups, resulting in 12 overarching themes in the field of smart charging. These themes display dominating research topics in the field of smart charging. Taking the themes as a starting point, Paper A investigates the stakeholder focus as well as the methodological approach within each theme. Bringing all aspects together result in three qualitatively and quantitatively distinctive thematic domains – technology-oriented, human-centered, and integrative domain.

Complementarily, Paper A proposes to analyze the variables and parameters that were used to characterize the user of smart charging. The objective hereby is to unfold specific patterns of disciplines, methods, and research topics to include the user into smart charging research. The analysis delivers six categories, with several subcategories each. The categories capture the user characteristics as follows:

- Contextual information: These factors are outward-looking, considering the context within the decision-making process, framing perceptions, attitudes, and behaviors.
- User behavior: Capturing the user's statistical charging and mobility patterns.
- Perceptions and attitudes: Capturing the user's perceptions and attitudes toward a product and its attributes, namely EVs and smart charging. Perceptions and attitudes are oftentimes influenced by underlying values, which are also included in this category, though they are more fundamental, influencing attitudes and perceptions.
- Preferences: Assessing preference structures regarding a product and its attributes, namely, EVs and the charging process.
- Benefit and barriers: Capturing the monetary, environmental, and technical benefits and barriers of the technology at stake.

5.1.3 Key results

The systematic literature review unfolded the underlying logic of three research domains, dealing with smart charging – technology-oriented, human-centered, and an integrative research domain. These domains are qualitatively and quantitatively distinctive and cover different research topics. The majority of studies fall into the technology-oriented domain, typically basing their analyses on quantitative models and focusing on charging and mobility behavior and smart charging preferences as the main user parameters. Hence, this kind of studies integrates user characteristics in a very generic way. Individual and consumer-specific aspects, as well as contextual information, are less well-integrated. In contrast, topics with a focus on the human-dimension of smart charging center research around the user's perceptions and attitudes toward smart charging, their motives to participate in smart charging programs, or barriers that hinder them to do so. With this, these studies open up a complementary perspective that supports the introduction of smart charging technology into people's routines and daily lives. Integrative studies, as the third research domain, combine both perspectives, bridging the gap between human-centered and technology-centered topics. In a methodological sense, they are not necessarily accompanied by mixed-methods, but rather by interdisciplinary cooperation between disciplines from different schools of thought. This integrative character is reflected in a wide range of user characteristics, including contextual information, behavior, perceptions, attitudes, and preferences, with a special focus on values, EV preferences, and perceptions, and attitudes toward EVs, allowing to draw a manifold picture of the user of smart charging.

5.1.4 Critical appraisal

This systematic literature review aimed at providing an overview of the current state of the art research on smart charging, with a particular focus on the user role and how this role is integrated. This paper hereby seeks to reveal patterns of different disciplinary research strands. Yet, our approach to creating the research themes is prone to subjective bias, as this process always necessitates the researcher's judgment to determine the theme, which is, e.g., influenced by the researcher's background.

Moreover, we chose to analyze the user categories descriptively. This procedure does not allow the display of the relations and interlinkages between the user categories. Future research could thus focus on the relationship between user characteristics, illuminate the underlying theories, and quantify the relationships within a meta-analysis.

5.2 Paper B: Users' willingness to accept V2G – A comparison between German and UK households

5.2.1 Motivation and research objectives

Assessing factors determining users' willingness to participate in V2G is crucial for a successful market ramp-up of this technology. These factors can be either assessed in terms of user or product characteristics, V2G objectives, or social context factors (Section 3.2). Conceptually, this study combines social context factors and user characteristics to understand user motivations to participate in V2G: Thereby, *Paper B (Baumgartner et al., 2024)* focuses on user perceptions and values, and on contextual factors referring to structural aspects, as well as the spatial context (Black et al., 1985; Devine-Wright, 2008). In this study, psychological factors determine underlying motives for acting in a certain way, while the other enables the person to do so (Steg et al., 2015).

The objectives of this study are to shed light on monetary compensation requirements (WTA) from a user perspective for providing flexibility to the electricity market and to build a hierarchical multi-regression model to look at factors determining users' willingness to participate in V2G. Importantly, Paper B strives for a country comparison, comparing the model results for Germany and the UK. Paper B seeks to answer the following two research questions:

i. What is the expected compensation in Germany and the UK for providing flexibility to the electricity market, including battery degradation?
ii. To what extent do contextual and psychological factors predict the intention to participate in V2G in Germany and the UK?

5.2.2 Procedure

Addressing these research questions, we conducted an online survey in December 2023, targeting German and UK households. The final sample included N=1100 valid responses. Predictors, relevant to this study, assessed contextual factors according to the "Mobilität in Deutschland" (MiD) (Nobis and Kuhnimhof, 2018), psychographic characteristics, including environmental self-identity (van der Werff and Steg, 2016), consumer novelty seeking and consumer independent judgment making (Wolske et al., 2017) and perceived barriers, with a particular focus on battery degradation (Geske and Schumann, 2018). Like Paper C (Baumgartner et al., 2022), Paper B operationalized V2G acceptability in monetary terms, reflecting users' (in-)convenience to participate in V2G (Section 4.2.1). Additionally, Paper C operationalized acceptability by assessing users' willingness to participate in a V2G charging service, largely following the example described in Geske and Schumann (2018).

To answer the research questions of Paper B, we applied descriptive statistics and regression analysis and built a hierarchical multi-regression model, stepwise integrating all predictors described above. The model is set up in three steps, and the variables are entered hierarchically. In step 1, we entered the contextual variables (rent vs. ownership, type of region, EV ownership, commuting), which we believed to be particularly interesting in a country comparison. In step 2 we entered two variables capturing battery degradation (battery aging and compensation for battery aging), before entering in step 3 the psychographic variables (environmental self-identity, consumer novelty seeking, and consumer independent judgment making). We dummy-coded the variables rent vs. ownership and type of region. Rent is the reference category for the first variable, while it is big city for the latter. Importantly, as data was collected in two countries, this study provides the model results for both countries.

5.2.3 Key results

Enquiring users' acceptability in monetary terms is accompanied by several challenges, particularly resulting from the circumstance that V2G tariffs are, until now, a hypothetical setting (Section 4.2). To deal with this issue, respondents were informed about the costs of a V2G wallbox and asked about their attitude toward it. The same procedure was carried out with the issue of battery degradation. Thus, as expected, the required compensation was rather high in both countries, which can be explained, among others, by the perceived additional costs stemming from a shortened battery life.

An alternative to operationalizing users' acceptability of V2G is to question respondents about their general willingness to participate in V2G. Paper B thus proposes that particularly psychographic and contextual factors, as well as perceived barriers, are likely to influence users' general anticipation of V2G. Results of the hierarchical multi-regression analysis reveal that barriers and psychographic variables seem to play a much bigger role in explaining the willingness to participate in V2G than contextual variables. This is an important finding as it highlights that the circumstances people live in are far less decisive for people to adopt innovative technologies than their interest in new technologies and their attitude towards the environment. Interestingly, this finding holds for both countries, Germany and the UK.

In particular, the models (3rd step) show that, as expected, battery aging negatively affects users‘ willingness to participate, yet the effect of receiving compensation for battery aging is stronger, indicating greater relevance than battery aging. Interestingly, among all predictors in model 3, receiving compensation for battery degradation has the strongest effect. Both models show similar patterns. Astonishingly, the effect of consumer novelty seeking is the second strongest effect for the German sample, while it is environmental self-identity in the UK.

5.2.4 Critical appraisal

This study operationalized V2G acceptability in two ways, first in monetary terms and second by asking respondents about their general willingness to participate in V2G. Hereby, results reaffirm the relevance of battery aging on both acceptability indicators. Yet, specifically with regard to compensation requirements, further factors might have an effect, e.g., socio-demographic or socio-economic factors, which were not considered in this study. Following on from this, we only studied the user’s viewpoint on compensation, neglecting the extent to which current market conditions allow for such compensation. Future research could thus follow an integrative approach, contrasting the user and market perspective on monetary benefits (e.g., Signer et al., 2024).

Unexpectedly, the country comparison revealed only marginal differences, particularly with respect to contextual factors. Yet, we only tested contextual factors on users’ general willingness to participate. Indeed, contextual factors, in terms of infrastructure and geographies might be more relevant when looking at adoption and specific usage of this technology. Closely related, we didn’t test statistically for country differences, but only compared the two separately calculated models between countries. It would thus be beneficial to elaborate more on contextual factors by integrating the country variables into the model or by setting up an integrated model.

5.3 Paper C: Does experience matter? Assessing user motivations to accept a V2G charging tariff[17]

5.3.1 Motivation and research objectives

EV experience decisively influences users’ evaluation of V2G technology, as well as the motivations and requirements underlying participation in V2G. Previous research points to the notion that users’ experience with EVs in general represents a critical factor in creating an informed decision about issues in the realm of V2G (Chen et al., 2020; Noel et al., 2019a) (see also Section 4.2). This study assumed that the perceptions and knowledge of individuals with different levels of user experience differ for the V2G systems. In other words, V2G is evaluated differently by those who own an EV and those who did not yet buy or got the chance to test an EV and thus do not necessarily have an updated and informed perception of this technology and its usage. As

[17] The authors have requested a corrigendum for this paper at the publisher. The corrigendum is currently being processed. The requested changes refer to the interpretation of the indirect effects. The summary of Paper C already incorporates the correct interpretation.

V2G will diffuse, not only innovators and early adopter groups but also the early and late majority and laggards will at some point be confronted with V2G. Hence, it is precisely the comparison between non-experienced users and EV-experienced users that might be helpful to drawing conclusions on how to motivate these different target groups.

Just like the level of EV experience, motivations, and benefits can guide users' evaluation of V2G as well. Hereby, *Paper C (Baumgartner et al., 2022)* focuses on three overarching motives, derived from the framework developed by Huber et al. (2019) (Section 3.4.1.1) – environmental goals, i.e., higher integration of RES and reduced CO_2 emissions, technical goals, i.e., contributing to grid stability, economic goals, i.e., monetary benefits from participating in V2G. Based on these motives, Paper C tests three charging strategies, i.e., climate-neutral, grid-beneficial, and cost-minimized charging. The objective of Paper C is to investigate the role of user experience and underlying motivations to evaluate willingness to pay and minimum range requirements for a V2G charging service and to answer the following research question: *How does EV experience influence user requirements with respect to minimum range and required savings within a V2G charging tariff and to what extent do underlying motives influence this relationship?*

5.3.2 Methodological approach

To answer the research question, an online survey was conducted in 2021. As a focal point of this study is to evaluate the influence of EV experience on V2G acceptability, the authors collected data using combined randomized and purposive sampling (Section 4.2.2). Next to the sample of people having no EV experience (N=691), this strategy resulted in a comparatively high share of EV-experienced people (N=241) and EV owners (N=264). This was particularly relevant, as this study seeks to contextualize V2G acceptability in terms of EV knowledge and experience.

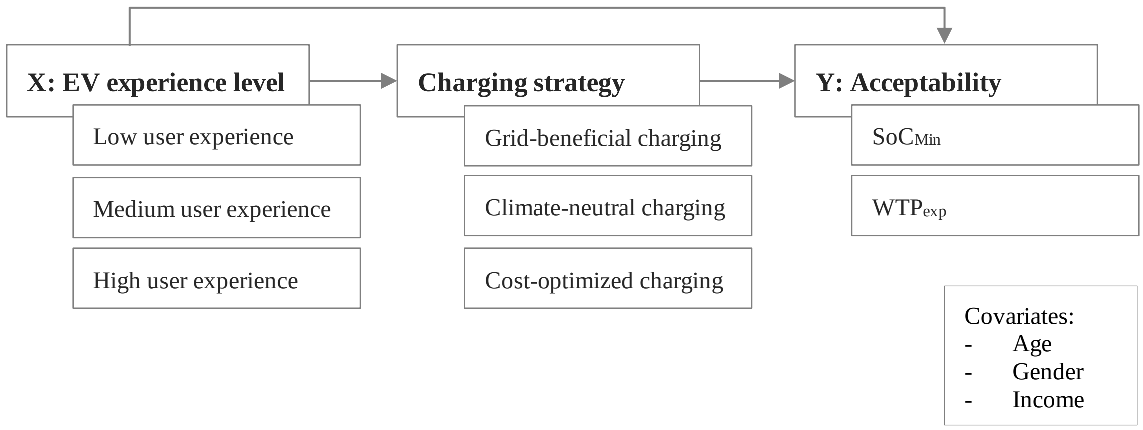


Figure 13: Mediation analysis for X= level of user experience, M= charging strategy, Y= Acceptability for N=1178, illustration based on Baumgartner et al. (2022).

This study first assessed users' minimum range requirements (SoC_{Min}), as a precondition to participate in V2G. Similar to Paper B, Paper C operationalizes V2G acceptability in monetary terms. Yet, while Paper B assesses compensation requirements, the present study asks for users' WTP for a V2G charging tariff (Section 4.2.1). Bringing these aspects together, we built a mediation model (Figure 13), to evaluate the importance of three charging strategies to guide users' minimum range requirements and expected monetary savings. We performed a mediation analysis using the PROCESS macro in SPSS, a methodology that is based on Hayes and Preacher (2014). With this method, the overall relationship between the predictor (X) and the outcome variable (Y) can be explained by both of their relationships with a third variable, the mediator (M), thus reflecting a causal sequence. Mediation occurs when the effect of the independent variable X on the dependent variable Y is reduced by integrating the mediator variable M. We used the bias-corrected bootstrap procedure with multilevel categorical variables (Haye's Model No. 4, N= 10.000) to estimate the direct, total, and indirect (standardized) effects of the linear model. Since the mediators are derived from a constant sum query, we created a separate model for each mediator.

5.3.3 Key results

The results revealed that expectations for the minimum charging level were high, independent of the level of user experience. While user experience alone couldn't explain differences in SoC_{Min}, underlying motivations did. Pursuing a climate-neutral charging strategy or a cost-minimizing charging strategy mediated high user experience compared to low user experience. Both charging strategies lead to accepting lower SoC_{Min} values. This insight is especially relevant from an aggregator's perspective, as these strategies result in higher flexibility potentials that can be raised. A second key result of this study is that users' WTP for a V2G charging service is rather low compared to the reference price, suggesting, that users assign a great value to flexibility, leading to a significantly lower WTP or a higher readiness to pay more in order to gain additional flexibility. Additionally, with regard to user experience, the results were unexpected, in that proficient users were willing to pay significantly lower electricity prices to charge their EV than inexperienced users. EV users thus required higher compensation or, to turn the argument around, EV users expect the monetary benefits arising from V2G to be higher than inexperienced users.

Furthermore, the mediation analysis revealed that a climate-neutral and a cost-minimized charging strategy significantly influenced EV users' WTP for a V2G charging tariff. EV users are thus willing to pay more because a climate-neutral or cost-minimized charging strategy is pursued. EV users thus require lower compensation compared to inexperienced users. A grid-beneficial strategy proves to be non-significant for all groups.

5.3.4 Critical appraisal

To overcome the hypothetical character of the tariff design we specifically targeted EV-experienced people, assuming a higher knowledge level about EVs and V2G in particular. We thus expected more realistic estimations with regard to SoC_{Min} values and WTP for the second tariff level. Yet, even though we detected differences between proficient EV owners and non-experienced people, the effects were different than expected. Moreover, due to a regulatory gap in Germany on selling electricity within a V2G service, we solely focused on the net-purchasing price to charge the EV. Yet, these regulations have changed over time (Section 2.3.2), opening new avenues for concretizing the V2G charging tariff design. Future work could thus integrate and evaluate this new regulatory framework in a V2G tariff scheme. Backing up the tariff design with regulatory information could also be beneficial for drawing more concrete scenarios on V2G. This could also support the assessment of users' WTP for a V2G charging tariff.

Finally, our results revealed that experienced EV users' motivations could be raised by offering a climate-neutral or cost-minimized charging strategy. Further research needs to specifically target the group of people without EV experience in order to achieve the ambitious EV goals. Moreover, the question of which benefits could be raised from an aggregator's perspective by pursuing different V2G charging strategies while accounting for user requirements with low EV experience could be subject to further research.

5.4 Paper D: Personal and community factors as drivers for new energy technology adoption - The case of V2G in three European countries

5.4.1 Motivation and research objectives

Understanding the drivers that underpin the adoption of new energy technologies is key to fostering a successful energy transition. Previous research has highlighted the importance of individual energy behavior in this transition and focused on identifying personal motivations beyond economic and self-interest motives such as ecological or altruistic motives, that underlie sustainable energy use or technology adoption (Steg, 2016; Steg et al., 2015). However, individuals often act within particular social contexts or groups (Section 3.3), which can influence their decision-making as well (e.g., Fielding and Hornsey, 2016; Fritsche et al., 2018; Sloot et al., 2019). This suggests that not only individual behavior but also collective efforts can drive the system transformation. In particular, recent research has pointed to the role of community energy initiatives as one type of collective to facilitate the sustainable energy transition (Schwanitz et al., 2023).

In contrast to Papers B and C, *Paper D* (*Baumgartner et al., 2025*) focuses on social context factors, and personal values. It aims to understand the role that community energy initiatives can have in promoting the adoption of V2G technology. We thus consider the complex interplay between personal and social motivations in influencing citizenship behavior and sustainable practices. Additionally, we examine how those motivational factors are shaped by the local and national environment in which individuals operate, thus accounting for the important role of contextual factors in driving sustainable practices. Specifically, this paper has two main objectives:

i. Proposing a theoretical model that considers both personal and community factors as potential drivers of novel technology adoption.
ii. Testing the theoretical model through an empirical study based on nationally representative data collected in three European countries – Germany, France, and Switzerland – for the case of V2G technology.

5.4.2 Theoretical model

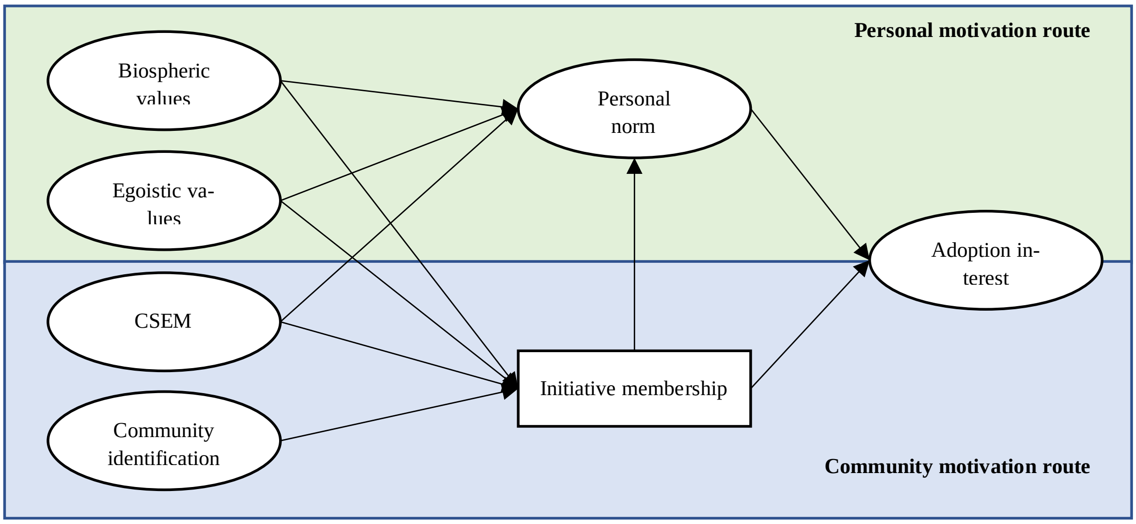


Figure 14: Dual-pathway motivation model of energy technology adoption (Baumgartner et al., 2025).

Paper D develops a theoretical model of energy technology adoption, considering personal motivations alongside community motivations as determinants of individuals' adoption interest (Figure 14). We denote this model dual-pathway model of energy technology adoption. This model suggests that specific factors on both levels can explain energy transition practices such as the adoption and usage of V2G. The personal-motivation route is based on biospheric and egoistic values, with biospheric values influencing adoption decisions positively, and egoistic values influencing adoption decisions negatively, both mainly via personal norms. The community-motivation route includes community factors, including community sustainable energy motivation (CSEM) and community identification, predicting adoption decisions mainly via initiative membership. Next to these two main routes, we propose that personal and community factors can also influence each other, suggesting an interplay between personal and community-based motivations (personal-community motivation route). More specifically, Paper D suggests that biospheric values are associated with initiative membership and in turn lead to a higher V2G adoption interest, while we propose the opposite for individuals with strong egoistic values. Moreover, we hypothesize that community motives (CSEM, initiative membership) have a positive effect on personal norms, and lead to a higher adoption interest of new energy technologies (community-personal motivation route).

5.4.3 Procedure

To test this model, in 2023 we conducted an online questionnaire study among homeowners in France, Germany, and Switzerland. In addition to sampling participants from the general population, we specifically contacted members of energy communities in the three countries (Section 4.2). As V2G technology has yet to be implemented in these three countries, we used a hypothetical adoption decision task to study citizens' adoption interest in the context of V2G. In particular, we created concrete scenarios describing various types of V2G tariffs and used the ratings of these scenarios to measure respondents' interest in adopting V2G (Section 4.2.1).

Methodologically, we used structural equation modeling to test our overall theoretical model and analyze the relationships between personal and community drivers on V2G adoption decisions. This method is well suited for testing our theoretical model and in particular the indirect decision routes, as it allows the modeling of simultaneous regression equations as well as assessing the overall model fit. We first test a model for all three countries and subsequently test a multigroup model to examine differences in effects between the three countries. Due to the number of parameters included in the model, we limited the analysis to an observed path model using mean scores and tested the measurement model in a separate confirmatory factor analysis (CFA), which showed a good overall model fit as well as acceptable item loadings for the variables included. As the structural model contained both continuous and binary endogenous variables (i.e., initiative membership), we estimated the model using a DWLS estimator. To test for the significance of the indirect effects, we used a bootstrapping procedure for standard errors, with 10,000 bootstrap draws in each model. All continuous variables were mean-centered. The multigroup model was tested by adding a group factor (i.e., country) to the model. We lastly compared a constrained model in which all regression parameters were set to be equal across countries to an unconstrained model in which all parameters were allowed to vary freely across the three countries.

5.4.4 Key results

Paper D reveals several interesting findings that have important theoretical implications. First, we find that not only personal factors but also community factors can act as drivers of adoption interest in novel energy technologies. Notably, we show that community factors are also uniquely related to adoption interest, even when accounting for the role of personal motivational factors. Specifically, the community-based route is driven by community identification and initiative membership, but, unexpectedly, not by CSEM via initiative membership. This result suggests that the degree of identification with one's community is more important in explaining adoption interest via initiative membership than what a person believes other community members to find important. While CSEM is seemingly not indirectly related to adoption interest via initiative membership, it is a significant direct predictor of both personal norm and adoption interest. Thus, while initiative membership is not motivated by what people from the neighborhood believe to be important, CSEM is important with regard to personal norms and the adoption interest of in new technologies. Especially with regard to the latter, the perceived motivations of others in the local community seem to matter and influence a person's interest in V2G technology directly. Our findings on CSEM thus extend previous literature by showing intrinsic group motivations as an additional social influence mechanism.

Additionally, our results underline the interdependencies between the two distinct routes – the personal motivation route and the community motivation route. This suggests that, next to being linked to adoption interest directly, initiative membership might strengthen the members' personal norms, implying that identities such as one's initiative membership can become internalized. Reversely, adoption interest is increased indirectly by egoistic values via an increased likelihood of being an initiative member. This finding is interesting, as we expected this motivation path to be primarily driven by non-monetary values, and the motivation to collectively foster a just and participatory energy transition. With regard to country differences, our findings show that indirect effects are similar for all three countries, suggesting that the process by which individuals form an adoption interest in novel energy technologies is more universal than it is distinct across the countries we studied.

5.4.5 Critical appraisal

The main contribution of Paper D is the development of a new theoretical model explaining energy technology adoption interest with personal and social factors, and their interdependencies. Yet, the main challenge arose with using a very specific, not yet established energy technology as a use case. As with Papers B and C, it was not possible to assess the respondents' behavior, but only their V2G adoption intention. Furthermore, V2G is a very complex technology, requiring some basic understanding of EV technology and the functioning of the energy system in order to anticipate and understand the challenges and potential benefits that could arise from V2G for the individual. To deal with this challenge, we created a scenario with three attributes, putting much emphasis on providing sufficient and intuitive information to the respondents in order to create a common knowledge base, and to provide a balanced description of the associated advantages and disadvantages. Yet, providing sufficient information to rate the choices adequately, while at the same time influencing the participant as little as possible is a challenging task (Sections 4.2 and 4.2.1).

With respect to the multigroup model, the results were ambiguous and not very pronounced. This might be due to the low number of initiative members per country. Moreover, especially the imbalanced and low numbers of initiative members might be one reason why we, for example, could not explain initiative membership in Germany, where, comparably, we had the smallest sample of initiative members (Section 4.2.2). Another reason might be that the adoption processes are universal across the countries we studied. Future research could, therefore, explore country differences in more detail. In our study, we focused on three neighboring, European countries. It would be particularly interesting to study countries that are more diverse in their political ambitions, their culture, and political structures.

Chapter 6

6 Conclusions

This thesis followed the aim to derive an improved understanding of the user's role in a V2G system. To this end, in the first step, this work elaborated on how the current state of research characterizes and integrates the user into the V2G system. Secondly, this thesis provided three empirical studies examining factors influencing the user acceptability of V2G technology. Due to the hypothetical nature of V2G, the focus was on the user's intention to use and engage with the technology in question. To gain a holistic understanding of V2G acceptability, the empirical studies focus on different factors, combined, covering relevant V2G acceptability dimensions technical, economic, environmental, and social factors. Moreover, by analyzing the research case for different groups and contexts, this thesis allows to relate specific motives to different sub-groups. Sub-group analysis is hereby deployed in terms of country comparisons and comparisons across different groups of people. Ultimately, the thesis aimed to understand user acceptability of V2G and its underlying motives for different groups and country contexts.

To do so, the author of this work undertook considerable efforts to conduct one systematic literature review and to design three empirical, and comparative studies. The empirical studies cover different V2G acceptability dimensions and strive for different comparisons. Moreover, the studies apply different statistical methods and are based on different theoretical concepts. The following section summarizes the findings and highlights theoretical and policy implications.

6.1 Summary of findings

Due to this thesis's structure, the results' nature is twofold. First, the findings are based on the systematic literature review, paving the way for the three empirical studies (B-D). Primarily, the systematic literature review revealed a lack of empirical research in the field of V2G. Additionally, and, more importantly, the user is integrated in a very simplified way by the majority of studies, not factoring in the complex nature of behavior. Particularly, due to the technology's characteristic as a nexus between the energy and mobility system, and between the user and the energy system, a study's research is deemed to focus on a particular aspect of this multilevel and multifaceted issue. Yet, the user is a primary actor in this system, influencing whether and to what extent flexibility is provided to the grid. While the majority of studies focus on easy-to-integrate variables, such as mobility or charging behavior, preferences, contextual factors, or values are less prominently represented. This is where the three empirical studies contribute. First, by outlining user requirements, second, by assessing V2G acceptability factors, and third, by analyzing different sub-groups.

User requirements. The user requirements to participate in V2G are oftentimes assessed in terms of compensation and range requirements, i.e., the minimun range that has to be available during all times of the charging process. Both requirements are important, as they implicitly reveal the user's inconvenience or readiness to participate in V2G and are important parameters in the framework of a V2G contract between the user and the aggregator, defining the terms and conditions for providing flexibility. Hence, Paper B assessed users' compensation requirements, and Paper C users' WTP and minimum range requirements. Both analyses reveal low WTP and high WTA. Consequently, compensation requirements are high in both cases. These results indicate that either, expectations to profit monetarily from V2G are high, or, conversely, that people are hesitant to participate and would only do so when compensated accordingly. In support of the first interpretation, the finding also shows that proficient EV users claim significantly higher compensation compared to inexperienced users. At the same time, minimum range requirements are high, independent of the level of EV experience. Hence, flexibility seems to be a valuable good. Combined, these results picture a hesitant end-user, with high requirements to participate in V2G. From an aggregator's point of view, considering users' minimum range requirements implies that only low flexibility potentials can be raised, and, additionally, high compensation is necessary.

Acceptability factors. The empirical studies tested a set of factors, that influence users' willingness to participate in V2G. Importantly, the factors were chosen such that they cover the four V2G acceptability dimensions. This theoretical framework is based on Huber et al. (2019), and was adjusted for this thesis (Section 3.4.1.1). The dimensions cover economic, technical, environmental, and social context factors. Yet, the dimensions are interrelated, and their borders are fluid. Importantly, all studies thereby created a case study, where participants had to directly rate a V2G tariff. With this, all studies relate to market acceptance on a household level (Wüstenhagen et al., 2007), as one dimension of social acceptance.

Economic factors. Economic factors are among the most important factors explaining participation in a V2G scheme. Although environmentally friendly behavior, such as the adoption of V2G, is seemingly not purely egoistic and driven by rational choices, economic motives can foster such a behavior as it might increase a person's social status or bear the prospect of earning revenues from V2G. Following these arguments, Paper C and D both emphasize the role of economic motives for the intention to participate in V2G. Concretely, Paper C shows that economic motives, operationalized in terms of a cost-minimized charging strategy, have the impact of guiding users' evaluation of the minimum range and WTP for a V2G charging tariff. Findings reveal that offering such a charging strategy decreases EV users' minimum range requirements while increasing EV owners' WTP. Consequently, higher flexibility potentials can be raised, while, at the same time, EV owners are willing to pay more than inexperienced users. While EV owners seem to value V2G differently than inexperienced users, we also find egoistic values – the propensity to strive for individual status, power, or monetary gains (Huijts et al., 2012) – to play a crucial role regarding the intention to adopt a V2G charging service. While egoistic values positively affect the intention to adopt V2G via personal norms, we also find these values to indirectly affect adoption interest via energy initiative membership. Hence, both studies highlight that though environmentally friendly behavior is not assumed to be primarily egoistic, these motives significantly determine an individual's decision to participate in V2G, emphasizing its potential monetary benefits as well as its potential to foster a person's social status.

Technical factors. Economic and technical factors are particularly closely related. For example, increased battery degradation as a direct effect of V2G charging comes along with monetary implications for the user, as it raises questions of warranty and who bears the additional costs. Its close relationship is shown in Paper B, assessing the importance of battery degradation by German and UK participants. Mean values were high and its effect on compensation requirements was significant, implying, that the stronger people believe battery degradation to be a problem, the higher the revenue requirements. This finding is true for both countries. Additionally, while battery degradation increases users' compensation requirements and decreases users' willingness to participate in V2G, providing compensation has the opposite effect, leading to the conclusion, that offering compensation in the frame of a contract can offset the potential fear of battery degradation. While these factors relate to one of the most important V2G barriers, technical factors can also motivate the adoption of V2G. Specifically, research highlights the role of contributing to grid stability as an important motive to participate in V2G. This motive also complements well with increasing the share of RES, by decreasing the need for expensive energy storage or backup capacities for balancing intermittent RES. Yet, Paper C finds no significant mediation effect of a grid-beneficial charging strategy on users' WTP or range requirements. This leads to the conclusion that users, independent of their level of experience, assign no importance to this charging strategy. Consequently, charging in a grid-beneficial manner does not affect user requirements. As battery degradation is not solely connected to V2G, but EV usage in general, it is a well-known issue to users while they are not equally familiar with issues relating to grid stability. Individuals are generally less knowledgeable about energy topics which leads to the suggestions to promote and communicate more intuitive advantages that subsequently benefit the grid, such as environmental benefits.

Environmental factors. Environmental factors reflect an intrinsic personal motivation to protect the environment and foster the likelihood of engaging in sustainable energy behavior. Participation in a V2G service has a strong environmental motivational component, as V2G enables a higher integration of intermittent RES into the energy system. Hence, all three empirical studies study the relevance of environmental factors, yet, taking different approaches. While study B includes the latent variable environmental self-identity into a hierarchical regression model, Paper C operationalizes this motivation as a charging strategy and Paper D assesses biospheric values. All three studies support the idea, that environmental factors are important direct and indirect determinants of V2G acceptability. Particularly, this is true on a personal level, where environmental values increase adoption interest via increased personal norms or act as a mediator, increasing EV owners' readiness to allow higher levels of flexibility while expecting lower revenues. This demonstrates, that environmental factors are important determinants of V2G acceptability and should be communicated when promoting this technology. As already stated, the environmental benefits of V2G go hand in hand with advantages for the grid, which, again, increases the importance of putting forward these arguments.

Social factors. Social factors consider behavior to be influenced by others, i.e., social groups, and memberships, to which individuals feel a sense of belonging. It is assumed that the values of the group become internalized thus shaping the personal identity. This specific factor was analyzed in Paper D, particularly using two constructs, community identification and CSEM. Results show that community factors explain the adoption interest of V2G, even when accounting for personal motivational factors. Moreover, we find that identification with one's community is more important in explaining adoption interest via initiative membership than what a person believes other members to find important. Additionally, what people from the neighborhood believe to be important, increases one's norms and the adoption interest of new technologies. This implies that the perceived motivations of others in the local community seem to matter and influence a person's interest in V2G technology directly. This is particularly interesting in the early adoption phase when a technology is not yet that known, pointing to the notion that energy initiatives can play a leading role in creating interest in and acceptance toward novel energy technologies.

User characteristics. All three studies include a sub-group analysis. Particularly, Papers C and D strive for a comparison based on user characteristics, i.e., people with different EV knowledge levels, and energy initiative members and non-members. Interestingly, these comparisons reveal significant findings. Particularly, comparing EV owners with non-proficient users shows that the degree of EV experience matters when assessing users' WTP. The WTP decreases with higher levels of EV experience. Yet, compared to people with no EV experience, the WTP increases for EV owners when offering either a cost-minimized or a climate-neutral charging strategy, while range requirements decrease for these charging strategies. In this sense, EV owners evaluate this service differently than inexperienced users. Hence, it is important to approach these groups differently with tailored strategies, such as communicating the environmental and economic benefits when promoting this technology and offering a service. While EV experience does not take the typical form of a group, it may unite these people, also considered the early adopters, shaping behavior more indirectly. Another group, that is yet more explicit and formal, is an energy initiative, where individuals identify as members of this group. Likewise, initiative membership plays a crucial role as well when explaining V2G adoption interest. Specifically, in this case, V2G adoption interest of a V2G service is tested for a personal and a community-based motivation route, showing, that the degree of identification with one's community is important in explaining adoption interest via initiative membership. Moreover, results show that adoption interest is predicted by membership via personal norms, illustrating that initiative membership strengthens members' personal norm, implying that identities such as one's initiative membership can become internalized. In this sense, energy initiatives play a unique role in the energy transition, suggesting that they can foster sustainable energy transition practices.

Countries. Country comparisons are conducted in the framework of Papers B and D. Hereby, the country is included as a specific context in the analysis. Particularly, Paper B studies Germany and the UK, while Paper D focuses on respondents from Germany, Switzerland, and France. Particularly, comparing results for Germany and the UK, reveal slight differences in effect size and significance of predictors. Yet, patterns are similar. This result is also true for the comparison between Germany, France and Switzerland within a multi-group model. Though patterns between countries seem to differ, no significant differences are found. This leads to the conclusion, that comparisons between the countries in focus of the author's studies seem less relevant in explaining adoption interest in V2G.

6.2 Additional contribution of this work

In addition to the thesis's findings, this work provides some noteworthy contributions to the research landscape. Particularly, the collected data in the course of the three empirical studies is very comprehensive and high in quality. Each empirical study provides data on individual motives to accept V2G technology, for either different countries and/or different population sub-groups, such as people with differing EV knowledge and energy initiative members. In particular, Paper B holds comprehensive data from individuals in Germany and the UK, collecting data with a specialized company. In contrast, for Papers C and D, the author followed a randomized and purposive sampling strategy. While the randomized sampling was realized with a specialized company, the purposive sampling was undertaken by the authors of the scientific studies. With considerable effort, the authors targeted and collected data among specific sub-groups, i.e., people with different EV-knowledge levels and members of energy initiatives in three European countries – Germany, Switzerland, and France. While the randomized sample is representative of predefined sociodemographic characteristics, the purposive samples are not. Yet, studying different sub-groups and comparing between countries increases the analysis's generalizability and transferability, outweighing representativeness. Noticeably, as outlined in Section 3.4, very few empirical studies exist that compare motives between different sub-groups or countries. This is where this work contributes to the current state of research. Moreover, it supports the provision of tailored recommendations for these groups. The comparative research approach applied in this thesis substantially contributes to achieving this goal.

Chapter 7

7 Critical appraisal and outlook

Despite the attention of this thesis to highlighting the user role in V2G research and assessing acceptability factors of V2G from a user perspective, the analyses and theoretical propositions have some limitations that should be considered when interpreting them. The following chapter discusses these limitations, provides an outlook toward future research, and points to promising methodological extensions.

The literature review covers 183 research papers, including all years since research began to explore the technology in question. Thus, the literature review contributes by providing a sound overview of the research landscape across disciplines and identifies typical patterns of how the user is integrated into the different research streams. This overview is an important contribution to the research landscape as it points to future research avenues. Yet, the review stays descriptive in its analysis and does not relate or test for the relevance of the different user variables, nor does it provide a deep analysis of the theoretical concepts and their interrelations, lying behind the user categories. Being beyond the scope of this contribution, future research could use the identified user categories and explore their theoretical concepts and how they relate, or focus on empirical studies only and conduct a meta-analysis to identify important indicators explaining the user acceptability of V2G.

The thesis's focus was on V2G, an energy technology that is adopted on an individual level, having wide-ranging implications for the energy system and its transformation. The systematic literature review as well as the empirical studies emphasized the user perspective, the potential motives to adopt this technology and provide flexibility to the energy system. It has to be kept in mind that, though individuals become prosumers in the course of the energy transitions, they are only one stakeholder among many, making a successful integration of energy technologies, such as V2G, happen. A successful integration needs the interplay of diverse stakeholders on different levels (household, regional, national, and international). Hence, the process has to be recognized and understood as complex, multifaceted, and multilevel. In this light, the studies do not represent these multilevel processes, but only capture a facet thereof. The appended papers A-D illuminate the user perspective, as one perspective out of many. Noticeably, this work recognizes that "the user" is not a single entity, but many identities with a diverse set of motives. While this work illustrates that it is important to study these sub-groups, it should not be misinterpreted as capturing the entirety of sub-groups and contexts, framing individual mindsets.

Following this argument, this work explored differences between countries and sub-groups characterized by their experience or membership in a group. As outlined in Section 6.1, the author did not find any pronounced differences between countries. Indeed, the comparisons were undertaken between European countries. The countries in focus – Germany, UK, Switzerland, and France –

pursue different energy transition strategies, promoting different energy technologies. Yet, all countries are united in the goal to reach carbon neutrality to reduce the impact of climate change. In this regard, the studies show that nationality did not particularly impact the interest in adopting V2G. While effect sizes in study B differ between countries, the pattern is similar. In study D, the few differences that the authors could detect in the multigroup model could also result from the low sample size of energy initiative members per country. Hence, future research could strengthen the endeavor to i.) reach higher sample sizes of sub-groups and ii.) widen the scope and study countries that are more diverse in their culture (individualistic vs. collective, different views on technology progress), or follow different political strategies. This would enrich the research landscape, as technology adoption is a necessary condition for successfully reaching climate neutrality, which can only succeed in a common effort of nations.

Studying sub-groups allows the identification of differences and similarities between groups. In all three empirical studies, the groups were categorical variables. While Paper B carries out a separate analysis for each group (country – two groups), Paper C applies dummy coding to compare between groups (EV knowledge levels – three groups) and Paper D integrates the grouping variables in terms of a moderator into the model (country - three groups). Inititiative membership is integrated as an endogenous categorical variable (initiative membership – two groups). Particularly, Paper C carries out a mediation model with categorical predictors, following the approach of Hayes and Preacher (2014). Yet, as the model does not calculate a parallel mediation, where several mediators are calculated in parallel, this model only allows a group comparison for a single mediator. Comparing the indirect effects in an integrated model (parallel mediation) for the three groups would be particularly advantageous. To account for path dependencies and interrelations between variables Paper D builds a structural equation model, including binary and continuous endogenous variables as well as binary grouping variables, allowing the modeling of simultaneous regression equations and assessing the overall model fit.

While structural equation modeling possesses many advantages, it requires large sample sizes to converge (Cheah et al., 2023). Thus, the sample size requirements increase with the model's complexity (Meuleman, 2019). As already noted, we couldn't detect pronounced effects between groups of the multi-group model, which might be due to the small sample size of initiative members in each country. While studying sub-groups has many advantages, it is a challenging task to collect the respective amount of data for these sub-groups. Specifically, collecting data from energy initiative members can only be collected with high effort. Other sub-groups, that may be relevant in this research context, such as neighborhoods, families, or political organizations, might be easier to reach. Moreover, some characteristics are subject to change over time. For example, as study C showed, it was possible to collect high numbers of EV owners and people, with some EV experience, solely by targeting these groups via specialized distributors. Looking at previous studies, most of them were only able to assess respondents' interest in EVs, as the penetration rate of EVs was rather low, only a few years ago. Hence, technological developments settle in society, change minds, and create experiences. To this end, taking up these trends, and including these changes in the analysis, e.g., by conducting longitudinal studies, would be an interesting future research avenue to follow.

These changes in knowledge and experience over time are also important concerning the case study of V2G. Evidently, V2G is a technology that is not yet available on the market but has only been tested in the course of pilot studies. Therefore, it is important to recognize that the results of the surveys reflect the stated momentary opinions of respondents toward the technology, which must not be equated with opinions based on real-life experience. The respondent's answers refer to a hypothetical situation, illustrating a V2G service or contract, and do not automatically reflect how respondents would choose or act in real life. To this end, intention and behavior, or acceptability and acceptance might diverge. Yet, this is a problem inherent to innovative technologies, which is widely acknowledged in technology acceptance research (Section 3.1). Therefore, insights into the divergence might be useful, which can, at the moment only be realized in small and highly selective sample pilot studies, questioning participants over time (e.g., Schmalfuß et al., 2015).

Finally, acknowledging V2G as a multilevel challenge, this thesis has a particular focus on the user level researching market acceptance. Its implications for the system level were largely neglected. Yet, due to V2G's characteristics as a linking element, i.e., sectors and individual and household level with the energy system, the interactions play a crucial role as well and are still underrepresented in current research. As the literature review outlined, there is very little interdisciplinary research on V2G, combining both perspectives, the user and the energy system perspective, studying the interactions and interrelations. Following the argumentation of the literature review, the user requirements have to be integrated as well and can serve as valuable input for energy system models. A follow-up study by Signer et al. (2024), thus considers the results of Paper C, qualitatively comparing the user's monetary requirements with revenues that can be provided to the user, calculated from an agent-based energy-system model. Future research could foster and intensify these efforts and could even strive towards application-oriented research, as the market-ramp up of V2G proceeds.

8 References

ACER, 2021. ACER Report on Distribution Tariff Methodologies in Europe, 88 pp.

Agora Energiewende, 2022. Climate-neutral power system 2035. How the German power sector can become climate-neutral by 2035., 22 pp.

Agora Verkehrswende, 2023. Verkehrssektor verfehlt 2022 erneut Klimaziel.

Anderson, J., Vadnjal, D., Uhlin, H.-E., 2000. Moral dimensions of the WTA–WTP disparity: an experimental examination. Ecological Economics 32, 153–162. https://doi.org/10.1016/S0921-8009(99)00074-9.

Arts, J.W., Frambach, R.T., Bijmolt, T.H., 2011. Generalizations on consumer innovation adoption: A meta-analysis on drivers of intention and behavior. International Journal of Research in Marketing 28, 134–144. https://doi.org/10.1016/j.ijresmar.2010.11.002.

Axsen, J., Goldberg, S., Bailey, J., 2016. How might potential future plug-in electric vehicle buyers differ from current “Pioneer” owners? Transportation Research Part D: Transport and Environment 47, 357–370. https://doi.org/10.1016/j.trd.2016.05.015.

Axsen, J., Kurani, K.S., 2012. Interpersonal Influence within Car Buyers’ Social Networks: Applying Five Perspectives to Plug-in Hybrid Vehicle Drivers. Environ Plan A 44, 1047–1065. https://doi.org/10.1068/a43221x.

Axsen, J., Langman, B., Goldberg, S., 2017. Confusion of innovations: Mainstream consumer perceptions and misperceptions of electric-drive vehicles and charging programs in Canada. Energy Research & Social Science 27, 163–173. https://doi.org/10.1016/j.erss.2017.03.008.

Azjen, I., 1991. The Theory of Planned Behavior. Organizational Behavior and Human Decision Processes, 179–211.

Bailey, J., Axsen, J., 2015. Anticipating PEV buyers’ acceptance of utility controlled charging. Transportation Research Part A: Policy and Practice 82, 29–46. https://doi.org/10.1016/j.tra.2015.09.004.

Bamberg, S., Möser, G., 2007. Twenty years after Hines, Hungerford, and Tomera: A new meta-analysis of psycho-social determinants of pro-environmental behaviour. Journal of Environmental Psychology 27, 14–25. https://doi.org/10.1016/j.jenvp.2006.12.002.

Bamberg, S., Rees, J., Seebauer, S., 2015. Collective climate action: Determinants of participation intention in community-based pro-environmental initiatives. Journal of Environmental Psychology 43, 155–165. https://doi.org/10.1016/j.jenvp.2015.06.006.

Baron, R.M., Kenny, D.A., 1986. The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. Journal of personality and social psychology 51, 1173–1182. https://doi.org/10.1037/0022-3514.51.6.1173.

Barth, M., Jugert, P., Fritsche, I., 2016. Still underdetected – Social norms and collective efficacy predict the acceptance of electric vehicles in Germany. Transportation Research Part F: Traffic Psychology and Behaviour 37, 64–77. https://doi.org/10.1016/j.trf.2015.11.011.

Barth, M., Masson, T., Fritsche, I., Fielding, K., Smith, J.R., 2021. Collective responses to global challenges: The social psychology of pro-environmental action. Journal of Environmental Psychology 74, 101562. https://doi.org/10.1016/j.jenvp.2021.101562.

Baumgartner, N., Kellerer, F., Dreisbusch, M., Mang, S., Ruppert, M., Fichtner, W., 2019. Persisting barriers in the context of vehicle to grid: exploring the role of minimum security range based on consumer experience. WEVJ 10, 77–83. https://doi.org/10.1049/icp.2021.2508.

Baumgartner, N., Kellerer, F., Ruppert, M., Hirsch, S., Mang, S., Fichtner, W., 2022. Does experience matter? Assessing user motivations to accept a vehicle-to-grid charging tariff. Transportation Research Part D: Transport and Environment 113, 103528. https://doi.org/10.1016/j.trd.2022.103528.

Baumgartner, N., Klumpp, N., Signer, T., Wadud, Z., Fichtner, W., 2024. Users' Willingness to Participate in V2G – A Comparison Between German and UK Households, in: 2024 20th International Conference on the European Energy Market (EEM). 2024 20th International Conference on the European Energy Market (EEM), Istanbul, Turkiye. 10.06.2024 - 12.06.2024. IEEE, pp. 1–8.

Baumgartner, N., Weyer, K., Eckmann, L., Fichtner, W., 2023. How to integrate users into smart charging – A critical and systematic review. Energy Research & Social Science 100, 103113. https://doi.org/10.1016/j.erss.2023.103113.

Baumgartner, N., Sloot, D., Günther, A., Hahnel, U.J., 2025. Development and test of a dual-pathway model of personal and community factors driving new energy technology adoption - The case of V2G in three European countries. Ecological Economics 230, 108514. https://doi.org/10.1016/j.ecolecon.2024.108514.

Bauwens, T., Gotchev, B., Holstenkamp, L., 2016. What drives the development of community energy in Europe? The case of wind power cooperatives. Energy Research & Social Science 13, 136–147. https://doi.org/10.1016/j.erss.2015.12.016.

BDEW, 2024a. Entwicklung des Nettostromverbrauchs nach Verbrauchern: Letztverbrauch Strom nach Verbrauchergruppen in Deutschland, 1 p.

BDEW, 2024b. BDEW - Strompreisanalyse Juli 2024. https://www.bdew.de/service/daten-und-grafiken/bdew-strompreisanalyse/.

Beise, M., Rennings, K., 2005. Lead markets and regulation: a framework for analyzing the international diffusion of environmental innovations. Ecological Economics 52, 5–17. https://doi.org/10.1016/j.ecolecon.2004.06.007.

Biel, A., Johansson-Stenman, O., Nilsson, A., 2011. The willingness to pay–willingness to accept gap revisited: The role of emotions and moral satisfaction. Journal of Economic Psychology 32, 908–917. https://doi.org/10.1016/j.joep.2011.07.010.

Black, J.S., Stern, P.C., Elworth, J.T., 1985. Personal and contextual influences on househould energy adaptations. Journal of Applied Psychology 70, 3–21. https://doi.org/10.1037/0021-9010.70.1.3.

Blumberg, G., Broll, R., Weber, C., 2022. The impact of electric vehicles on the future European electricity system – A scenario analysis. Energy Policy 161, 112751. https://doi.org/10.1016/j.enpol.2021.112751.

BMDV, 2024. Das BMDV bringt die Elektromobilität in Deutschland voran. https://bmdv.bund.de/SharedDocs/DE/Artikel/K/elektromobilitaet-in-deutschland.html.

BMUB. Kurzinformationen Elektromobilität bezüglich Strom- und Ressourcenbedarf, 9 pp. https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Verkehr/emob_strom_ressourcen_bf.pdf (accessed 22 June 2024).

Bradley, G.L., Deshpande, S., Paas, K.H., 2024. The personal and the social: Twin contributors to climate action. Journal of Environmental Psychology 93, 102194. https://doi.org/10.1016/j.jenvp.2023.102194.

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qualitative Research in Psychology 3, 77–101. https://doi.org/10.1191/1478088706qp063oa.

Breidert, C., Hahsler, M., Reutterer, T., 2006. A Review of Methods for Measuring Willingness-to-Pay. Innovative Marketing 2, 8–31.

Brinkel, N., Zijlstra, M., van Bezu, R., van Twuijver, T., Lampropoulos, I., van Sark, W., 2023. A comparative analysis of charging strategies for battery electric buses in wholesale electricity and ancillary services markets. Transportation Research Part E: Logistics and Transportation Review 172, 103085. https://doi.org/10.1016/j.tre.2023.103085.

Brunner, C., Deac, G., Braun, S., Zöphel, C., 2020. The future need for flexibility and the impact of fluctuating renewable power generation. Renewable Energy 149, 1314–1324. https://doi.org/10.1016/j.renene.2019.10.128.

Bühler, F., Cocron, P., Neumann, I., Franke, T., Krems, J.F., 2014. Is EV experience related to EV acceptance? Results from a German field study. Transportation Research Part F: Traffic Psychology and Behaviour 25, 34–49. https://doi.org/10.1016/j.trf.2014.05.002.

Bundesministerium für Wirtschaft und Klimaschutz. Bundes-Klimaschutzgesetz.

Bundesministerium für Wirtschaft und Klimaschutz. Gesetz über die Elektrizitäts- und Gasversorgung: Energiewirtschaftsgesetz – EnWG.

Bundesministerium für Wirtschaft und Klimaschutz, 2023. Gesetz für den Ausbau erneuerbarer Energien: Erneuerbare-Energien-Gesetz - EEG.

Burger, J., Hildermeier, J., Jahn, A., Rosenow, J., 2022. The time is now: smart charging of electric vehicles, Belgium, 49 pp.

Busse, M., Siebert, R., 2018. Acceptance studies in the field of land use—A critical and systematic review to advance the conceptualization of acceptance and acceptability. Land Use Policy 76, 235–245. https://doi.org/10.1016/j.landusepol.2018.05.016.

BVES - Bundesverband Energiespeicher Systeme e. V. (Ed.), 2023. Ausschussdrucksache 20(25) 476: Stellungnahme des BVES zur öffentlichen Anhörung des Ausschuss für Klimaschutz und Energie im Deutschen Bundestag, 27. September 2023, 10 pp.

Chadwick, K., Russell-Bennett, R., Biddle, N., 2022. The role of human influences on adoption and rejection of energy technology: A systematised critical review of the literature on household energy transitions. Energy Research & Social Science 89, 102528. https://doi.org/10.1016/j.erss.2022.102528.

Chard, E., Bergstad, C.J., Steentjes, K., Poortinga, W., Demski, C., 2024. Gender and cross-country differences in the determinants of sustainable diet intentions: a multigroup analysis of the UK, China, Sweden, and Brazil. Frontiers in psychology 15, 1–14. https://doi.org/10.3389/fpsyg.2024.1355969.

Cheah, J.-H., Amaro, S., Roldán, J.L., 2023. Multigroup analysis of more than two groups in PLS-SEM: A review, illustration, and recommendations. Journal of Business Research 156, 113539. https://doi.org/10.1016/j.jbusres.2022.113539.

Chen, C., Zarazua de Rubens, G., Noel, L., Kester, J., Sovacool, B.K., 2020. Assessing the socio-demographic, technical, economic and behavioral factors of Nordic electric vehicle adoption and the influence of vehicle-to-grid preferences. Renewable and Sustainable Energy Reviews 121, 1–13. https://doi.org/10.1016/j.rser.2019.109692.

Conner, M., Armitage, C.J., 1998. Extending the Theory of Planned Behavior: A Review and Avenues for Further Research. J Applied Social Pyschol 28, 1429–1464. https://doi.org/10.1111/j.1559-1816.1998.tb01685.x.

Contu, D., Mourato, S., 2020. Complementing choice experiment with contingent valuation data: Individual preferences and views towards IV generation nuclear energy in the UK. Energy Policy 136, 111032. https://doi.org/10.1016/j.enpol.2019.111032.

Das, H.S., Rahman, M.M., Li, S., Tan, C.W., 2020. Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review. Renewable and Sustainable Energy Reviews 120, 109618. https://doi.org/10.1016/j.rser.2019.109618.

Daziano, R.A., 2022. Willingness to delay charging of electric vehicles. Research in Transportation Economics 94, 101177. https://doi.org/10.1016/j.retrec.2021.101177.

Dean, M.D., Kockelman, K.M., 2024. Americans' opinions and interests in plug-in electric vehicle smart charging programs. Transportation Research Part D: Transport and Environment 129, 104129. https://doi.org/10.1016/j.trd.2024.104129.

Delmonte, E., Kinnear, N., Jenkins, B., Skippon, S., 2020. What do consumers think of smart charging? Perceptions among actual and potential plug-in electric vehicle adopters in the United Kingdom. Energy Research & Social Science 60, 1–12. https://doi.org/10.1016/j.erss.2019.101318.

Devine-Wright, P., 2008. Reconsidering public acceptance of renewable energy technologies: A critical review, in: Grubb, M., Jamasb, T., Pollitt, M.G. (Eds.), Delivering a low carbon electricity system: Technologies, economics, and policy, 1st ed. Cambridge Univ. Press, Cambridge.

Die Bundesregierung, 2024. Ein Plan fürs Klima. https://www.bundesregierung.de/breg-de/themen/tipps-fuer-verbraucher/klimaschutzgesetz-2197410.

Dietz, T., 2015. Environmental value. Oxford University Press, 329–350. https://doi.org/10.1093/acprof:oso/9780198716600.003.0016, 329-350.

DIHK, 2020. Strombeschaffung und Stromhandel: Hintergründe, Herausforderungen, Hinweise, 23 pp.

Dudenhöffer, K., 2015. Akzeptanz von Elektroautos in Deutschland und China: Eine Untersuchung von Nutzungsintentionen im Anfangsstadium der Innovationsdiffusion. Zugl.: Duisburg-Essen, Univ., Diss., 2014. Springer Gabler, Wiesbaden, 398 pp.

Dütschke, E., Paetz, A.-G., 2013. Dynamic electricity pricing—Which programs do consumers prefer? Energy Policy 59, 226–234. https://doi.org/10.1016/j.enpol.2013.03.025.

Emmerich, P., Hülemeier, A.-G., Jendryczko, D., Baumann, M.J., Weil, M., Baur, D., 2020. Public acceptance of emerging energy technologies in context of the German energy transition. Energy Policy 142, 111516. https://doi.org/10.1016/j.enpol.2020.111516.

Emodi, N.V., Dwyer, S., Nagrath, K., Alabi, J., 2022. Electromobility in Australia: Tariff Design Structure and Consumer Preferences for Mobile Distributed Energy Storage. Sustainability 14, 6631. https://doi.org/10.3390/su14116631.

Englberger, S., Abo Gamra, K., Tepe, B., Schreiber, M., Jossen, A., Hesse, H., 2021. Electric vehicle multi-use: Optimizing multiple value streams using mobile storage systems in a vehicle-to-grid context. Applied Energy 304, 117862. https://doi.org/10.1016/j.apenergy.2021.117862.

Ensslen, A., Ringler, P., Dörr, L., Jochem, P., Zimmermann, F., Fichtner, W., 2018. Incentivizing smart charging: Modeling charging tariffs for electric vehicles in German and French electricity markets. Energy Research & Social Science 42, 112–126. https://doi.org/10.1016/j.erss.2018.02.013.

EPEX SPOT, 2022. Trading at EPEX Spot, 8 pp.

Expertenbeirat Klimaschutz in der Mobilität, 2023. Den Hochlauf in der Elektromobilität stärken: Instrumente zur Erreichung des 15 Millionen-Ziels: Policy Brief, 36 pp.

FfE, bayernwerk netz, BMW Group, KEO, Kostal, TenneT, PPC, 2022. Zwischenspeicherung von Energie in bidirektional ladenden Elektrofahrzeugen zur Optimierung des Ladevorgangs am Intraday-Markt - Ein BDL-Positionspapier zu der Vehicle-to-Intraday Anwendung. https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://www.ffe.de/wp-content/uploads/2022/11/Positionspapier_V2I_versand.pdf&ved=2ahUKEwif9-773u6GAxVw7LsIHRawBjUQFnoECBEQAQ&usg=AOvVaw1vypLl-pSGQNQLwzXzCxvQZ.

Field, A., 2018. Discovering statistics using IBM SPSS statistics, 5th ed. SAGE, Los Angeles, London, New Delhi, Singapore, Washington DC, Melbourne, 1070 pp.

Fielding, K.S., Hornsey, M.J., 2016. A Social Identity Analysis of Climate Change and Environmental Attitudes and Behaviors: Insights and Opportunities. Frontiers in psychology 7, 121. https://doi.org/10.3389/fpsyg.2016.00121.

Fielding, K.S., McDonald, R., Louis, W.R., 2008a. Theory of planned behaviour, identity and intentions to engage in environmental activism. Journal of Environmental Psychology 28, 318–326. https://doi.org/10.1016/j.jenvp.2008.03.003.

Fielding, K.S., Terry, D.J., Masser, B.M., Hogg, M.A., 2008b. Integrating social identity theory and the theory of planned behaviour to explain decisions to engage in sustainable agricultural practices. The British journal of social psychology 47, 23–48. https://doi.org/10.1348/014466607X206792.

Fraunhofer ISE, 2024. Energy-Charts: Öffentliche Nettostromerzeugung in Deutschland. https://www.energy-charts.info/charts/power/chart.htm?l=de&c=DE&week=24.

Fournis, Y., Fortin, M.-J., 2017. From social 'acceptance' to social 'acceptability' of wind energy projects: towards a territorial perspective. Journal of Environmental Planning and Management 60, 1–21. https://doi.org/10.1080/09640568.2015.1133406.

Frank, D.-A., Chrysochou, P., Mitkidis, P., 2023. The paradox of technology: Negativity bias in consumer adoption of innovative technologies. Psychology and Marketing 40, 554–566. https://doi.org/10.1002/mar.21740.

Franke, T., Krems, J.F., 2013. Interacting with limited mobility resources: Psychological range levels in electric vehicle use. Transportation Research Part A: Policy and Practice 48, 109–122. https://doi.org/10.1016/j.tra.2012.10.010.

Fritsche, I., Barth, M., Jugert, P., Masson, T., Reese, G., 2018. A social identity model of pro-environmental action (SIMPEA). Psychological review 125, 245–269. https://doi.org/10.1037/rev0000090.

Fritsche, I., Masson, T., 2021. Collective climate action: When do people turn into collective environmental agents? Current opinion in psychology 42, 114–119. https://doi.org/10.1016/j.copsyc.2021.05.001.

Georgantzís, N., Navarro-Martínez, D., 2010. Understanding the WTA–WTP gap: Attitudes, feelings, uncertainty and personality. Journal of Economic Psychology 31, 895–907. https://doi.org/10.1016/j.joep.2010.07.004.

Geske, J., Schumann, D., 2018. Willing to participate in vehicle-to-grid (V2G)? Why not! Energy Policy 120, 392–401. https://doi.org/10.1016/j.enpol.2018.05.004.

Ghotge, R., Nijssen, K.P., Annema, J.A., Lukszo, Z., 2022. Use before You Choose: What Do EV Drivers Think about V2G after Experiencing It? Energies 15, 4907. https://doi.org/10.3390/en15134907.

Gifford, R., Nilsson, A., 2014. Personal and social factors that influence pro-environmental concern and behaviour: a review. International journal of psychology: Journal international de psychologie 49, 141–157. https://doi.org/10.1002/ijop.12034.

Gschwendtner, C., Knoeri, C., Stephan, A., 2023. The impact of plug-in behavior on the spatial–temporal flexibility of electric vehicle charging load. Sustainable Cities and Society 88, 104263. https://doi.org/10.1016/j.scs.2022.104263.

Gschwendtner, C., Sinsel, S.R., Stephan, A., 2021. Vehicle-to-X (V2X) implementation: An overview of predominate trial configurations and technical, social and regulatory challenges. Renewable and Sustainable Energy Reviews 145, 110977. https://doi.org/10.1016/j.rser.2021.110977.

Hampton, H., Foley, A., Del Rio, D.F., Smyth, B., Laverty, D., Caulfield, B., 2022. Customer engagement strategies in retail electricity markets: A comprehensive and comparative review. Energy Research & Social Science 90, 102611. https://doi.org/10.1016/j.erss.2022.102611.

Harthan, R.O., Förster, H., Borkowski, K., Böttcher, H., Braungardt, S., Bürger, V., Emele, L., Görz, W.K., Hennenberg, K., Jansen, L.L., Jörß, W., Kasten, P., Loreck, Charlotte, Ludig, Sylvie, Matthes, F., Mendelevitch, R., Nissen, C., Repenning, J., Scheffler, M., Steinbach, I., Bei der Wieden, L., Wiegmann, K., Brugger, H., Fleiter, T., Mandel, T., Rehfeldt, Matthias, Rhode, C., Yu, S., Steinbach, J., Deurer, Jana: Fuß, Roland, Rock, J., Osterburg, B., Rüter, S., Adam, S., Dunger, KArsten, Rösemann, Claus, Stürmer, W., Tiemeyer, B., Vos, C., 2023. Projektionsbericht 2023 für Deutschland. Climate Change 39/2023, 274 pp.

Haustein, S., Jensen, A.F., Cherchi, E., 2021. Battery electric vehicle adoption in Denmark and Sweden: Recent changes, related factors and policy implications. Energy Policy 149, 112096. https://doi.org/10.1016/j.enpol.2020.112096.

Hayes, A.F., Preacher, K.J., 2014. Statistical mediation analysis with a multicategorical independent variable. The British journal of mathematical and statistical psychology 67, 451–470. https://doi.org/10.1111/bmsp.12028.

Hayes, A.F., Scharkow, M., 2013. The relative trustworthiness of inferential tests of the indirect effect in statistical mediation analysis: does method really matter? Psychological science 24, 1918–1927. https://doi.org/10.1177/0956797613480187.

Heilmann, C., Friedl, G., 2021. Factors influencing the economic success of grid-to-vehicle and vehicle-to-grid applications—A review and meta-analysis. Renewable and Sustainable Energy Reviews 145, 111115. https://doi.org/10.1016/j.rser.2021.111115.

Helferich, M., Tröger, J., Stephan, A., Preuß, S., Pelka, S., Stute, J., Plötz, P., 2024. Tariff option preferences for smart and bidirectional charging: Evidence from battery electric vehicle users in Germany. Energy Policy 192, 114240. https://doi.org/10.1016/j.enpol.2024.114240.

Henriksen, I.M., Throndsen, W., Ryghaug, M., Skjølsvold, T.M., 2021. Electric vehicle charging and end-user motivation for flexibility: a case study from Norway. Energ Sustain Soc 11. https://doi.org/10.1186/s13705-021-00319-z.

Hildermeier, J., Burger, J., Jahn, A., Rosenow, J., 2023. A Review of Tariffs and Services for Smart Charging of Electric Vehicles in Europe. Energies 16, 1–13. https://doi.org/10.3390/en16010088.

HM Government, 2021. Net Zero Strategy: Build Back Greener: Presented to Parliament pursuant to Section 14 of the Climate Change Act 2008, 368 pp.

Hofstetter, R., Miller, K.M., 2009. Precision pricing: Measuring consumers' willingness to pay accurately. Zugl.: Bern, Univ., Diss., 2008. Books on Demand, Norderstedt, 280 pp.

Horowitz, J.K., McConnell, K.E., 2002. A Review of WTA/WTP Studies. Journal of Environmental Economics and Management 44, 426–447. https://doi.org/10.1006/jeem.2001.1215.

Houser, M., Gazley, B., Reynolds, H., Grennan Browning, E., Sandweiss, E., Shanahan, J., 2022. Public support for local adaptation policy: The role of social-psychological factors, perceived climatic stimuli, and social structural characteristics. Global Environmental Change 72, 102424. https://doi.org/10.1016/j.gloenvcha.2021.102424.

Huang, B., Meijssen, A.G., Annema, J.A., Lukszo, Z., 2021. Are electric vehicle drivers willing to participate in vehicle-to-grid contracts? A context-dependent stated choice experiment. Energy Policy 156, 112410. https://doi.org/10.1016/j.enpol.2021.112410.

Huber, J., Schaule, E., Jung, D., Weinhardt, C., 2019. Quo Vadis Smart Charging? A Literature Review and Expert Survey on Technical Potentials and User Acceptance of Smart Charging Systems. WEVJ 10. https://doi.org/10.3390/wevj10040085.

Huckebrink, D., Bertsch, V., 2021. Integrating Behavioural Aspects in Energy System Modelling—A Review. Energies 14, 4579. https://doi.org/10.3390/en14154579.

Huijts, N., Molin, E., Steg, L., 2012. Psychological factors influencing sustainable energy technology acceptance: A review-based comprehensive framework. Renewable and Sustainable Energy Reviews 16, 525–531. https://doi.org/10.1016/j.rser.2011.08.018.

Ilg, A., 2024. Flexibility options in a sustainable power system - Approaches from different power system perspectives. Karlsruher Institut für Technologie (KIT).

IRENA, 2023. Innovation landscape for smart electrification: Decarbonising end-use sectors with renewable power. https://www.irena.org/Publications/2023/Jun/Innovation-landscape-for-smart-electrification.

Jackson, T., 2005. Motivating Sustainable Consumption: a review of evidence on consumer behaviour and behavioural change. a report to the Sustainable Development Research Network. Sustain Dev Res Netw 29.

Jansen, M., Gross, R., Staffell, I., 2024. Quantitative evidence for modelling electric vehicles. Renewable and Sustainable Energy Reviews, 114524. https://doi.org/10.1016/j.rser.2024.114524.

Jansson, J., Marell, A., Nordlund, A., 2011. Exploring consumer adoption of a high involvement eco-innovation using value-belief-norm theory. Journal of Consumer Behaviour 10, 51–60. https://doi.org/10.1002/cb.346.

Jensen, A.F., Cherchi, E., Mabit, S.L., 2013. On the stability of preferences and attitudes before and after experiencing an electric vehicle. Transportation Research Part D: Transport and Environment 25, 24–32. https://doi.org/10.1016/j.trd.2013.07.006.

Johnson, D.S., Bardhi, F., Dunn, D.T., 2008. Understanding how technology paradoxes affect customer satisfaction with self-service technology: The role of performance ambiguity and trust in technology. Psychology and Marketing 25, 416–443. https://doi.org/10.1002/mar.20218.

Kahneman, D., Knetsch, J.L., Thaler, R.H., 1990. Experimental Tests of the Endowment Effect and the Coase Theorem. Journal of Political Economy 98, 1325–1348. https://doi.org/10.1086/261737.

Kemmler, A., Wünsch, A., Burret, H., 2021. Entwicklung des Bruttostromverbrauchs bis 2030: Berechnungsergebnisse aus dem Szenario 1. erstellt im Rahmen des Vorhabens Projektionen zu nationalen und europäischen Energie- und Klimazielen und zu Wirkungen von Einzelmaßnahmen und Maßnahmenprogrammen, 5 pp. https://www.prognos.com/sites/default/files/2021-11/20211116_Kurzpaper_Bruttostromverbrauch2018-2030.pdf (accessed 24 May 2024).

Kempton, Tomić, 2005. Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy. Journal of Power Sources 144, 280–294. https://doi.org/10.1016/j.jpowsour.2004.12.022.

Kempton, W., Letendre, S.E., 1997. Electric Vehicles as a new Power Source for Electric Utilities. Transportation Research Part D: Transport and Environment, 3, 157–175.

Kern, T., Dossow, P., Morlock, E., 2022. Revenue opportunities by integrating combined vehicle-to-home and vehicle-to-grid applications in smart homes. Applied Energy 307, 118187. https://doi.org/10.1016/j.apenergy.2021.118187.

Kester, J., Zarazua de Rubens, G., Sovacool, B.K., Noel, L., 2019. Public perceptions of electric vehicles and vehicle-to-grid (V2G): Insights from a Nordic focus group study. Transportation Research Part D: Transport and Environment 74, 277–293. https://doi.org/10.1016/j.trd.2019.08.006.

Khezri, R., Steen, D., Le Anh Tuan, 2024. Willingness to Participate in Vehicle-to-Everything (V2X) in Sweden, 2022—Using an Electric Vehicle's Battery for More Than Transport. Sustainability 16, 1792. https://doi.org/10.3390/su16051792.

Klöckner, C.A., 2014. The dynamics of purchasing an electric vehicle – A prospective longitudinal study of the decision-making process. Transportation Research Part F: Traffic Psychology and Behaviour 24, 103–116. https://doi.org/10.1016/j.trf.2014.04.015.

Klok, C.W., Kirkels, A.F., Alkemade, F., 2023. Impacts, procedural processes, and local context: Rethinking the social acceptance of wind energy projects in the Netherlands. Energy Research & Social Science 99, 103044. https://doi.org/10.1016/j.erss.2023.103044.

Knezovic, K., Martinenas, S., Andersen, P.B., Zecchino, A., Marinelli, M., 2017. Enhancing the Role of Electric Vehicles in the Power Grid: Field Validation of Multiple Ancillary Services. IEEE Trans. Transp. Electrific. 3, 201–209. https://doi.org/10.1109/TTE.2016.2616864.

Knezović, K., Marinelli, M., Zecchino, A., Andersen, P.B., Traeholt, C., 2017. Supporting involvement of electric vehicles in distribution grids: Lowering the barriers for a proactive integration. Energy 134, 458–468. https://doi.org/10.1016/j.energy.2017.06.075.

Koirala, B.P., Araghi, Y., Kroesen, M., Ghorbani, A., Hakvoort, R.A., Herder, P.M., 2018. Trust, awareness, and independence: Insights from a socio-psychological factor analysis of citizen knowledge and participation in community energy systems. Energy Research & Social Science 38, 33–40. https://doi.org/10.1016/j.erss.2018.01.009.

Kollmuss, A., Agyeman, J., 2002. Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? Environmental Education Research 8, 239–260. https://doi.org/10.1080/13504620220145401.

Kraftfahrtbundesamt, 2024. Jahresbilanz 2024: Zahlen, Daten, Fakten. https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/Jahrebilanz_Bestand/fz_b_jahresbilanz_node.html.

Kramer, J., Petzoldt, T., 2022. A matter of behavioral cost: Contextual factors and behavioral interventions interactively influence pro-environmental charging decisions. Journal of Environmental Psychology 84, 101878. https://doi.org/10.1016/j.jenvp.2022.101878.

Kubli, M., 2022. EV drivers' willingness to accept smart charging: Measuring preferences of potential adopters. Transportation Research Part D: Transport and Environment 109, 103396. https://doi.org/10.1016/j.trd.2022.103396.

Kubli, M., Loock, M., Wüstenhagen, R., 2018. The flexible prosumer: Measuring the willingness to co-create distributed flexibility. Energy Policy 114, 540–548. https://doi.org/10.1016/j.enpol.2017.12.044.

Kucevic, D., Englberger, S., Sharma, A., Trivedi, A., Tepe, B., Schachler, B., Hesse, H., Srinivasan, D., Jossen, A., 2021. Reducing grid peak load through the coordinated control of battery energy storage systems located at electric vehicle charging parks. Applied Energy 295, 116936. https://doi.org/10.1016/j.apenergy.2021.116936.

Lacey, G., Putrus, G., Bentley, E., 2017. Smart EV charging schedules: supporting the grid and protecting battery life. IET Electrical Systems in Transportation 7, 84–91. https://doi.org/10.1049/iet-est.2016.0032.

Lagomarsino, M., van der Kam, M., Parra, D., Hahnel, U.J., 2022. Do I need to charge right now? Tailored choice architecture design can increase preferences for electric vehicle smart charging. Energy Policy 162, 112818. https://doi.org/10.1016/j.enpol.2022.112818.

Larson, P.D., Viáfara, J., Parsons, R.V., Elias, A., 2014. Consumer attitudes about electric cars: Pricing analysis and policy implications. Transportation Research Part A: Policy and Practice 69, 299–314. https://doi.org/10.1016/j.tra.2014.09.002.

Lee, C.-Y., Jang, J.-W., Lee, M.-K., 2020. Willingness to accept values for vehicle-to-grid service in South Korea. Transportation Research Part D: Transport and Environment 87, 1–10. https://doi.org/10.1016/j.trd.2020.102487.

Lee, S.S., Kim, Y., Roh, T., 2023. Pro-environmental behavior on electric vehicle use intention: Integrating value-belief-norm theory and theory of planned behavior. Journal of Cleaner Production 418, 138211. https://doi.org/10.1016/j.jclepro.2023.138211.

Lehmann, N., 2023. Regionality in Electricity Products – A Residential Consumer Perspective. Dissertation, 363 pp.

Lehmann, N., Huber, J., Kiesling, A., 2019. 16th International Conference on the European Energy Market (EEM): 18-20 September 2019, Ljubljana, Slovenia. IEEE, Piscataway, NJ, 1 p.

Libertson, F., 2022a. (No) room for time-shifting energy use: Reviewing and reconceptualizing flexibility capital. Energy Research & Social Science 94, 102886. https://doi.org/10.1016/j.erss.2022.102886.

Libertson, F., 2022b. Requesting control and flexibility: Exploring Swedish user perspectives of electric vehicle smart charging. Energy Research & Social Science 92, 102774. https://doi.org/10.1016/j.erss.2022.102774.

Lindberg, S., Steg, L., 2013. What Makes Organizations in Market Democracies Adopt Environmentally-Friendly Policies?, in: Hergatt Huffman, A., Klein, S.R. (Eds.), Green organizations: Driving change with I-O psychology, 1st ed. Routledge, New York, pp. 93–114.

Lindenberg, S., Steg, L., 2007. Normative, Gain and Hedonic Goal Frames Guiding Environmental Behavior. Journal of Social Issues 63, 117–137. https://doi.org/10.1111/j.1540-4560.2007.00499.x.

Lund, H., Kempton, W., 2008. Integration of renewable energy into the transport and electricity sectors through V2G. Energy Policy 36, 3578–3587. https://doi.org/10.1016/j.enpol.2008.06.007.

Martinenas, S., Knezovic, K., Marinelli, M., 2017. Management of Power Quality Issues in Low Voltage Networks Using Electric Vehicles: Experimental Validation. IEEE Trans. Power Delivery 32, 971–979. https://doi.org/10.1109/TPWRD.2016.2614582.

Mehdizadeh, M., Nayum, A., Nordfjærn, T., Klöckner, C.A., 2024. Are Norwegian car users ready for a transition to vehicle-to-grid technology? Transport Policy 146, 126–136. https://doi.org/10.1016/j.tranpol.2023.11.014.

Meuleman, B., 2019. Multilevel Structural Equation Modeling for Cross-National Comparative Research. Köln Z Soziol 71, 129–155. https://doi.org/10.1007/s11577-019-00605-x.

Miller, K.M., Hofstetter, R., Krohmer, H., Zhang, Z.J., 2011. How Should Consumers' Willingness to Pay be Measured? An Empirical Comparison of State-of-the-Art Approaches. Journal of Marketing Research 48, 172–184. https://doi.org/10.1509/jmkr.48.1.172.

Moesker, K., Pesch, U., Doorn, N., 2024. Making sense of acceptance and acceptability: Mapping concept use in energy technologies research. Energy Research & Social Science 115, 103654. https://doi.org/10.1016/j.erss.2024.103654.

Müller, M., Kern, T., Ostermann, A., Dossow, P., Blume, Y., Bruckmeier, A., Djamali, A., Hinterstocker, m., Engwerth, V., Faller, S., Fattler, S., Hawran, J., Haug, T., Jooß, N., Murmann, A., Regener, V., Reinhard, J., Springmann, E., Wendlinger, C., Wohlschlager, D., 2023. Abschlussbericht zum Projekt: BDL - Bidirektionales Lademanagement, 113 pp.

Next Kraftwerke. Was ist die Residuallast? https://www.next-kraftwerke.de/wissen/residuallast (accessed 5 December 2024).

Next Kraftwerke, 2024. Was ist Peak Shaving? https://www.next-kraftwerke.de/wissen/peak-shaving.

Nobis, C., Kuhnimhof, T., 2018. Mobilität in Deutschland – MiD. Ergebnisbericht. infas, DLR, IVT, infas 360, Bonn, Berlin, 136 pp. http://www.mobilitaet-in-deutschland.de/pdf/MiD2017_Ergebnisbericht.pdf (accessed 27 July 2021).

Noel, L., Papu Carrone, A., Jensen, A.F., Zarazua de Rubens, G., Kester, J., Sovacool, B.K., 2019a. Willingness to pay for electric vehicles and vehicle-to-grid applications: A Nordic choice experiment. Energy Economics 78, 525–534. https://doi.org/10.1016/j.eneco.2018.12.014.

Noel, L., Rubens, G.Z. de, Kester, Johannes, Sovacool, Benjamin K., 2019b. Vehicle-to-Grid: A Sociotechnical Transistion Beyond Electric Mobility. Palgrave Macmillan, Cham, Switzerland, 271 pp.

Noel, L., Zarazua de Rubens, G., Kester, J., Sovacool, B.K., 2021. Leveraging user-based innovation in vehicle-to-X and vehicle-to-grid adoption: A Nordic case study. Journal of Cleaner Production 287, 125591. https://doi.org/10.1016/j.jclepro.2020.125591.

Noel, L., Zarazua de Rubens, G., Sovacool, B.K., Kester, J., 2019c. Fear and loathing of electric vehicles: The reactionary rhetoric of range anxiety. Energy Research & Social Science 48, 96–107. https://doi.org/10.1016/j.erss.2018.10.001.

Noppers, E.H., Keizer, K., Bolderdijk, J.W., Steg, L., 2014. The adoption of sustainable innovations: Driven by symbolic and environmental motives. Global Environmental Change 25, 52–62. https://doi.org/10.1016/j.gloenvcha.2014.01.012.

NOW, 2024. Positionspapier Bidirektionales Laden diskriminierungsfrei ermöglichen: Handlungsempfehlungen des Beirats der Nationalen Leitstelle Ladeinfrastruktur zur Umsetzung der Maßnahme 47 des Masterplans Ladeinfrastruktur II, 60 pp. https://www.now-gmbh.de/wp-content/uploads/2024/03/Bidirektionales-Laden_240306.pdf (accessed 6 October 2024).

Ostermann, A., Engwerth, V., Sommer, K., 2022. Analysis of the peak shaving potential of bidirectionally chargeable electric vehicles in a field trial, in: 6th E-Mobility Power System Integration Symposium (EMOB 2022). 6th E-Mobility Power System Integration Symposium, The Hague, Netherlands. 10 October 2022. IET, Stevenage, Hertfordshire, UK.

Ozaki, R., 2011. Adopting sustainable innovation: what makes consumers sign up to green electricity? Bus. Strat. Env. 20, 1–17. https://doi.org/10.1002/bse.650.

Ozaki, R., Sevastyanova, K., 2011. Going hybrid: An analysis of consumer purchase motivations. Energy Policy 39, 2217–2227. https://doi.org/10.1016/j.enpol.2010.04.024.

Pearre, N.S., Ribberink, H., 2019. Review of research on V2X technologies, strategies, and operations. Renewable and Sustainable Energy Reviews 105, 61–70. https://doi.org/10.1016/j.rser.2019.01.047.

Perlaviciute, G., Steg, L., 2014. Contextual and psychological factors shaping evaluations and acceptability of energy alternatives: Integrated review and research agenda. Renewable and Sustainable Energy Reviews 35, 361–381. https://doi.org/10.1016/j.rser.2014.04.003.

Pospeschill, M., 2010. Testtheorie, Testkonstruktion, Testevaluation: Mit 77 Fragen zur Wiederholung. Ernst Reinhardt Verlag, München, Basel, 246 pp.

Reed Johnson, F., Lancsar, E., Marshall, D., Kilambi, V., Mühlbacher, A., Regier, D.A., Bresnahan, B.W., Kanninen, B., Bridges, J.F.P., 2013. Constructing experimental designs for discrete-choice experiments: report of the ISPOR Conjoint Analysis Experimental Design Good Research Practices Task Force. Value in health : the journal of the International Society for Pharmacoeconomics and Outcomes Research 16, 3–13. https://doi.org/10.1016/j.jval.2012.08.2223.

Rezvani, Z., Jansson, J., Bengtsson, M., 2018. Consumer motivations for sustainable consumption: The interaction of gain, normative and hedonic motivations on electric vehicle adoption. Bus Strat Env 27, 1272–1283. https://doi.org/10.1002/bse.2074.

Rezvani, Z., Jansson, J., Bodin, J., 2015. Advances in consumer electric vehicle adoption research: A review and research agenda. Transportation Research Part D: Transport and Environment 34, 122–136. https://doi.org/10.1016/j.trd.2014.10.010.

Rogers, E.M., 1983. Diffusion of innovations, 3rd ed. Free Press; Collier Macmillan, New York, London, 236 pp.

Rozin, P., Royzman, E.B., 2001. Negativity Bias, Negativity Dominance, and Contagion. Pers Soc Psychol Rev 5, 296–320. https://doi.org/10.1207/S15327957PSPR0504_2.

Schade, J., Schlag, B., 2003. Acceptability of urban transport pricing strategies. Transportation Research Part F: Traffic Psychology and Behaviour 6, 45–61. https://doi.org/10.1016/S1369-8478(02)00046-3.

Schmalfuß, F., Mair, C., Döbelt, S., Kämpfe, B., Wüstemann, R., Krems, J.F., Keinath, A., 2015. User responses to a smart charging system in Germany: Battery electric vehicle driver motivation, attitudes and acceptance. Energy Research & Social Science 9, 60–71. https://doi.org/10.1016/j.erss.2015.08.019.

Schmidt, L., Waxmann, N., Reichert, D., Boesche, K.V., 2023. Bidirektionales Laden in Deutschland - Marktentwicklung und Potenziale, 104 pp.

Schuitema, G., Anable, J., Skippon, S., Kinnear, N., 2013. The role of instrumental, hedonic and symbolic attributes in the intention to adopt electric vehicles. Transportation Research Part A: Policy and Practice 48, 39–49. https://doi.org/10.1016/j.tra.2012.10.004.

Schumacher, K., 2019. Public acceptance of renewable energies – an empirical investigation across countries and technologies. Dissertation. KIT Scientific Publishing, 338 pp.

Schumacker, R.E., Lomax, R.G., 2010. A beginner's guide to structural equation modeling, 3rd ed. Routledge, New York, xx, 510.

Schwanitz, V.J., Wierling, A., Arghandeh Paudler, H., Beck, C. von, Dufner, S., Koren, I.K., Kraudzun, T., Marcroft, T., Mueller, L., Zeiss, J.P., 2023. Statistical evidence for the contribution of citizen-led initiatives and projects to the energy transition in Europe. Scientific reports 13, 1342. https://doi.org/10.1038/s41598-023-28504-4.

Signer, Unger, Ruppert, Fichtner, 2023. Economic Potential of V2G in Electricity Markets – A Systematic Literature Review, in: 2023 IEEE Vehicle Power and Propulsion Conference (VPPC): Proceedings: Milan, Italy, 24-27 October 2023. 2023 IEEE Vehicle Power and Propulsion Conference (VPPC), Milan, Italy. 10/24/2023 - 10/27/2023. IEEE, Piscataway, NJ, pp. 1–6.

Signer, T., Baumgartner, N., Ruppert, M., Sandmeier, T., Fichtner, W., 2024. Modeling V2G spot market trading: The impact of charging tariffs on economic viability. Energy Policy 189, 114109. https://doi.org/10.1016/j.enpol.2024.114109.

Sloot, D., Jans, L., Steg, L., 2019. In it for the money, the environment, or the community? Motives for being involved in community energy initiatives. Global Environmental Change 57, 101936, 2–10. https://doi.org/10.1016/j.gloenvcha.2019.101936.

Sloot, D., Lehmann, N., Ardone, A., 2022. Explaining and promoting participation in demand response programs: The role of rational and moral motivations among German energy consumers. Energy Research & Social Science 84, 102431, 1–15. https://doi.org/10.1016/j.erss.2021.102431.

Sovacool, B.K., Axsen, J., Kempton, W., 2017. The Future Promise of Vehicle-to-Grid (V2G) Integration: A Sociotechnical Review and Research Agenda. Annu. Rev. Environ. Resour. 42, 377–406. https://doi.org/10.1146/annurev-environ-030117-020220.

Sovacool, B.K., Hirsh, R.F., 2009. Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition. Energy Policy 37, 1095–1103. https://doi.org/10.1016/j.enpol.2008.10.005.

Sovacool, B.K., Kester, J., Noel, L., Zarazua de Rubens, G., 2020. Actors, business models, and innovation activity systems for vehicle-to-grid (V2G) technology: A comprehensive review. Renewable and Sustainable Energy Reviews 131, 109963. https://doi.org/10.1016/j.rser.2020.109963.

SPD, Bündnis 90/Die Grünen and FDP, 2021. Koalitionsvertrag: Daring more progress. Alliance for freedom, justice and sustainability, 178 pp.

Statista, 2023. wichtigste Pumpspeicherkraftwere in Deutschland nach installierter Netto-Nennleistung im Juli 2023 (in Megawatt) [Graph].

https://de.statista.com/statistik/daten/studie/310041/umfrage/wichtigste-pumpspeicherkraftwerke-in-deutschland-nach-installierter-leistung/ (accessed 6 October 2024).

Steg, L., 2016. Values, Norms, and Intrinsic Motivation to Act Proenvironmentally. Annu. Rev. Environ. Resour. 41, 277–292. https://doi.org/10.1146/annurev-environ-110615-085947.

Steg, L., Bolderdijk, J.W., Keizer, K., Perlaviciute, G., 2014a. An Integrated Framework for Encouraging Pro-environmental Behaviour: The role of values, situational factors and goals. Journal of Environmental Psychology 38, 104–115. https://doi.org/10.1016/j.jenvp.2014.01.002.

Steg, L., Groot, J. de, 2012. Environmental values, in: Clayton, S. (Ed.), The Oxford handbook of environmental and conservation psychology. Oxford University Press, pp. 81–92.

Steg, L., Perlaviciute, G., van der Werff, E., 2015. Understanding the human dimensions of a sustainable energy transition. Frontiers in Psychology (Front. Psychol.).

Steg, L., Perlaviciute, G., van der Werff, E., Lurvink, J., 2014b. The Significance of Hedonic Values for Environmentally Relevant Attitudes, Preferences, and Actions. Environment and Behavior 46, 163–192. https://doi.org/10.1177/0013916512454730.

Stern, P.C., Dietz, T., Abel, T., Guagnano, G.A., Kalof, L., 1999. A Value-Belief-Norm Theory of Support for Social Movements: The Case of Environmentalism. Human Ecology Reviews, 2, 81–97.

Stoetzel, J., 1954. Le Prix Comme Limité, in: Reynaud, P.L. (Ed.), La Psychologie Economique. Librairie Marcel Riviere et Cie, Paris, pp. 183–188.

Stromsteuergesetz: StromStG, in: BGBI. 1.

Tagesschau, 2024. Steinmeier unterschreibt neues Klimaschutzgesetz. https://www.tagesschau.de/inland/innenpolitik/klimaschutzgesetz-steinmeier-faq-100.html#umweltverbaende.

Tibbe, T.D., Montoya, A.K., 2022. Correcting the Bias Correction for the Bootstrap Confidence Interval in Mediation Analysis. Frontiers in Psychology (Front. Psychol.) 13, 810258.

Tsaousoglou, G., Giraldo, J.S., Paterakis, N.G., 2022. Market Mechanisms for Local Electricity Markets: A review of models, solution concepts and algorithmic techniques. Renewable and Sustainable Energy Reviews 156, 111890. https://doi.org/10.1016/j.rser.2021.111890.

UBA, 2024. Emissionen des Verkehrs. https://www.umweltbundesamt.de/daten/verkehr/emissionen-des-verkehrs#verkehr-belastet-luft-und-klima-minderungsziele-der-bundesregierung (accessed 11 July 2024).

Übertragungsnetzbetreiber CC-BY-4.0, 2023. Netzentwicklungsplan Strom 2037 / 2045: zweiter Entwurf, 34 pp.

UNFCCC, 2015. Paris Agreement to the United Nations Framework Convention on Climate Change, 27 pp.

Upham, P., Oltra, C., Boso, À., 2015. Towards a cross-paradigmatic framework of the social acceptance of energy systems. Energy Research & Social Science 8, 100–112. https://doi.org/10.1016/j.erss.2015.05.003.

van der Kam, M., van Sark, W., 2015. Smart charging of electric vehicles with photovoltaic power and vehicle-to-grid technology in a microgrid; a case study. Applied Energy 152, 20–30. https://doi.org/10.1016/j.apenergy.2015.04.092.

van der Werff, E., Steg, L., 2016. The psychology of participation and interest in smart energy systems: Comparing the value-belief-norm theory and the value-identity-personal norm model. Energy Research & Social Science 22, 107–114. https://doi.org/10.1016/j.erss.2016.08.022.

van der Werff, E., Steg, L., Keizer, K., 2013. It is a moral issue: The relationship between environmental self-identity, obligation-based intrinsic motivation and pro-environmental behaviour. Global Environmental Change 23, 1258–1265. https://doi.org/10.1016/j.gloenvcha.2013.07.018.

van Heuveln, K., Ghotge, R., Annema, J.A., van Bergen, E., van Wee, B., Pesch, U., 2021. Factors influencing consumer acceptance of vehicle-to-grid by electric vehicle drivers in the Netherlands. Travel Behaviour and Society 24, 34–45. https://doi.org/10.1016/j.tbs.2020.12.008.

van Westendorp, P.H., 1976. NSS-Price Sensitivity Meter (PSM): A New Approach to Study Consumer Perceptions of Prices, in: Proceedings of the 29th ESOMAR Congress: Research That Works For Today's Marketing Problems. 5-9 September, pp. 139–167.

van Zomeren, M., Postmes, T., Spears, R., 2008. Toward an integrative social identity model of collective action: a quantitative research synthesis of three socio-psychological perspectives. Psychological bulletin 134, 504–535. https://doi.org/10.1037/0033-2909.134.4.504.

Vernay, A.-L., Sebi, C., Arroyo, F., 2023. Energy community business models and their impact on the energy transition: Lessons learnt from France. Energy Policy 175, 113473. https://doi.org/10.1016/j.enpol.2023.113473.

Weiller, C., Neely, A., 2014. Using electric vehicles for energy services: Industry perspectives. Energy 77, 194–200. https://doi.org/10.1016/j.energy.2014.06.066.

Wentura, D., Pospeschill, M., 2015. Strukturgleichungsmodelle, in: Wentura, D., Pospeschill, M. (Eds.), Multivariate Datenanalyse. Springer Fachmedien Wiesbaden, Wiesbaden, pp. 195–218.

Wietschel, M., Link, S., Biemann, K., Helms, H., 2022. Langfristige Umweltbilanz und Zukunftspotenzial alternativer Antriebstechnologien. Studie zum deutschen Innovationssystem 9-2022. Fraunhofer ISI, Institut für Energie- und Umweltforschung Heidelberg, Berlin, 67 pp.

Will, C., Schuller, A., 2016. Understanding user acceptance factors of electric vehicle smart charging. Transportation Research Part C: Emerging Technologies 71, 198–214. https://doi.org/10.1016/j.trc.2016.07.006.

Wolske, K.S., Stern, P.C., Dietz, T., 2017. Explaining interest in adopting residential solar photovoltaic systems in the United States: Toward an integration of behavioral theories. Energy Research & Social Science 25, 134–151. https://doi.org/10.1016/j.erss.2016.12.023.

Wong, S.D., Shaheen, S.A., Martin, E., Uyeki, R., 2023. Do incentives make a difference? Understanding smart charging program adoption for electric vehicles. Transportation Research Part C: Emerging Technologies 151, 104123, 1–22. https://doi.org/10.1016/j.trc.2023.104123.

Wüstenhagen, R., Wolsink, M., Bürer, M.J., 2007. Social acceptance of renewable energy innovation: An introduction to the concept. Energy Policy 35, 2683–2691. https://doi.org/10.1016/j.enpol.2006.12.001.

Yilmaz, M., Krein, P.T., 2013. Review of Battery Charger Topologies, Charging Power Levels, and Infrastructure for Plug-In Electric and Hybrid Vehicles. IEEE Trans. Power Electron. 28, 2151–2169. https://doi.org/10.1109/TPEL.2012.2212917.

Zhao, X., Lynch, J.G., Chen, Q., 2010. Reconsidering Baron and Kenny: Myths and Truths about Mediation Analysis. J Consum Res 37, 197–206. https://doi.org/10.1086/651257.

Part II

Research Paper

Paper A

How to integrate users into smart charging – A critical and systematic review

Nora Baumgartner [a], Kira Weyer [b], Lars Eckmann [a], Wolf Fichtner [a]

[a] *French-German Institute for Environmental Research, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany*
[b] *Faculty of Economics, Baden-Wuerttemberg Cooperative State University (DHBW) Mannheim, Mammheim, Germany*

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Abstract

Many countries worldwide have adopted policies to foster the transformation from internal combustion engine vehicles to electric vehicles (EV) to reach national climate goals. An uptake of EVs however, irrevocably leads to an increased power demand. To meet this problem, smart charging concepts are on the rise. As smart charging implies an active role of the EV user, studying the user in the smart charging system is vital for a successful market ramp-up. Despite the user's primary role, many studies only include a limited set of user characteristics into their research design. We aim to create transparency on how the user is characterized in current research and on how different disciplines deal with and consider the user in their research. Learning how different research strands deal with the user of smart charging is the main objective of this review.

This systematic review provides an overview of 183 peer-reviewed journal articles from the past 20 years of research on smart charging. We find that the type of data that is included to characterize the user of smart charging is related to the research focus. While technology-centered research topics typically approach the user in terms of mobility and charging behavior, or smart charging preferences, human-centered research retrieves qualitative as well as quantitative data that enables in-depth knowledge about values, norms and perceptions of smart charging. Finally, we identified two topics that can be characterized as being integrative, as they create an interface for combining human-centered and technology-centered perspectives in a unique manner.

Keywords: User perspective, Vehicle-to-grid (V2G), Smart charging, Thematic analysis, Systematic literature review.

A.1 Introduction

The electrification of the transport sector is an essential part of national strategies worldwide for reducing greenhouse gas emissions and reaching ambitious climate goals to prevent the negative effects of climate change. In 2021, six million electric vehicles (EV) were sold worldwide, which is twice as many as in 2020 (International Energy Agency, 2022). This was primarily fostered by national subsidies with the aim of phasing out internal combustion engine vehicles (ICEV) to reach the climate goals (International Energy Agency, 2022). In light of the current energy crisis since the Russian invasion of Ukraine, the energy and mobility transition gained more significance. Recently, the European Parliament voted to ban ICEVs in the European Union by 2035 (Abnett, 2022). This will certainly strengthen the market uptake of EVs in the European Union. However, new challenges arise from this profound transition, which will irrevocably lead to an increased electricity demand and thus evoke further challenges for the electricity grid (Gonzalez Venegas et al., 2021). At the same time, fossil energy sources are being replaced by renewable energy sources (RES), leading to an increasing decentralization of the energy system. In order to meet the associated challenges such as more secure and flexible grid operation, EVs used as decentralized energy storage units (Kempton and Tomić, 2005) are seen as one promising element toward a more secure energy system. Therefore, the idea of shifting loads from EV charging to off-peak hours and to let EVs provide ancillary services to the grid is of increasing interest (García-Villalobos et al., 2014).

Without a doubt, there are various technical and economic challenges surrounding different forms of uni- and bidirectional charging[1] – in the following referred to as "smart charging" – producing a great demand for specific solutions from an economic and engineering perspective. Therefore, it is not surprising that there is abundant technical research on smart charging, which is reflected in a variety of literature reviews with a focus on the techno-economic aspects of smart charging (e.g., Yilmaz and Krein, 2013b) or the technical details of vehicle-to-everything (V2X) use concepts, including V2G, grid-to-vehicle (G2V), and vehicle-to-building (V2B) (cf. e.g., Pearre and Ribberink, 2019). Yet, the expansion of these technologies will require changes in user behaviors,

1 During the past 20 years, research explored differing concepts of uni- and bidirectional charging as a means of dealing with the mentioned challenges. From a technical perspective, these concepts are very different (Yilmaz and Krein, 2013a). While unidirectional charging intelligently delays the charging process in response to a steering signal, a bidirectional chargeable EV serves on one hand as a vehicle and on the other hand as a power source storing electricity during grid shortages and discharging during off-peak hours (Sovacool and Hirsh, 2009). Many synonyms and denominations exist. For example, unidirectional charging is described as "controlled charging" and is defined by Huber et al. (2019, p. 2) 'as an information system that optimizes the charging process toward one or multiple objectives besides reaching a desired state of charge (SoC) within a given time frame'. Terms such as "vehicle-to-grid" (V2G), and "mobile energy" are used to describe the vehicle not only as a consumer of electricity but also as a power source (Sovacool et al., 2020). The terms have in common that they require a certain level of control over the charging process (Will and Schuller, 2016). This can include the coordination of the charging process of EVs and the provision of ancillary services from the vehicle to the grid (Tomić and Kempton, 2007). We focus on both, uni- and bidirectional charging, hereby referred to as "smart charging" (cf., Spencer et al., 2021), both implying an active role of the EV user.

and, not least, will depend on their acceptance. A majority of studies, however, use and develop models in order to offer a solution to a specific technical or economic problem. The human dimension, including behavior, preferences, perceptions, and attitudes is often neglected. As is argued by Huckebrink and Bertsch (2021, p.2), ‘adoption rates and market shares are important, [yet] the active use of a technology is what ultimately determines energy demand’.

This implicitly demonstrates the essential role of the EV user in the smart charging system. To be successful, smart charging requires the active participation of several actors, which can be characterized as primary and secondary actors (Noel et al., 2019b). While primary actors directly interact with the smart charging technology – the user is one crucial actor out of three that can be categorized as primary actor –, secondary actors represent the “periphery network” (Noel et al., 2019b).

Sovacool et al. (2009) argue in early 2009 that, besides the technical challenges associated with the implementation of smart charging, there are other important, more subtle socio-technical barriers for the market ramp-up of EV smart charging. These include, for example, uncertainties about payback-periods of EVs and potential fuel savings, resistance to infrastructural changes, cultural and social values, and business practices. The authors further point out that “socio-technical” challenges are easily overlooked and might be difficult to identify due to their non-tangible nature. Roughly one decade later Sovacool et al. (2017) and Sovacool et al. (2018) reconfirm that techno-economic approaches still dominate research on smart charging, mostly focusing on optimizing the financial costs of the systems, and make very simplified exogenous assumptions about user behavior. Emphasizing socio-technical aspects is, however, a precondition for a successful market-uptake of smart charging.

The above-mentioned studies criticize the currently applied approaches as being too specialized but do not recommend approaches to increase the integration of socio-technical aspects in research designs. This is where this review contributes to the literature by creating transparency on how the user is characterized in the different schools of thought. Learning how these research strands elaborate on the human dimension of smart charging is the main objective of this review. By doing so, we provide the basis for developing feasible and accepted pathways for future smart charging.

We promote visibility by reviewing 183 peer-reviewed journal articles from various disciplines. This will enable researchers to gain a holistic and comprehensive understanding of the typical user characteristics included in smart charging research. This transparency is, to our understanding, an important prerequisite for the market uptake of a complex, cross-sectoral innovation with high societal impacts, such as the diffusion of smart charging technology. We thus aim to answer the following research question: What variables are usually retrieved to study the user of smart charging and what patterns exist to characterize the user? More specifically, this review aims at making the following contributions to the state of the art:

i. Analyze the current state of research on smart charging by investigating disciplines and methods of smart charging and by identifying stakeholders and dominating research topics throughout the various disciplines;

ii. Investigate how the human factor of smart charging is approached by predominating topics, methods, and disciplines and provide examples of research topics and the way in which the user characteristics are typically integrated.

The remainder of this paper is structured as follows: In Section 2, we introduce the systematic review process and the categories that we used for conducing the thematic analysis. We then present our results in Section 3, followed by a comprehensive discussion in Section 4. We conclude our review by providing recommendations to the scientific community in Section 5.

A.2 Systematic literature review: materials and methods

The main goal of this review is to identify the human factor of smart charging in the body of literature. This study is explorative, aiming to provide transparency about the predominating approaches to include the user in smart charging studies. In order to further elaborate on this, we chose an inductive approach.

A.2.1 Review process

Reviews uncover research gaps which determine the focus of future research, connect existing knowledge, and draw meaningful conclusions such as new theories and serve as overviews of the knowledge of an area (Petticrew and Roberts, 2006; Webster and Watson, 2002). A variety of types of literature reviews exist, all sharing the goal of analyzing already existing literature. However, they differ regarding the analysis methods and the type of reviewed literature.

Meta-analysis, for example, synthesizes literature in a quantitative way (Grant and Booth, 2009), using similar dependent variables (Petticrew and Roberts, 2006). Qualitative literature reviews focus on the overall concept of qualitative studies (Grant and Booth, 2009) and narrative literature reviews do not necessarily follow a rigid protocol (Littell et al., 2008; Tranfield et al., 2003). Finally, systematic literature reviews introduce transparency through their systematic and reproducible process and can help to minimize confirmation bias. This kind of review does not privilege a certain literature (Littell et al., 2008). We conducted a systematic literature review following the protocol by Mayring (2015). We chose a systematic approach, since it allows to capture a variety of existing literature on user characteristics within smart charging literature. However, because systematic reviews are susceptible to a poor literature quality, a scheme was established to ensure a certain quality level (Littell et al., 2008), which is described in detail in the following.

We conducted the literature review in 2020 and 2021. Our systematic review process is described in Figure 1. Based on previous research, especially previous literature reviews, we identified the research gap and developed our research questions (Step 1). Taking this as a basis for the literature search, several keywords have been identified (Step 2). These keywords relate on the one hand to smart charging itself and on the other to the human dimension of smart charging. All literature searches have been based on the search engine Scopus because it offers abundant literature from several disciplines (Wolsink, 2018). This review focuses solely on literature in English (Step 3). In Step 4 of the process, the keywords have been tested and evaluated iteratively and repetitively,

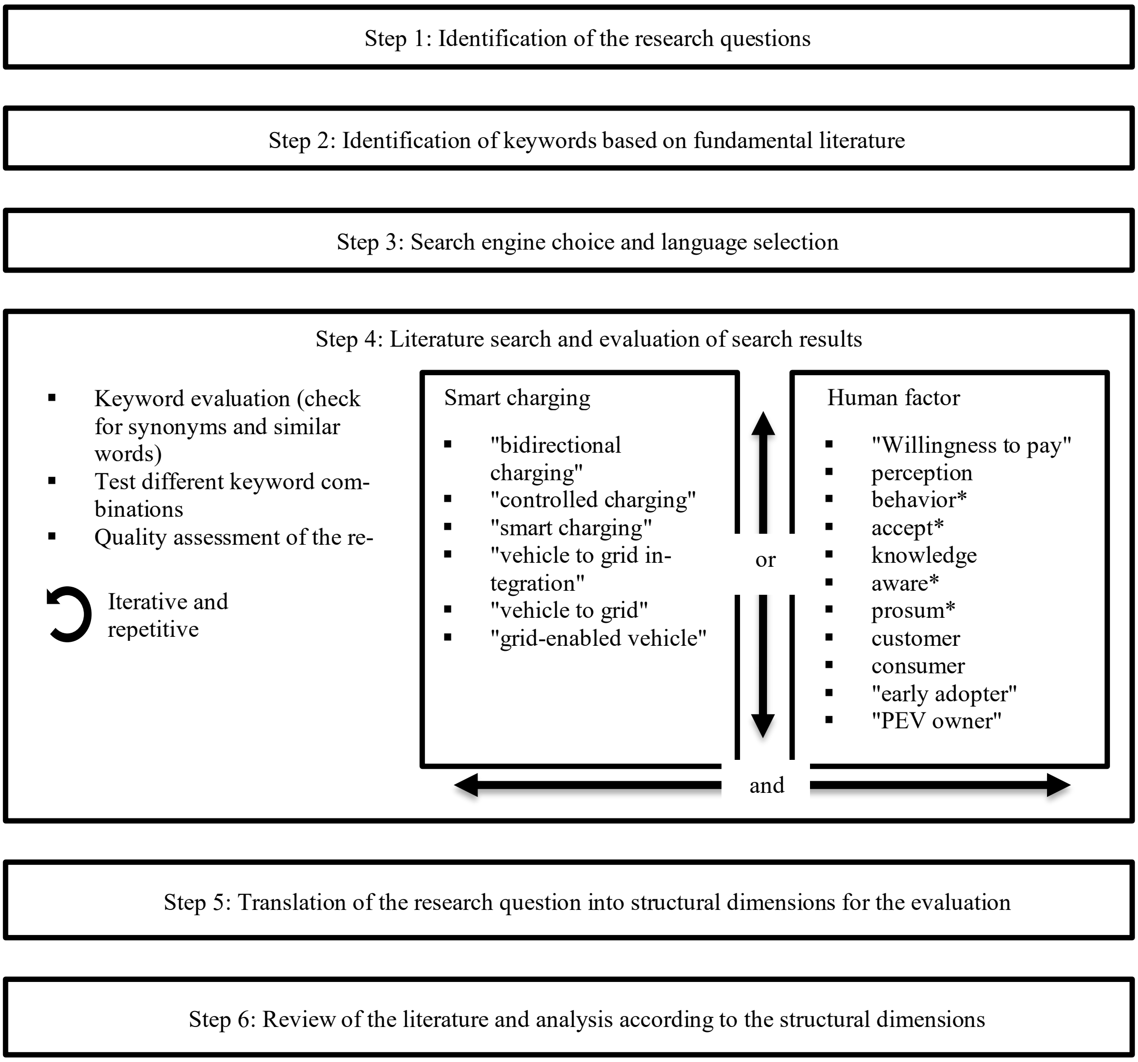

Figure 1. Design of the systematic literature review process.

resulting in two final clusters of keywords. The clusters themselves are combined with Boolean operators, “or” or “and”. The final cluster is disclosed in Step 4.

Following the establishment of two keyword clusters, we assessed the quality of the journal articles and journals to ensure a high quality of the literature. Only journals of the first and second quartiles of the SciMago Journal Ranking of 2018 were further considered, leading to a total of 309 remaining articles. To assess the relevance and quality of these articles, a metric was developed to calculate the papers’ citation frequency. Articles which had received less than two citations per year were excluded based on the following ratio $\frac{\#citations}{2*age} \geq 1$. After applying this score, 183 papers remained. The dataset includes studies from the years 1997 to 2020. The final dataset was analyzed using thematic analysis and quantitative content analysis. For this, we developed structural dimensions for the evaluation (Section 2.2) before starting the analysis (Step 6).

A.2.2 Analytical approach

Since we aim at answering the question as to how the user of smart charging is approached within different research topics, disciplines, and methods, we established several structuring categories (Figure 2). These include the research topics and stakeholder focus of the study. We identified the research topics, applying thematic analysis according to Braun and Clarke (2006). Thematic analysis can be described as a process for ‘identifying, analyzing, and reporting patterns (themes) within data’ (Braun and Clarke, 2006, p.79). We chose a data-driven approach to identify semantic themes. The themes were thus identified based on the existing data and are therefore not based on a pre-existing coding scheme. Even though the themes were developed inductively and are strongly linked to the data set, we acknowledge that this process always necessitates the researcher’s judgement to determine the theme (Braun and Clarke, 2006), which is e.g. influenced by the researchers background (Chadwick et al., 2022). The themes were created based on abstract and author keywords. In a first step, we produced initial codes for each paper. Second, we added the codes of each paper to a sub-theme, which described the research focus of each paper. We then organized the data into meaningful groups and searched for potential themes. The coding as well as the identification of the sub-themes and overarching themes was a recursive and iterative process, including multiple reads and discussions in the research team. In total, we identified 12 overarching themes in the field of smart charging, some of them including up to nine sub-themes. These themes display dominating research topics[1] in the field of smart charging.

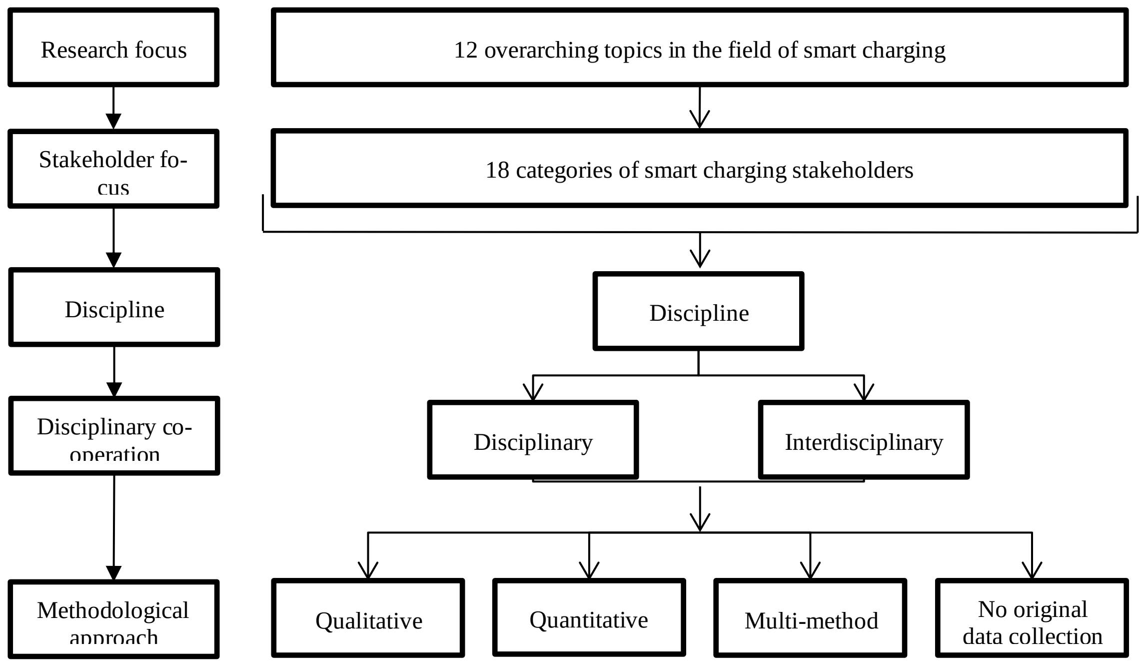

Figure 2. Structuring categories for the analytical framework.

[1] In the following, we use the terms “themes” and “topics” synonymously.

Using research topics as a categorizing element is of interest, as they provide a first hint to the research interest. Also, the research focus might have implications for the characteristics chosen to approach the user of smart charging. These might emphasize the importance of including certain characteristics while leaving others aside. For example, designing charging strategies might necessitate the inclusion of a bandwidth of variables defining mobility and charging behavior. Values, however, might be less important or even insignificant.

Table 1 Disciplines in smart charging research

Categories	Examples of included disciplines
Business	Business Development and Technology; Industrial and Information Management; Sustainable Enterprise; Technology Management Economics and Policy
Computer Science	Electronics, Computer Science and Systems; Information and Communication Technology and Society; Security, Privacy and Communication; Electrical, Electronic and Communications Engineering; Process Optimization and Intelligent Decision-making
Economics	Energy Economics and Modelling; Health Economics; Economics and Technology
Energy	Energy Systems; Energy Security, Distribution and Markets; Renewable Energy; Energy Economy and Grid Operation; Energy, Transport and the Environment
Engineering	Industrial Engineering; Electrical and Computer Engineering; Technology and Environment; Electrical Engineering and Automation; Civil Engineering; Renewable Energy and Environmental Engineering; Urban Construction and Safety Engineering
Geography	Geography; Geography and the Environment
Hard Science	Chemistry; Materials Protection and Advanced Materials in Electric Power;
Life Science	Intelligent Systems, Georesources and Renewable Energies; Forest and Biomaterials; Resource and Environmental Management; Environment and Sustainability
Planning	Planning; Sustainable Energy Planning
Political Science	Science Policy Research; Energy Policy Research; Energy and Environmental Policy
Psychology	Cognitive and Engineering Psychology; Usability Research and Engineering; Psychology
Transport	Sustainable Road Freight Transport; Sustainable Transport

Once we had finalized our thematic analysis, we investigated the stakeholder and methodological focus within each theme. While we only assigned one topic to each study, it was possible to assign several stakeholders to one study. For stakeholders, we started with the most important stakeholders in a smart charging system. We added further categories to this predefined set, until we covered all relevant stakeholders. In total, we identified 18 stakeholders.

Third, we included the authors' training, which was the basis for determining the discipline and the interdisciplinary character of the study. Table 1 provides an overview of the disciplines that were involved in conducting a study in the field of smart charging. The disciplinary categories are based on the authors' training and were created based on a study by Sovacool (2014). Furthermore, we distinguished between disciplinary and interdisciplinary studies. A study was assigned to be interdisciplinary, when either at least two persons from different disciplines contributed to a study or when the discipline had a clear interdisciplinary character.

We then included the methodological approaches that were applied. We categorized the applied methodologies into "qualitative", "quantitative", "no original data collection", and "mixed-method". For example, qualitative methods include qualitative interviews or focus groups, while quantitative methods include all kinds of statistical methods, choice models, simulations, and optimization approaches, GIS-based models or cost-benefit analyses. Studies that applied a combination of qualitative and quantitative approaches were categorized as mixed-methods.

In a final step, we integrated the methodological approaches and stakeholder analysis into our thematic analysis. In each topic, we analyzed the stakeholder focus as well as the applied methodologies, deriving three thematic domains – technology-oriented themes, human-centered-themes, and integrative themes. These domains are qualitatively and quantitatively different.

We further analyzed the studies with regard to variables that were used to characterize the user of smart charging. Based on the smart charging literature, we developed several user categories and sub-categories. Additionally, during the review process, we added further categories, resulting in six categories with 16 sub-categories (Figure 3). It is important to note, that it is not our objective to analyze the theoretical concepts that lie behind these variables. Rather, we aim to unfold specific patterns of disciplines, methods, and research topics to include the user into smart charging research. With this, we aim to identify typical patterns of user integration. In the following, we describe the user categories and sub-categories in more detail (cf. Figure 1, Step 5).

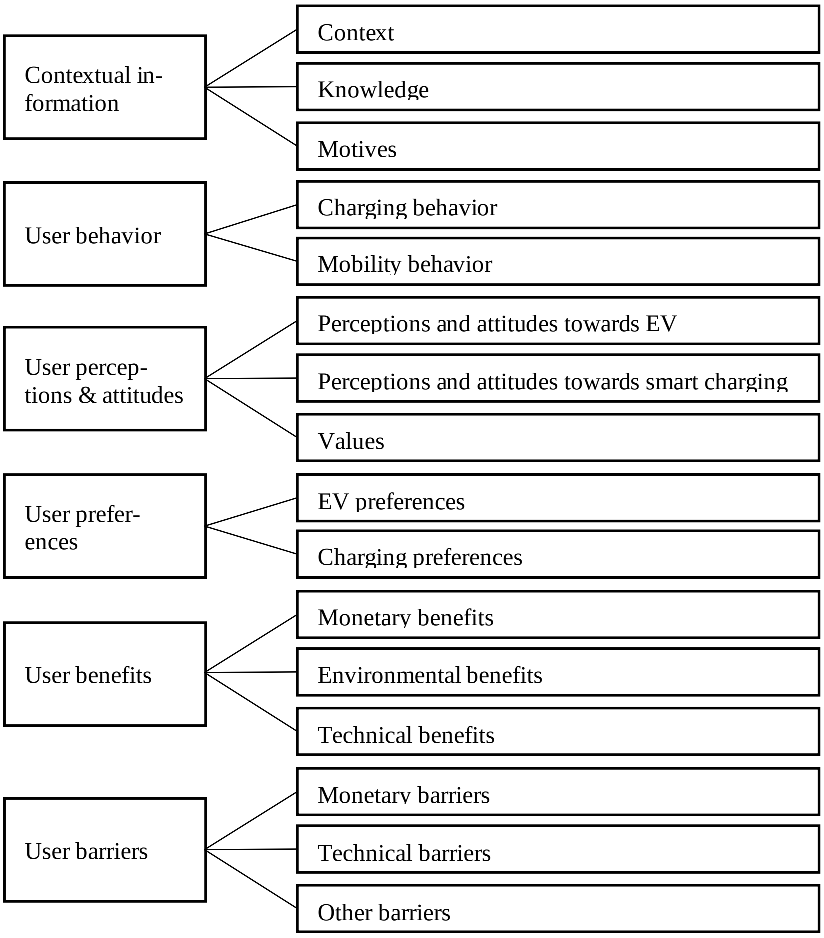

Figure 3. Categories and subcategories to characterize the smart charging user.

Contextual information, captures all kinds of input regarding customer size, weekdays, type of trip, number and type of EVs, EV-related knowledge or interest in smart charging and purchase motivation. User behavior is divided into charging and mobility behavior. While charging behavior covers charging duration, battery capacity or the charging mode, behavior with regard to mobility focuses on arrival and departure times, trip duration, modal choice, or immobility times. The category perceptions and attitudes is divided into perceptions and attitudes toward EV and toward smart charging. We also identified a variety of values that we assigned to this category. Variables such as innovativeness, driving attitudes, usefulness, political orientation, or social values can be found in these subcategories. These characteristics are of a more qualitative nature. Preferences follow the same structure as behavior, and are thus divided into user preferences regarding EVs and the charging process. These categories relate to preferences with regard to the EV purchase price, safety, design, charging costs, and the minimum state of charge (SoC). Finally, monetary and financial aspects were included either as a benefit or barrier. Technical benefits especially relate to grid stability and improved power quality, while technical barriers include battery degradation and replacement costs or privacy issues. Finally, the benefits of including RES and less air pollution are mentioned in the subcategory environmental benefits.

A.3 Results integrating the user perspective in research on smart charging

In this section, we present the major findings of the systematic literature review. First, we provide a descriptive overview of the disciplines and methodologies that were applied in the sample before delving deeper into the analysis of stakeholders and themes, which are subject to smart charging research. Our thematic analysis revealed three thematic domains, which follow very different rationales of integrating user characteristics into smart charging. We structure our analysis of user characteristics based on these three domains.

A.3.1 Disciplines, methodologies, and data sources in smart charging research

The final sample contains 183 research articles. Figure 4 provides an overview of the involved disciplines. The disciplines are coded on paper and not on author basis, which explains the high share of interdisciplinary studies. In total, 342 authors were involved in conducting the research. As already mentioned in Section 2.2 we first coded the disciplinary affiliation of each author. Cooperation between different disciplines or disciplines which involved an interdisciplinary training was summarized under the term "Interdisciplinary". Our analysis reveals that 42% of all studies were conducted in an interdisciplinary cooperation. The various types of disciplinary cooperation can be seen in Figure 4. The majority of all interdisciplinary cooperation took place between energy and engineering science (32%), followed by computer science and engineering (9%) and life science (8%). Beside this high amount of interdisciplinary cooperation, 40% of all studies were conducted by engineering disciplines. All other disciplines can be said to only play a marginal role.

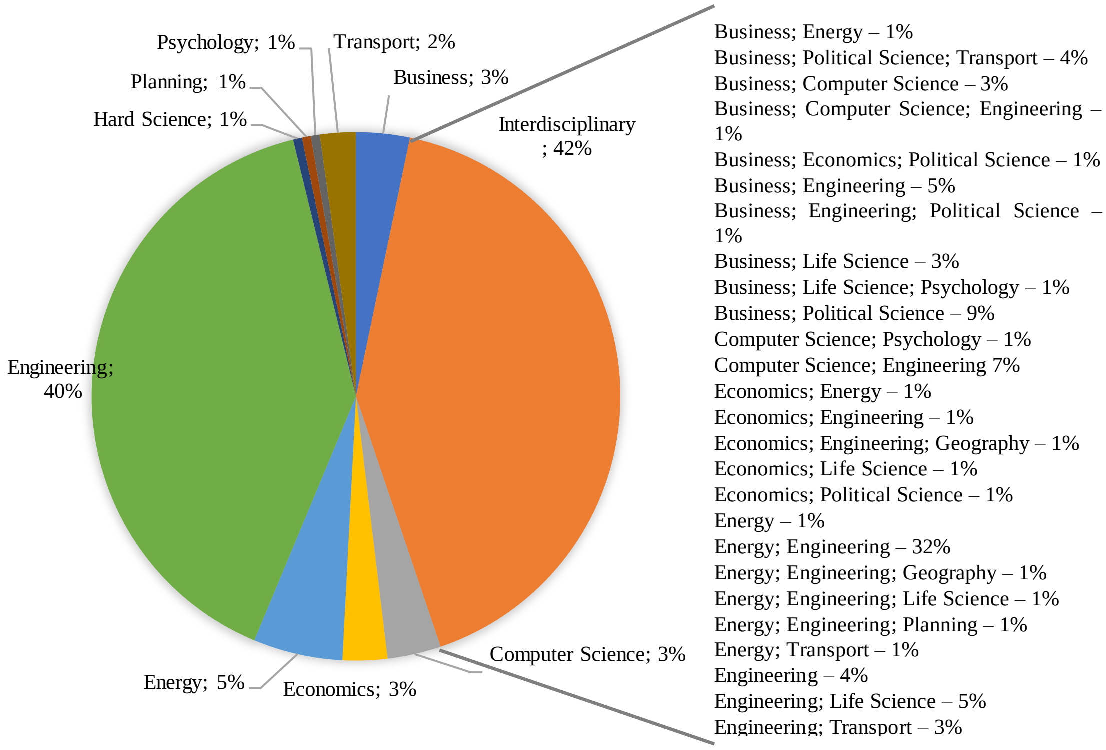

Figure 4. Disciplines in the field of smart charging, 1997-2020 (N=183).

With regard to applied methodologies, it is striking that nearly 90% of all studies are based on quantitative methods, whereas 4% used qualitative methods and another 4% were of a theoretical nature, meaning they did not retrieve any original data. Finally, only 2% applied a mix of qualitative and quantitative methods in their research design, where two out of four mixed-method studies were conducted in a disciplinary context. This suggests that interdisciplinary cooperation does not automatically foster the application of mixed-method approaches, as could be suspected.

The cumulative allocation of the publications from the past 24 years is shown in Figure 5. We did not predefine the publication period of interest, which is why the first publication in our sample is one of the key publications on V2G by Kempton and Letendre (1997). Even though this is known as the starting point in this research area, it took more than 10 years until this topic gained widespread attention in the research community. This corresponds to the starting point of global EV uptake (International Energy Agency, 2021, 2020). Since then, a continuous growth took place with the result of increased visibility and importance in research. This is especially true for smart charging research assigned to quantitative methods. Other methodological approaches also record an increase, however less prominently.

The articles from the final sample derive from a variety of journals. Most publications are placed in established, international journals in the field of energy economics, such as Energies (25), Energy (22), and Applied Energy (16). Further publications are from journals with a focus on

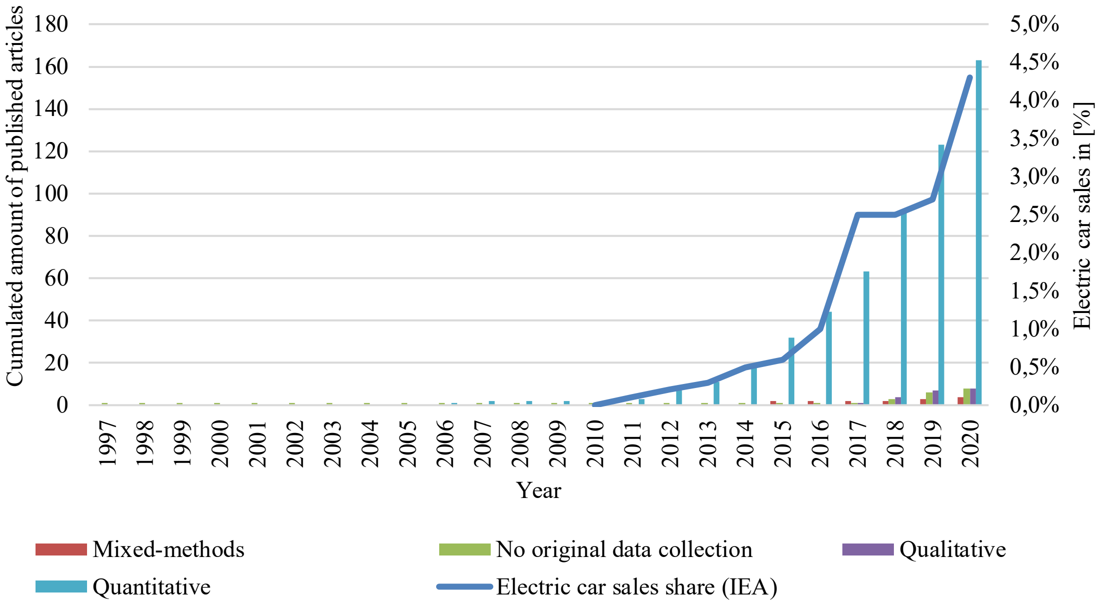

Figure 5. Overview on the total sample – published articles in the field of smart charging since 1997and EV sales share based on International Energy Agency (2020).

transportation and mobility, such as Transportation Research Part D (9) or those with an interdisciplinary priority, such as Energy Policy (8), Energy Research and Social Science (7), or Transport Policy (2). This demonstrates acceptance of the topic within a broad research community.

Finally, as it is the goal of this review to analyze the kind of data that is used to integrate the user perspective into studies of smart charging, we critically reflect upon the type of data sources. The considered data sources include, for instance, literature based on national statistical data bases, survey data, literature and GPS data. Statistical national data bases provide information on, for example, the number of photovoltaic (PV) installations, the number of EVs, public charging stations, (Bagherzade et al., 2019; Bhattarai et al., 2017; Bin Humayd and Bhattacharya, 2017; Druitt and Früh, 2012; Hariri et al., 2019; Hoog et al., 2015; Jain et al., 2019; Naghdizadegan Jahromi et al., 2017; Sachan and Adnan, 2018; Su et al., 2019), and socio-demographic data (e.g., van der Kam et al., 2018) or car sales (Lyon et al., 2012).[1]

Also, few studies conduct surveys to include primary data into their respective models. For example, Alonso et al. (2014) and Sun et al. (2019) both use travel survey data to estimate EV charging demand, while Bishop et al. (2016) use data on vehicle availability to build an empirically-derived battery degradation model. DeGennaro et al. (2015) employed GPS devices to collect data on driving behavior. Another possibility to collect primary data was used by Schmalfuß et al. (Schmalfuß et al., 2015), who conducted a field study where study participants reported on their experiences testing smart charging technology. Historical data is another commonly applied data source, which is, for example, data from electricity tariffs (Adika and Wang, 2014), load and

[1] For a detailed review of datasets on EV driving behaviour see Jia and Long (2020).

driving profiles (Aoun et al., 2019; Benalcázar et al., 2019; Brandt et al., 2017; Flammini et al., 2019; Ramakrishna Reddy and Meikandasivam, 2020) or consumption data based on smart meters (Andersen et al., 2019). Besides charging and travel patterns, few studies use neighborhood characteristics and population data to explain diffusion patterns (Eising et al., 2014). Contrary to including primary data sources, some studies use secondary data (Bhattarai et al., 2017; Fan et al., 2016; Noel et al., 2018b), and other studies generate e.g., EV driving patterns with respect to their probability (Aliasghari et al., 2018).

A.3.2 Research topics and stakeholders

To analyze the current state of research in the field of smart charging, we propose to take research themes as a starting point for the following analysis. Identifying research themes allows to gain a clear picture of the research landscape, including dominating as well as underexamined topics. Moreover, merging the analysis on topics with key stakeholders and methods allows to draw an even more precise picture of the state of the art. Within this framework, we identify patterns to integrate user characteristics of smart charging. In the following, we exclude literature from the following analysis that fell into the category "no original data collection", because we were interested in variables and parameters used to characterize the user in smart charging studies.

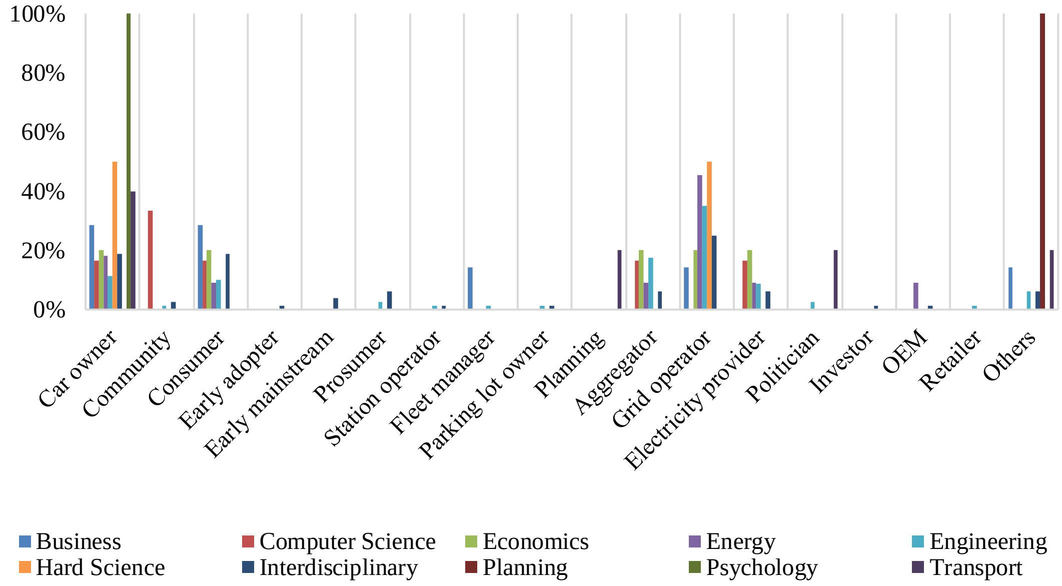

Figure 6. Stakeholders focus in smart charging research.

Figure 6 provides the results of the stakeholder analysis. Our stakeholder analysis covers a wide range of different stakeholders, including all important primary and secondary actors (Noel et al., 2019b). Primary actors include the consumer, aggregator, and grid operator. The user is represented in our data as car user, community, prosumer, or early adopter. As the role of the aggregator[2] is not yet finally defined, the tasks of the aggregator can also be taken by e.g., the fleet manager or parking lot owner. Finally, the grid operator is responsible for transmitting electricity production to demand areas. According to Noel et al., (2019b), secondary actors include the electricity provider, the government, or industrial actors, such as the original equipment manufacturer (OEM) or the retailer. We find these actors represented in our data as well, although less prominently.

Table 2 Research topics and examples in smart charging research

Research topics	Examples
Topic 1: User knowledge, perceptions, motivations, preferences	Consumer characteristics; preferences; motivations; knowledge; perceptions; real-life experience
Topic 2: Optimal EV charging based on user needs / behavior / incentives	Reduce charging service time; optimization of charging process considering incentives for users; peak shaving under consideration of user interests and willingness;
Topic 3: Optimization of system operation and economic benefits	Operation cost; microgrid reliability; economic benefits; battery swapping operation; day-ahead energy resource scheduling; dynamic electricity pricing; large-scale V2G optimization
Topic 4: Barriers, (non-monetary) costs and benefits	Barriers; benefits
Topic 5: Demand-response program	Demand response program; demand side management; dynamic demand control of EVs; demand management model for aggregators;
Topic 6: Business models and economic performance	Economic performance of V2B; emergency cases; peak shaving in parking lots; revenue streams; economic costs and benefits of shifting charging demand; shared car parking concepts
Topic 7: Infrastructure planning / EV routing and technical components for smart charging	Charging infrastructure design; controller for EV charging; transmission expansion planning including PEVs; energy system planning; EV routing problem
Topic 8: Interaction between RES and EV	Wind integration; RES integration; solar parking lots; high wind power penetration and EVs; microgrid scheduling with PHEVs and RES
Topic 9: Operation scheduling / load frequency control / reliability and security	Multi-objective scheduling; voltage regulation; operation scheduling; scheduling smart distribution grid; smart grid reliability; day-ahead control; distribution network reliability
Topic 10: Optimization of EV charging / smart charging dispatch strategy	Smart charging dispatch strategies; Day ahead optimization; Charging algorithm; Battery lifecycle analysis in V2G; Stochastic day-ahead residential charging;
Topic 11: User demand / market potential / costs and benefits / willingness to pay	Load-shift incentivizing tariff; profitability and market potential; customer values; willingness to pay; potential consumer demand; potential mainstream market; cost and benefit
Topic 12: Willingness to participate	EV adoption interest; willingness to participate; co-creation of flexibility; willingness to accept

Figure 6 reveals that most studies address the car owner, followed by the grid operator and the consumer. We distinguished between car owner and consumer, to include a more general and a

[2] Aggregators can be defined as a third party, combining individual EVs to participate in the electricity market (Das et al., 2020; Noel et al., 2019b). By doing so, EVs can provide complex electricity grid services (Noel et al., 2021). Thus, the main task of the aggregator is to “gather (…) information about the market situation, schedule (…) charging and discharging according to the bargained rules and expected revenues” (Geske and Schumann, 2018, p. 392).

more specific term for the user. Consumer is thus used to describe the broader society in general while the car owner is specifically set to describe the (potential) user of an EV.

While across disciplines, most literature is concerned with primary actors, we identified several secondary actors that are only relevant to few disciplines. For example, station operator and retailer are only relevant in the field of business or fields with an interdisciplinary priority. Furthermore, there are some user categories, that are only studied by interdisciplinary science, such as the investor, the early mainstream or the early adopter. Finally, studies in the field of psychology solely address the car owner, while stakeholders in the field of planning seem not to fall into one of the categories.

Having analyzed the stakeholder focus in current smart charging research, we will now move on to describe the results of the thematic analysis. In total, we identified 12 research themes (Table 2), and gained four interesting insights: First, we identified three topics that quantitatively dominate in the overall sample. The most often addressed research topic is Topic 9 (18 %), followed by Topic 2 (11%) and Topic 7 (11%). Furthermore, these topics are only subject to quantitative approaches. Second, with 2%, Topics 4 and 12 only play a subordinate role in the overall sample. Third, most topics are of interest to disciplines in the realm of engineering or interdisciplinary science (Figure 7). Finally, Topic 4 is the only topic that is solely studied in an interdisciplinary cooperation.

However, beside these insights, the topics can also be characterized content-wise. Examples of the specific research foci that are included in each topic can be found in Table 2. Based on our thematic analysis, we identified three thematic domains. The first one is comprised of the majority

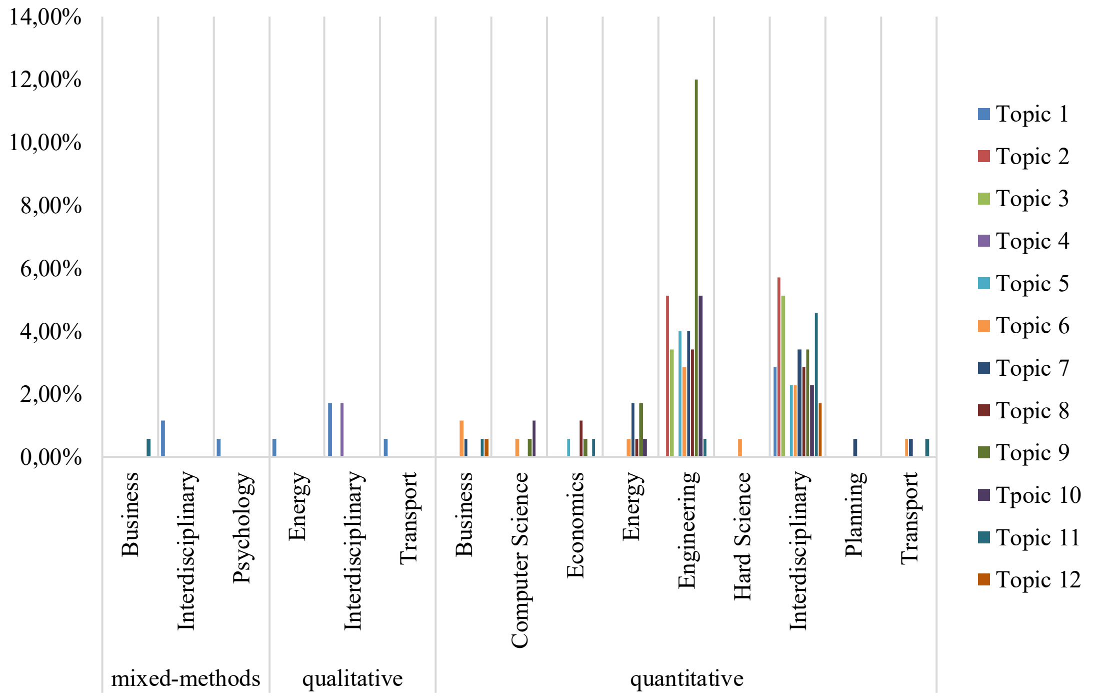

Figure 7. Topics according to methods and disciplines in smart charging research.

of topics, and addresses these topics with quantitative research methods while having a clear focus on the technology in question. The second domain includes three topics, Topics 1, 4, and 12. These topics center their research focus on the human dimension of smart charging. Methodologically, these topics are approached using quantitative, qualitative but also mixed-methods. Finally, we identified a few topics that can be characterized as being integrative, as they are situated at the interface between the more technology-oriented research disciplines and human-centered disciplines. In the following, we will describe these research domains and provide examples of how they integrate the user into smart charging research.

A.3.3 User characterization in smart charging research

The preceding analysis builds the basis for investigating the human factor of smart charging in more detail. We therefore structure this section according to the three topic domains, which we previously identified. In the following, we will provide examples of how the user is integrated in technology-centered, human-centered, and integrative topics. We do so by analyzing stakeholders, methods, and the selection of variables that were used to integrate the user of smart charging.

A.3.3.1 User characteristics in technology-centered research topics

The majority of topics has a clear focus on technology specific aspects of smart charging. Studies in these topics base their research on quantitative methods. We chose three topics in order to exemplify the way in which studies in these topics approach the user of smart charging. We chose Topics 6 and 7 as they are covered by a wide range of disciplines. Seven different disciplines deal with business models and economic performance (Topic 6), and six different disciplines with infrastructure planning and EV routing problems (Topic 7). Furthermore, we chose Topic 9, which refers to questions surrounding grid-related issues, such as operation scheduling, load frequency control, and reliability and security issues. 18% of all quantitative studies deal with this topic. Besides the quantity, studies in Topic 9 are limited to engineering disciplines and interdisciplinary collaborations.

Studies in Topic 6 conduct research on business models and the economic performance thereof. In this context, it is not surprising that these studies focus on primary actors, such as the aggregator (Chen et al., 2020b; Toquica et al., 2020; Xu et al., 2020), the grid operator (Buonomano, 2020; Ioakimidis et al., 2018; Kordkheili et al., 2016; Li et al., 2020; Lyon et al., 2012), the EV user (Cheng et al., 2020; Jain et al., 2019; Kahlen et al., 2018; Li et al., 2020), or stakeholders who could develop business models with smart charging, such as the fleet manager (Kahlen et al., 2018) or the parking lot owner (Brandt et al., 2017). Two studies also highlight the perspective of the retailer (Nojavan and Zare, 2018) and the electricity provider (Schill, 2011).With regard to user characterization, most of these studies incorporate the mobility behavior (30%) of users, as well as smart charging preferences (23%) and monetary benefits (18%). Right at the forefront of mobility behavior are driving profiles (Cheng et al., 2020; Kahlen et al., 2018; Kordkheili et al., 2016; e.g., Toquica et al., 2020), travel distance (e.g., Jain et al., 2019; Li et al., 2020), information on driving routes (Buonomano, 2020), and arrival and departure times (Cheng et al., 2020; Ioakimidis et al., 2018; e.g., Jain et al., 2019). Regarding smart charging preferences, studies include preferences of the minimum SoC (Ioakimidis et al., 2018; Jain et al., 2019; Kordkheili et al., 2016), the preference to charge when electricity is cheap (Li et al., 2020; Nojavan and Zare, 2018) and preferences in terms of contract conditions (Brandt et al., 2017). A large share of studies also refer to monetary benefits. These benefits can occur in terms of free or cost-reduced charging (Brandt et al., 2017; e.g., Lyon et al., 2012; Xu et al., 2020), reduced parking fees (Brandt et al., 2017), additional revenues (e.g., Jain et al., 2019; Kahlen et al., 2018), or a consumer rent (Schill, 2011).

Research conducted on Topic 7 investigates optimal EV routing and the respective infrastructure. Therefore, it is not surprising that the charging (21%) and mobility behavior (26%) of users, as well as smart charging preferences (34%) are most interesting in this context. With regard to the stakeholder perspective, most studies chose the viewpoint of the grid operator (e.g., Bin Humayd and Bhattacharya, 2017; Capasso and Veneri, 2015; Faddel et al., 2018), who would be the responsible actor with regard to infrastructure improvements. One study focuses on the fleet manager (Abdulaal et al., 2017), another study has a specific focus on charging infrastructure planning alongside the EV user (DeGennaro et al., 2015). Charging behavior is included in terms of the required energy for the charging process (Bin Humayd and Bhattacharya, 2017; Noorollahi et al., 2020), and the charging duration (Abdulaal et al., 2017; Bin Humayd and Bhattacharya, 2017; Capasso and Veneri, 2015). Driving behavior, on the other hand, is included as the driving distance (Bin Humayd and Bhattacharya, 2017; Jargstorf and Wickert, 2013; Noorollahi et al., 2020) or arrival and departure times (Abdulaal et al., 2017; Bin Humayd and Bhattacharya, 2017; Noorollahi et al., 2020). In contrast, Ul-Haq et al. (2017) include information on the parking duration. Concerning charging preferences, most studies refer to minimizing travel costs by charging when the electricity prices are low (e.g., Abdulaal et al., 2017; Faddel et al., 2018; Jian et al., 2018; Mazza et al., 2020). Two more interesting user preferences that are integrated refer to minimizing the customer waiting time while charging (Abdulaal et al., 2017; Bin Humayd and Bhattacharya, 2017; Jiang et al., 2018) and the preference for available parking spots close by (DeGennaro et al., 2015).

Finally, with 18 % Topic 9 includes the highest share of studies. Similarly to Topic 7, Topic 9 has a strong focus on smart charging preferences (31%), mobility (26%) and charging behavior (21%). All other categories can be neglected due to their low overall relevance. Nearly half of all studies with this research focus take the perspective of the grid operator. When diving into the considered user characteristics, we find foremost that charging behavior is mainly implemented in terms of supply and consumption profiles (Benalcázar et al., 2019; Sadeghian et al., 2019; Zalzar et al., 2017), charging or discharging rates (Bagher Sadati et al., 2019), power demand (Ahmad and Khan, 2020; Aluisio et al., 2017), and diverse specifications of the SoC (Alilou et al., 2020; Aluisio et al., 2017; e.g., Andersen et al., 2019; Barone et al., 2020). In terms of mobility behavior, several studies include information on mobility patterns and EV occupancy rates (e.g., Aluisio et al., 2017; Bagher Sadati et al., 2019; Barone et al., 2020; Lotfy et al., 2017; Sharma et al., 2018 - 2018), which is an alternative to determining mobility behavior based on arrival and departure times (Ahmad and Khan, 2020; Alilou et al., 2020; e.g., Fan et al., 2016; Huang, 2019).

Moreover, driving time (Kavousi-Fard and Khodaei, 2016; Lee et al., 2020b; e.g., Zalzar et al., 2017), distance (e.g., Hariri et al., 2019; Wang et al., 2017), and travel intervals (Druitt and Früh, 2012; Huang, 2019; Rostami and Raoofat, 2016) are included as well. What can be observed is that even though the topics in this research domain account for the majority of studies in the field of smart charging, these studies only exhibit a limited number of possible characterizations to include the user into their approach.

A.3.3.2 Exemplifying user integration in technology-centered topics

So far, results from Section 3.3 showed that it is a question of the research focus, which user characteristics are primarily included in the study. As such, the majority of topics in quantitative methods put the focus on a set of user characteristics in terms of charging and mobility behavior and smart charging preferences. Yet, we identified some studies in technology-centered topics that chose more elaborate approaches to include user characteristics. Table 3 provides examples of terms and definitions used by different authors in order to approach the user of smart charging more prominently.

Obviously, most terms and definitions are quite similar, referring to specific conditions in the EV charging process. For example, the terms *PEV user convenience* and *PEV owner convenience* both approach convenience by including the condition of a fully charged EV at departure time. Also, the definition by Amoroso and Cappuccino (2012) targets a fully charged EV at the end of the charging process. Similarly to achieving a fully charged battery, Azzouz et al. (2015) target with the term *customer priority* the issue of battery degradation. Another issue that is brought up is energy security. Adika and Wang (2014) include the condition that deferrable loads are used to prevent too many energy interruptions, which is termed *consumer frustration*. As already shown in Section 3.3.1, monetary preferences constitute an important aspect in quantitative studies. This aspect is also taken up by fulfilling *customer satisfaction*, which aims at maximizing user revenue (Ramakrishna Reddy and Meikandasivam, 2020). In the case of an EV routing problem, Abdulaal et al. (2017) introduce the term *customer utility*, which is included in the target function, aiming at minimizing EV user travel costs and waiting time. Finally, Jeon et al. (2020) use customer savings as an indication for *inconvenience*.

All above-mentioned studies acknowledge the importance of including user characteristics into quantitative approaches. These definitions reveal current efforts of introducing advanced approaches. Moreover, they call attention to the accompanying challenges, especially the issue of translating qualitative information into quantitative variables (cf., Jeon et al., 2020).

A.3.3.3 User characteristics in human-centered research fields

Human-centered research fields are comprised of three topics, Topics 1, 4, and 12. Yet, with 2%, Topic 12 only plays a marginal role in the overall sample. In the following, we will dive deeper into describing and comparing Topics 1 and 4.

Table 3 Approaches to consider the user in quantitative approaches

Terms	Definitions	Source
(Social) welfare	"The objective function of this approach is the maximization of the distribution system profit with considering the welfare of the EV owners."	Bagher Sadati et al., 2019, p.161
Economic social welfare	"Through this integrated and iterative ED [economic dispatch], the maximization of the economic social welfare (ESW) of both the utility and PEV is reached."	Benalcázar et al., 2019, p. 3
Customer welfare	"As PEV owners are rational, they will make their own decisions to maximize their welfare considering all the information available, including other owners' behaviors."	Chen et al., 2020b, p. 2234
PEV user convenience	"The main goal is to flatten the residential distribution transformer load profile on a 24-h basis without compromising PEV user convenience (full SOC at time of departure)."	Erden et al., 2018, p. 1496
PEV owner convenience	"This paper explicitly considers PEV owner convenience, which can be mainly characterized by a desired SOC at the departure time."	Huang, 2019, p. 4156
User satisfaction degree	"(…) calculated as the ratio between the energy actually stored into the battery at the end of the charging process and the energy required by the vehicle battery at the beginning of the charging process."	Amoroso and Cappuccino, 2012, p. 5
Customer dissatisfaction	"Two criteria are considered in evaluating the customer dissatisfaction in this article: 1) the time that the customer has to wait before reaching the desired SoC level after the minimum required charge duration and 2) the battery SoC in each time step."	Ebrahimi et al., 2020, p. 1028
Customer utility	"The multi variant electric vehicle routing problem solution cost [is investigated], if the objective was to minimize the customer waiting time."	Abdulaal et al., 2017, p. 246
Customer priority	"Thus, the V2GQ [vehicle-to-grid reactive power support] sustains the battery life time, which is of the highest customer priorities (…) customer satisfaction is considered the highest priority."	Azzouz et al., 2015, p. 3237
Customer satisfaction	"Along with this, customer satisfaction is considered through maximization of customer revenue."	Ramakrishna Reddy and Meikandasivam, 2020, p. 261
Consumer frustration	"To mitigate on this consumer frustration, deferrable loads have been designed such that after two consecutive interruptions, they are assigned maximum priorities. Therefore, they will be allowed to run first in the subsequent periods."	Adika and Wang, 2014, p. 234
Cost of inconvenience	"The cost of inconvenience for customers in providing the DR service must be considered. However, as this cost is subjective and difficult to quantify, we calculate the net cost saving for customers and discuss whether it is enough to offset the inconvenience of providing the DR service in the discussion."	Jeon et al., 2020, p. 18

While Topic 1 is subject to research with quantitative, qualitative and mixed-methods, Topic 4 is solely represented in qualitative approaches, with three studies in total (Kester et al., 2019; Kester et al., 2018; Noel et al., 2018a). These studies are the result of an interdisciplinary cooperation between business and political science. As these studies are concerned with barriers, (non-monetary) costs and benefits, it is not astonishing that all three studies include perceptions and attitudes toward EVs (9%) and toward smart charging (9%), as well as variables referring to technical (18%), monetary (18%), and other barriers (45%). The most often mentioned barriers are battery degradation, costs and low consumer acceptance or even resistance toward smart charging technology. Contrary to Topic 4, Topic 1 has a strong focus on values (24%). Values in this respect refer to the environmental and technological orientation, traditions, or the car as a symbolic status representation. Perceived functional attributes and attitudes toward the charging scheme fall into perceptions and attitudes toward EVs (17%). Of similar importance in this topic is the charging behavior with 17%, including the charging habit, the target SoC, or the interaction with the domestic solar energy supply.

Topic 1 includes 13 studies in total, from which five studies can be assigned to both qualitative and quantitative methods. The remaining three studies pursue a mixed-methods design. The qualitative studies have a strong focus on values (24%), charging behavior (17%), and perceptions and attitudes toward EVs (17%). Regarding stakeholder focus, these studies center their analyses on the user of smart charging, with one exception. A study by Earl and Fell (2019) highlights the perspective of the OEM.

With only four studies, mixed-method studies play a marginal role in the smart charging literature. Three out of four studies were assigned to Topic 1 (Döbelt et al., 2015; Schmalfuß et al., 2015; Sovacool et al., 2019). One study (Schmalfuß et al., 2015) was conducted by a research team from psychology. The remaining two studies were conducted in cooperation between psychology and computer science (Döbelt et al., 2015) and in cooperation between business and political science (Sovacool et al., 2019). All studies focus on the user as the main stakeholder. This aspect is also reflected in the variables that are used to characterize the user. Values, EV preferences, and perceptions and attitudes toward the EV are the main categories to display the EV user in mixed-method approaches in the realm of smart charging. By contrast, motives, mobility behavior, and benefits are not represented in these studies. Values are included in terms of fairness, environmental awareness, functional, emotional, or economic values. Moreover, these studies investigate a variety of EV preferences, such as preferences regarding the purchase price, operational costs, range or technical reliability. Finally, perceptions and attitudes toward the EV are covered by variables such as innovativeness, perceived level of autonomy, or suitability for daily life.

When turning to quantitative approaches in Topic 1, it can be highlighted that these studies are the results of interdisciplinary research teams from life science, business, political science, transport and computer science. All studies focus on the user of smart charging, specifically, Bailey and Axsen (2015) study the early mainstream, and Will and Schuller (2016) the early adopter group of smart charging technology. As in qualitative and mixed-method studies, Topic 1 has a strong focus on values (23%). Additionally, knowledge (12%) and contextual information (12%) are strongly represented. Contextual information refers in this context to household and demographic variables (Axsen et al., 2016; Will and Schuller, 2016), and information regarding car ownership (Sovacool et al., 2018). Moreover, two studies also include gender (Sovacool et al., 2018, 2019a). Knowledge is assessed in terms of EV knowledge and interest (Axsen et al., 2016; Will and Schuller, 2016), EV experience (Sovacool et al., 2018; Will and Schuller, 2016), and ownership (Sovacool et al., 2018). Finally, values play an important role in this setting. Most studies captured environmental values (Axsen et al., 2016; Sovacool et al., 2018, 2019a; Will and Schuller, 2016), but also technological orientation or affinity (Bailey and Axsen, 2015; Will and Schuller, 2016), biospheric and altruistic values (Axsen et al., 2016; Bailey and Axsen, 2015) are included. What is striking is the accumulation of the same or similar variables. This might be due to the fact that several studies from the same authors are included in this cluster.

A.3.3.4 User characteristics in integrative research fields

Integrative topics can be characterized by their way of bridging human-centered and technology-centered topics. These studies employ a diverse set of methods (not necessarily mixed-methods) and variables to integrate the user of smart charging into technology-oriented research topics. In the following, we will exemplify this on the basis of Topic 2.

Topic 2 includes 20 studies in total. As studies that were assigned to this topic aim to assess and optimize EV charging behavior by including user needs, behavior, and incentives, it is not astonishing that most of them take the perspective of a primary actor of smart charging, which are the aggregator (Ferro et al., 2020; Sachan and Adnan, 2018; van der Kam et al., 2019), the grid operator (Alonso et al., 2014; Erden et al., 2018; Ramakrishna Reddy et al., 2019; Ramakrishna Reddy and Meikandasivam, 2020), and the user of smart charging (e.g., Barbecho Bautista et al., 2019; Bryden et al., 2019; Maeng et al., 2020), with one specificity, namely the early mainstream (Kamiya et al., 2019). Finally, two further studies target the electricity provider as the main actor (Daina et al., 2017; Su et al., 2019). It is interesting that approximately half of all studies are of interdisciplinary nature.

Regarding user characteristics, studies in Topic 2 are mainly conducted using quantitative methods. However, compared to previously presented quantitative studies (Topics 6, 7, 9), Topic 2 exceeds these studies by dedicating a remarkable share to contextual information (14%). For instance, they include a bandwidth of variables, such as socio-demographic data (Daina et al., 2017; Fetene et al., 2017; Maeng et al., 2020; van der Kam et al., 2020), number of available EVs and home electricity conditions (Alonso et al., 2014; Jin et al., 2019; Kamiya et al., 2019; Ramakrishna Reddy et al., 2019), route conditions, such as the number of traffic lights or average speed (Barbecho Bautista et al., 2019), and travel purpose (Alonso et al., 2014; Maeng et al., 2020). Furthermore, while charging behavior is limited to charging time (e.g., Bhattarai et al., 2017; Daina et al., 2017; Flammini et al., 2019; Jin et al., 2019), and battery capacity (Alonso et al., 2014; Ramakrishna Reddy et al., 2019; Ramakrishna Reddy and Meikandasivam, 2020), mobility behavior includes a variety of variables, including driving patterns (Maeng et al., 2020; Maigha and Crow, 2018), driving needs (van der Kam et al., 2019) and distance (Barbecho Bautista et al., 2019; Kamiya et al., 2019), and preferred departure time (Daina et al., 2017) for different travel purposes (Ramakrishna Reddy et al., 2019).

Finally, 30% of all characteristics are dedicated to a variety of smart charging preferences. These reach from minimum ranges to financial incentives, preferences regarding the flexibility potential and the fuel type to the accessibility of charging stations through to reduced charging and waiting times and preferences regarding the charging slot. Yet, monetary aspects are by far the most often applied category to capture smart charging preferences. For example, preferences are steered by financial incentives to either motivate participation in smart charging (Bhattarai et al., 2017) or to postpone the charging process (Fetene et al., 2017). Moreover, some studies capture preferences in terms of minimized charging costs (Bhattarai et al., 2017; Daina et al., 2017; Fetene et al., 2017; Jin et al., 2019; Maeng et al., 2020; Ramakrishna Reddy et al., 2019; Ramakrishna Reddy and Meikandasivam, 2020; van der Kam et al., 2019).

A.4 Integrating the user in studies of smart charging

The past 10 years not only brought an increase in research on smart charging but also an increase in the variety of topics and methodological approaches. Such interest and recognition in the research community irrevocably lead to noteworthy improvements for including the user in this research field. From our point of view, considering user characteristics in studies of smart charging is a pivotal step, as these broaden the research perspective to the human factor of smart charging.

What follows is a discussion of the most important findings from our literature review to provide guidance for future research. The major contribution of this comprehensive review of peer-reviewed journal publications is twofold. First, we provide insights on the current state of research on smart charging by investigating disciplines, methods, and stakeholders of smart charging and by identifying dominating research topics throughout the various disciplines. Second, we investigate how the human factor of smart charging is approached by predominating topics and methods and provide examples of research topics and the way in which the user characteristics are typically integrated.

A.4.1 Implications of disciplines, methods and data sources for integrating the user into smart charging

So far, most research on smart charging is conducted by applying quantitative methods, while only very few studies follow a qualitative or a mixed-method approach. Thus, qualitative and mixed-method studies are clearly underrepresented. This does not mean that there is not a wealth of quantitative methods that have been applied. But this finding already provides a first indication of the kind of data that is retrieved. As described in Section 3.1, the majority of studies rely on statistical databases, for example to quantify driving behavior. These data bases are population-representative but might not be representative of the technology in question. Moreover, the bandwidth of variables that can be retrieved of these sources is limited, meaning that data on charging behavior might be part of the portfolio, while data on charging requirements might not. Therefore, such specific variables are often replaced by assumptions based on general behavior, which must not necessarily reflect an individual's preference. Apart from this, perceptions and norms influence user behavior in many ways. However, it is difficult to translate qualitative information into quantitative variables. Consequently, considering human complexity in a quantitative manner or in a simplified model is challenging (cf., Huckebrink and Bertsch, 2021). Yet, Pettifor et al. (2017) recommend to consider the effect of social norms on consumers' adoption of alternative fuel vehicle technologies in modeling adoption processes. The authors base their statement on the results of a meta-analysis of 21 empirical studies. Similarly, Sachan and Adnan (2018) argue that social and psychological components impact charging methods. However, no attempt was made to put this into practice. The authors solely consider EV arriving times that are obtained from the National Household Travel Survey (NHTS) and do not consider further variables.

Moreover, most research is conducted by disciplines in the realm of engineering, followed with a large gap by authors with a training in energy-related disciplines and business. Moreover, 42% of all studies were conducted in research collaborations. Previous literature outlined the added value of interdisciplinary cooperation for research on technologies that can be described as socio-technical systems (Sovacool et al., 2018; 2017). However, most research cooperation in our sample took place between disciplines in the realm of energy and engineering, which are two research fields with overlapping topics and methods. Cooperation between disciplines with less intuitive connections could hardly be identified. Thus, the majority of studies were conducted by authors with an engineering background.

It is astonishing that smart charging seems to be more important to energy- and engineering related disciplines than to disciplines with a specific transport focus. Besides the lack of studies conducted by disciplines with a transport focus, very few studies were conducted by disciplines that would take a human-centered perspective on smart charging, i.e., for example political science and psychology. The same can be observed for disciplines that traditionally are located at the interface of natural, social, and human science and focus more broadly on the interactions between spatial dimensions and human actions, such as geography and planning.

A.4.2 Stakeholders in smart charging research

As the smart charging technology is developing, business opportunities are growing, as are the relevant stakeholder groups[1]. Aside from this, the user of the technology can be seen as one core stakeholder, as his driving and charging routines might be disrupted due to smart charging. Therefore, it is not surprising that most studies focus on the primary stakeholders of a smart charging system, which also includes the user of smart charging. However, the way in which the user is integrated varies. While integrative topics or topics that fall into the domain of social sciences place the user in the center of interest, studies with a technical research interest mostly take a system perspective with the aim of increasing the system's effectiveness. As such, the user is one out of several actors in a smart charging ecosystem. Thus, the individual perspective stands against a system perspective, making it difficult to find an intersection for combining or aligning these perspectives. However, we believe that there are several research topics, that could be worth highlighting from the individual as well as from the system perspective. Such topics noteworthy to be further investigated would be business models and economic gains (Topic 6), optimal operation strategies (Topic 9) and infrastructure planning (Topic 7).

Economic gains are mainly elucidated from the view point of the aggregator (e.g., Ferro et al., 2018; Kara et al., 2015; Li et al., 2020). With respect to the EV user, these studies indicate expected user revenues in terms of the battery degradation cost (e.g., Li et al., 2020; Maigha and Crow, 2018; Sufyan et al., 2020). Li et al. (2020) note that besides battery depreciation costs,

[1] For a comprehensive review of stakeholders and business models of V2G see Sovacool et al. (2020).

additional electricity charges due to V2G have to be considered when EV user participation is assumed. The general importance of considering the user perspective is brought forward by Kara et al. (2015) stressing that "the objective function should capture the desired benefits from a stakeholder's perspective" (Kara et al., 2015, p. 519) as well. The authors thus assess possible revenues for various actors in their optimization approach. On the other hand, social science studies focus either on users' willingness to pay for smart charging as one out of several EV features (e.g., Noel et al., 2019a) or users' willingness to provide flexibility (Kubli et al., 2018). The economic assessment also indicates besides a monetary value, a general acceptance or rejection of the technology under specified conditions (Lee et al., 2020a). To our understanding, contrasting these different perspectives would reveal important insights into the different actors' requirements on one hand and calculated monetary gains on the other. Furthermore, a discussion across disciplines and stakeholders on whether users would accept these calculated revenues and under which conditions could be fostered. Additionally, the system perspective would learn about users' expectations and requirements to accept a certain revenue or not. It would also provide an indication of the actors' willingness to participate in such smart charging scheme. The contrast could also be applied to negotiate possible charging strategies and the respective scheduling of the EV. Maigha and Crow (2018) call the attention to this issue by choosing a multi-objective optimization to weigh user interests, which in this case is to minimize battery degradation against the system operator's interest to maintain the system's load profiles.

According to Hardman et al. (2018), considering the user perspective for infrastructure planning is a necessity. In their review, the authors focus on studies dealing with consumer interactions with the charging infrastructure for PEVs. The authors stress the need for considering consumers' use patterns for the development of charging infrastructure due to the relevance to both, achieving higher adoption rates by consumers and ensuring a sound management of electricity grids with increased demand from PEVs. In our dataset, we identified two studies using driving patterns as a basis for developing recommendations on infrastructure development (DeGennaro et al., 2015; Hoog et al., 2015).

A.4.3 Patterns to integrate user characteristics in smart charging research

Research topics imply a set of possible methods or the type of data that will be necessary to answer the research question. Thus, they also entail patterns to include user characteristics in smart charging research, which we aim to identify.

In the course of our literature review process, we identified 12 topics that are relevant to smart charging literature that also includes the user perspective. These topics capture a variety of aspects. Yet, most of these topics can be placed at the interface between the energy and the mobility system, while only a few topics approach smart charging against the background of a societal context. For example, there is a strong focus on operation scheduling, business models, economic performance, and infrastructure planning. These topics have a strong focus on technology, and surely are of interest and importance to the research community. Yet, the user of smart charging only plays a subordinate role. This reveals that the human dimension of smart charging is not sufficiently explored. Considering this perspective is, however, important as it provides information on the user behavior, preferences regarding technological innovations, or on how the user interacts with the smart charging system. This information is of importance as it reveals whether and under which conditions the user will engage with the smart charging system. Finally, there is a third stream of research topics that enables the inclusion of both, focusing on technical aspects as well as acknowledging the human dimension in an adequate manner. In the following, we will provide examples of these identified patterns.

A.4.3.1 The user in topics addressing the technical dimension of smart charging

As described in Section 3.3.1, most topics address technical aspects of smart charging. We exemplified this choosing Topics 6, 7 and 9 as these are represented most in our data set. It is striking that these topics are based on quantitative methods, are mainly conducted by engineering disciplines and interdisciplinary cooperation (the majority being comprised of disciplines in the field of engineering and energy), and only use a limited number of possible characterizations to include the user into their approach (Table 4). These topics can thus be characterized by their technology-orientation. Even though the topics cover a wide range of smart charging aspects, they include user characteristics in terms of smart charging preferences, mobility and charging behavior – all of which are categories that are more or less easily integrated into quantitative approaches.

Table 4 Typical user characteristics in studies with a technical research focus

Charging preferences	Charging behavior	Mobility behavior
Minimum range at departure time	Battery capacity	Arrival and departure times
Low charging costs / charging when electricity prices are low	Charging duration	Driving duration and pattern
Charging strategy that considers battery life	Charging pattern	Travel frequency
Preferences regarding flexibility provision	Initial SoC	Parking duration
Preferences regarding charging strategy, e.g., charging with RES		
Reduced charging and waiting time		

The charging preference is one out of three categories that are most often used to specify user characteristics in the technical topics. It can be observed that preferences are either included as model restriction (e.g., Erden et al., 2018; Su et al., 2019; Sufyan et al., 2020) or as part of the target function (e.g., Bryden et al., 2019; DeForest et al., 2018; Moghaddam et al., 2018). Preferences are derived as estimates or, less often, based on empirical datasets. Along with smart charging preferences, mobility and charging behavior are dominating categories to include the user in studies of smart charging. Typical variables in this category are departure and arrival times, the driving distance or frequency. This data is typically retrieved from national household surveys, such as the NHTS (e.g., Sachan and Adnan, 2018; Tarroja et al., 2016). Moreover, many studies make use of assumptions (e.g., Deilami, 2018; Ferro et al., 2018; Liu et al., 2014; Ramakrishna Reddy et al., 2019) and probabilities (Bryden et al., 2019), thus simplifying charging and mobility-related behavior even more. Kester et al. (2019, p. 278) criticize that the current literature relies too much on a 'technical rational model'. However, this does not fully account for the obstacle, that especially in the realm of smart charging, the body of empirical charging behavior data is quite small, impeding the integration of empirically-derived data in smart charging studies. This obstacle is in line with Li et al. (2020) who retrieve studies of the charging behavior of EVs and raw data including the links to the respective sources to enable further investigation. They argue that despite a growing body of literature, the collection of empirical charging data evolves rather slowly, because of the high share of private purchases of EVs, which make data collection sensitive to data protection issues and are thus difficult to assess.

Few studies in our dataset collected empirical data on charging and mobility patterns, though based on the driving behavior of ICEVs (e.g., DeGennaro et al., 2015). Kara et al. (2015) illustrate this point clearly by arguing that V2G charging patterns are different from the charging of ICEVs and thus not totally transferrable. As a response to this critique, Kara et al. (2015) extract trip and customer characteristics collected from PG&E territory. The authors conclude that EV charging and driving behavior as well as user characteristics can be displayed much more realistically compared to mere assumptions. Collecting such data is, however, time-consuming, which might be one reason why we identified only few authors using data obtained from field trials (e.g., DeForest et al., 2018; DeGennaro et al., 2015; Erden et al., 2018; O'Connell et al., 2014) or EV representative data (Dixon et al., 2020). Consequently, there seems to be a trade-off between the effort put into collecting this data and the accuracy of implementing data on behavior.

Directly connected with this issue is an argument brought forward by Luh et al. (2022), stating that most approaches today consider long timeframes but are based on historic data. Exemplarily, Ensslen et al. (2018) and Kamiya et al. (2019) state that it is questionable whether future driving behavior will be the same as driving behavior today. This is especially true for transport and energy models, where everything is at a turning point. Consequently, foreseeing technical improvements, regulatory changes and possibly changing mobility patterns, norms and values become even more challenging. Considering the fact that smart charging can still be defined as a technological innovation with not yet defined regulatory frameworks, the reliability of these results is questionable.

To summarize, the user in the technical research fields is integrated in a very generic way. Individual and consumer-specific aspects are less well-integrated, and only few topics include contextual information. In our understanding, however, this information is relevant since charging and mobility behavior are affected or even motivated by the amount of available charging locations in a region (e.g., Delmonte et al., 2020), the amount of cars in a household (Chen et al., 2020b; Dixon et al., 2020), or household characteristics (Axsen et al., 2018; Axsen et al., 2016; Chen et al., 2020a; Sovacool et al., 2018). It obviously makes a difference whether a household owns one or more cars, or whether the user is a tenant or a houseowner taking his own energy-related decisions. Based on this contextual information, more realistic charging and driving patterns could be generated, resulting in a more reliable forecast of flexibility potentials. Therefore, it is vital to display behavior, but also charging preferences, such as charging locations, preferred charging strategies, or requirements to accept smart charging, such as the minimum range as realistically as possible, without compromising the model's main dynamics. Finally, we believe that few additional data would be needed to put this into practice and that the actual work effort would be increased only minimally.

A.4.3.2 The user in human-centered topics

In contrast to technology-oriented topics, topics that solely focus on the human dimension of smart charging center research around the user's perceptions and attitudes toward smart charging, their motives to participate in smart charging programs or barriers that hinder them to do so. With this, these studies open up a complementary perspective that supports the introduction of smart charging technology into people's routines and daily lives. Additionally, the type of data that is retrieved in these studies can potentially replace commonly used assumptions based on general statistics referring, for example, to minimum range requirements. Finally, it can guide the more technical research streams in conceptualizing their research problems.

Topics 1 and 4 capture research that delves into the human dimension of smart charging. While Topic 4 is solely studied using qualitative methods, Topic 1 includes both, qualitative and quantitative methods, as well as mixed-methods. These studies were conducted using either surveys, interviews or focus groups. Table 5 provides examples of typical characteristics that were used to study the user of smart charging. Compared to Table 4, it is striking that all categories and most of the subcategories are relevant in these research streams. Even though the quantity of studies in this research stream is alarmingly low, the variety of variables is large, especially with regard to perceptions and attitudes.

As outlined in Section 4.3.1, data sources in technically-focused topics face the challenge of identifying available data sources to include user characteristics in an appropriate way. Thus, the majority of studies is based on statistics and assumptions, mostly because of data availability issues. Few exceptions exist. However, this circumstance supports the argument that very little is known about actual charging behavior, charging preferences, or concerns with regard to this technology. This is where human-centered research, among other things, can contribute. Topic 1, for example, has a strong focus on assessing knowledge, perceptions, preferences and user motivations to participate in smart charging. As such, studying e.g., knowledge about smart charging is paramount for decision-makers. Knowledge is the basis of a diffusion process. Knowing about an innovation enables to form an attitude and lastly a decision to adopt or reject the innovation (Rogers, 1983). Therefore, studying knowledge can for example provide important insights into the diffusion process, and might inform investment decisions. Related thereto are information on purchase and use motivations. These are valuable as well to decision-makers, but also to companies designing business models. Studying these motivations is an essential aspect, as only business models that are relevant to or foster specific values of users lead to a successful market uptake. Finally, values are important as well in that they might be an indication of preferred charging strategies. Smart charging is expected to contribute to a more reliable and efficient grid operation and better integration of RES into the grid (Blumberg et al., 2022; Dixon et al., 2020; Schuller et al., 2015), thus leading to a more decentralized, secure, and flexible energy system (Sovacool and Hirsh, 2009). These potentials address a set of values, that might be important to a user which could subsequently be part of a charging strategy. Aside from this, studying values entails important indications of possible target groups.

Table 5 Typical user characteristics in human-centered smart charging topics

Category	Sub-category	Examples of variables
Context	Contextual information	Number of cars; socio-demographic and household characteristics; gender; charging location; education and occupation
	Motives	Purchase and use motivation; self-determination
	Knowledge	Technological knowledge and awareness; EV driving experience; EV interest and ownership
Behavior	Charging behavior	Energy demand; charging behavior / habit; charging frequency; target SoC
	Mobility behavior	Mobility practices; actual vs. stated behavioral intention; driving need; driving distance; driving frequency; modal choice; departure time
Perception and attitudes	Towards EVs	Environmental performance; functional attributes; attitude towards smart charging; perceived risks and barriers; complexity; suitability for daily life; usefulness
	Toward smart charging	Public charging station availability; loss of control; skepticism regarding reduction potential of consumption
	Values	Environmental values, technological orientation; traditional, biospheric, egoistic, altruistic values; openness; instrumental values; fairness; classism; equity; political orientation; car as a symbolic status
Preferences	Toward EVs	EV price; acceleration; range; size; safety; design; vehicle type
	Toward smart charging	Cheaper charging; minimum range; use of flexibility; electricity source; contract duration; charging availability; charging strategy
Benefits	Monetary	Cost savings
	Environmental	Green electricity; RES integration
Barriers	Technical	Range; charging time; battery life; privacy
	Monetary	Upfront costs
	Others	Reduction of comfort; concerns about the technology; consumer resistance

By focusing on a human-centered research perspective, the variety of motivations, perceptions and values influencing a user's decision to participate in smart charging can be revealed. Especially qualitative methods can provide further insights into actual consumer reasoning and behavior, thus informing representative quantitative surveys (Coffman et al., 2017). Strengthening both, quantitative as well as in-depth qualitative research is thus essential to provide insight into the context in which smart charging should be integrated and into the requirements to be successful.

A.4.3.3 An integrative perspective

Topics bridging the gap between human-centered and technology-centered topics, also in a methodological sense, are not necessarily accompanied by mixed-methods, but rather by interdisciplinary cooperation between disciplines from different schools of thought. We identified two topics that we describe as integrative, as they combine insights from technical and human-centered perspectives. This integrative character is reflected in the type of data that is retrieved to include the user in smart charging.

Table 6 Typical user characteristics in integrative smart charging topics

Category	Sub-category	Examples of variables
Context	Contextual information	Vehicle availability; socio-demographics; traffic conditions, trip type; home electricity conditions
	Knowledge	Technological knowledge; EV driving experience; EV interest and ownership
Behavior	Charging behavior	Energy demand; time of connection; charging time; initial SoC
	Mobility behavior	Departure and arrival time; travel requirements; total travel time; trip distribution; driving distance; EV usage patterns; driving needs; parking duration
Perception and attitudes	Toward EVs	Perception toward EVs; innovativeness; comfort; environmental importance
	Toward smart charging	Range anxiety
	Values	Environmental values; lifestyle; fairness; social, emotional, economic values
Preferences	Toward EVs	Vehicle price; annual net cost; range; maintenance fee; acceleration; environmental impact; technical reliability; ease of operation; design; safety
	Toward smart charging	Minimum driving range; minimized EV charging costs; postponed charging for a discount; flexibility potential; accessibility; charging strategy; reduced waiting time; charging slot; fuel type; recharging time; low battery degradation
Benefits	Monetary	Revenues; fuel savings
Barriers	Others	Lack of fast charging infrastructure; physical and behavioral constraints

For example, a bandwidth of studies in Topic 2 is concerned with charging strategies, while considering user needs (Bryden et al., 2019; Daina et al., 2017; Maeng et al., 2020; van der Kam et al., 2020; van der Kam et al., 2019). Half of all studies conducting research on this topic come from an interdisciplinary cooperation, while the other half comes from engineering disciplines. Another topic that provides various examples of this integrative character is Topic 11, assessing market potentials of smart charging based on user demand (Hidrue and Parsons, 2015; Hong et al., 2012; Khan and Bohnsack, 2020; van der Kam et al., 2018; Zarazua de Rubens, 2019) or willingness to pay for smart charging (Bishop et al., 2016; Noel et al., 2019a; Parsons et al., 2014). Interestingly, aside from quantitative methods, one study approaches this topic using mixed-methods (Khan and Bohnsack, 2020). Furthermore, this topic is primarily studied by an interdisciplinary cooperation, comprising business, political science, engineering, life science, transport, computer science, and economics. We previously pointed out, that even though 42% of research was conducted in an interdisciplinary cooperation, most cooperation took place between disciplines in the realm of engineering and energy. These topics however draw a different picture, illustrating that research can overcome boundaries between disciplines and their underlying schools of thought. The results are studies strengthening an integrative perspective by laying equal emphasis on the human dimension of smart charging as well as on technical and economic aspects. Fostering interdisciplinary cooperation across schools of thought enables research to increase ‘explanatory power, and practical applicability of research’ (Sovacool, 2014, p.13), which is especially important to research concerned with technological innovations that strive to provide solutions to environmental issues.

This effort is reflected in a wide range of user characteristics, including contextual information, behavior, perceptions, attitudes, and preferences, with a special focus on values, EV preferences, and perceptions, and attitudes toward EVs, allowing to draw a manifold picture of the user of smart charging (Table 6). With this, current research practices are challenged. For example, Daina et al. (2017, p. 37) mention in this context that 'the current practice for the appraisal of smart charging strategies assumes predefined charging scenarios and exogenous EV use patterns'. To build a charging behavior model that is capable of capturing tactical charging choices, the authors empirically investigate charging behavior. Based on the empirical information, charging preferences are estimated (Daina et al., 2017).

Surely, a research design that includes an empirical part to collect data and a quantitative modeling part is advantageous. Studies with such research design provide guidance for enabling a more holistic view of smart charging. Taking such a perspective is important, especially in light of profound transitions. Smart charging as such will entail lingering changes for the mobility and the energy system architecture, of which the individual is an essential part. To our understanding, these transitions are best captured by integrating both, the system and the individual or societal perspective in equal parts. Moreover, this opens up new possibilities to account for user acceptance.

Examples of this research practice are provided by Kamiya et al. (2019) who build two models. The first one entails empirical information on vehicle preferences, driving patterns, and recharge access with the aim of modeling the status quo of PEV usage in 2015. The data is representative of new vehicle buyers in Canada. Having said this, a downside is that this data is related to current driving patterns and might not reflect future driving patterns. This is important when taking a long-term perspective, which is the case for the second model. Nevertheless, the approach is rich in empirical methods, including three surveys and one travel-diary, accounting for contextual information, such as vehicle fleet, home electricity conditions, values, i.e., lifestyle, and driving and charging behavior, such as trip time, purpose and information concerning the parking location (Kamiya et al., 2019). Another example is provided by Ensslen et al. (Ensslen et al., 2018), assessing requirements of users and fleet managers to accept smart charging (Ensslen et al., 2018). These requirements include expected revenues and the minimum range. By calibrating these empirically obtained information in an agent-based model, which simulates the wholesale electricity market, economic, social and technical aspects are considered (Ensslen et al., 2018).

Finally, there is one study that stands out, since it considers a wide range of values on top of user behavior and preferences, which is an important aspect of decision-making. van der Kam et al. (2019, p. 2) justify their approach by pointing out that individuals 'are not rational decision makers who carefully balance costs and benefits to maximize the utility of their behavior, [but] (…) that normative considerations are important predictors for pro-environmental behavior'. Thus, the authors incorporate the theory of environmental self-identity in modeling EV charging behavior. Moreover, the authors take range anxiety into account, as well as driving needs, agent characteristics, and policy interventions. The overall goal of this approach is to investigate the effect of policy interventions on EV charging patterns (van der Kam et al., 2019). This approach is of great significance, as it illustrates that even norms, which are mostly obtained by qualitative approaches, can be transformed into a quantitative logic.

It can be concluded from this analysis that compared to pure technology-focused and human-focused research, integrative topics open up a space for interdisciplinary research across schools of thought, enable the application of diverse methods, and thus foster a diverse picture of the human dimension of smart charging. Most approaches, be they human-centered or technology-centered, are quite entrenched. While quantitative approaches fall short of recognizing human complexity and rely on cost-minimization (Huckebrink and Bertsch, 2021; Sovacool et al., 2015), social scientists ignore physical or engineering principles (Sovacool et al., 2015). However, creating inclusivity enhances robustness and might improve the reliability of results, which is especially required for complex, multi-dimensional challenges such as the integration of smart charging.

A.5 Conclusion

This systematic review provides an overview of studies from the past 20 years of research on smart charging. With this review, we aim to foster a deeper understanding of how the user of EV smart charging is integrated in different research areas. By doing so, we aim to enable research to create a truly holistic and more comprehensive picture of the future integration of smart charging. To our understanding, this transparency is an important prerequisite for the market uptake of a complex, cross-sectoral innovation with high societal impacts, such as the diffusion of smart charging. We make this visible by reviewing 183 peer-reviewed journal articles.

In a first step, we identified predominating disciplines in our sample, as well as interdisciplinary cooperation. Research on smart charging is dominated by engineering disciplines, followed by research conducted by interdisciplinary cooperation. At first glance, this seems impressive. However, when looking into the combinations of research cooperation, we find that the majority of cooperation takes place between disciplines in the realm of engineering and energy scientists. Only few collaborations exist between disciplines that follow different rationales, meaning looking at topics from different angles, and applying different methods. Consequently, the current research practice is rooted in disciplines, calling for the need to strengthen true interdisciplinary research cooperation. This is especially true against the background of pressing sustainability issues and the need to find practically applicable and accepted solutions

Secondly, we analyzed whether the studies used a quantitative, qualitative, or a mixed-method research design and provided statistics to show the general development of the topic over the past years. Clearly, the topic gained widespread attention of the research community. We recorded an increase in publications throughout all three methodological approaches – qualitative, quantitative, and mixed-methods – in the last years, headed by quantitative methods. We found few qualitative and equally few mixed-method studies. Combined with the insight that the majority of studies was conducted by engineering scientists, we identify the need for further empirical research. As smart charging can still be described as an innovation, there is not only the need for further statistical data on charging and driving behavior that can be the basis for simulating the transport and energy system, but also for further empirical methods to explore the societal context of smart charging in more detail. Especially qualitative approaches are suited to gain in-depth knowledge about user motivations to use or reject a new technology. Hence, we see the need for further empirical, and especially qualitative research on smart charging.

To dive deeper, based on author keywords and abstract, we identified dominating research topics in smart charging research using thematic analysis. Moreover, we identified stakeholders that are in the focus of research. This analysis revealed 18 different stakeholders, with the majority being part of the primary actors of a smart charging system. Regarding topics of interest, we identified 12 overarching research topics, which can be split into three domains. The majority of topics has a technology focus and is solely approached by quantitative methods. We called these topics "technology-centered" domain. Second, we identified topics that center around the human dimension of smart charging and can thus be called "human-centered" topics. This research field is investigated using qualitative, quantitative, and mixed-methods. The final research topics have an integrative character, as they act as an interface between human-centered and technology-centered topics.

Finally, we provided examples of typical user characteristics in the three different topic domains. Therewith, we analyzed variables on the one hand, stakeholders, methods, and data sources on the other hand. We furthermore showed, which type of data is typically retrieved or collected. While technology-oriented topics typically base their analyses on quantitative models and focus on charging and mobility behavior and smart charging preferences, topics with a focus on the human-dimension of smart charging focus on a specific stakeholder group and enable in-depth knowledge about values, norms, and perceptions of smart charging. Combining these perspectives is not trivial. Nonetheless, we identified two topics that are predestined to combine these schools of thought. Studies in the first topic (Topic 2) assess and evaluate smart charging strategies by including user needs, behavior, and incentives, while Topic 11 focusses on questions surrounding the market potential of smart charging or the potential consumer demand for this technology. This effort is reflected in a wide range of user characteristics, including contextual information, behavior, perceptions, attitudes, and preferences, with a special focus on values, EV preferences, and perceptions and attitudes toward EVs.

Moreover, these topics can be distinguished by their true interdisciplinary character. As outlined and discussed, nearly half of all studies were conducted in an interdisciplinary cooperation. Yet, most of these collaborations are comprised of scientists from energy and engineering disciplines. Only few collaborations exist that bridge the rationales of existing schools of thought. True interdisciplinary collaboration enables the combination of methods, leading to manifold user characteristics, including typical quantitative variables such as arrival and departure time, while at the same time retrieving data on values and user motivations. An integrated approach thus takes advantage of combining the societal perspective and the system perspective.

Finally, integrative topics create an interface for combining technology-centered and human-centered approaches in a unique manner. Thus, the advantages of both realms can be combined – including user characteristics, such as behavior, preferences, perceptions, and attitudes in a wider system perspective. This approach not only enables stakeholder-specific recommendations; it also provides guidance on technology-specific questions and their implementation into the energy and mobility system of the future, by considering user-specific information. Integrative approaches thus create a more holistic understanding of the diffusion of smart charging technologies by identifying interfaces between the disciplines to enable stronger interdisciplinary cooperation. Research might benefit from such an approach in a methodological way, while policy makers benefit from more reliable results, facilitating a societally feasible transition of the energy and mobility system.

Our approach is of course not without shortcomings. For example, drawing a clear line between categories and themes, especially the ones that were created inductively, are always based on subjective decisions and thus liable to subjective bias. Researchers from other research fields might have defined research topics differently. Yet, creating and defining research topics enabled us to identify typical patterns of how the user is integrated in human-centered, technology-centered, and integrative research topics. Furthermore, as we chose a descriptive approach, we are not able to display the relations between the user categories. However, this could be subject to future research. As such, our approach can be seen as a first step to guiding future research to include a more manifold picture of the user into smart charging research.

CRediT authorship contribution statement

Nora Baumgartner: Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing – Review & Editing, Visualization, Supervision, Project administration. **Kira Weyer**: Conceptualization, Writing – Review & Editing, Supervision, Project administration. **Lars Eckmann**: Software, Formal Analysis, Writing – Review & Editing. **Wolf Fichtner**: Writing – Review & Editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

References

Abdulaal, A., Cintuglu, M.H., Asfour, S., Mohammed, O.A., 2017. Solving the Multivariant EV Routing Problem Incorporating V2G and G2V Options. IEEE Trans. Transp. Electrific. 3, 238–248. https://doi.org/10.1109/TTE.2016.2614385.

Abnett, K., 2022. EU lawmakers back ban on new fossil-fuel cars from 2035. Reuters.

Adika, C.O., Wang, L., 2014. Smart charging and appliance scheduling approaches to demand side management. International Journal of Electrical Power & Energy Systems 57, 232–240. https://doi.org/10.1016/j.ijepes.2013.12.004.

Ahmad, A., Khan, J.Y., 2020. Real-Time Load Scheduling and Storage Management for Solar Powered Network Connected EVs. IEEE Trans. Sustain. Energy 11, 1220–1235. https://doi.org/10.1109/TSTE.2019.2921024.

Aliasghari, P., Mohammadi-Ivatloo, B., Alipour, M., Abapour, M., Zare, K., 2018. Optimal scheduling of plug-in electric vehicles and renewable micro-grid in energy and reserve markets considering demand response program. Journal of Cleaner Production 186, 293–303. https://doi.org/10.1016/j.jclepro.2018.03.058.

Alilou, M., Tousi, B., Shayeghi, H., 2020. Home energy management in a residential smart micro grid under stochastic penetration of solar panels and electric vehicles. Solar Energy 212, 6–18. https://doi.org/10.1016/j.solener.2020.10.063.

Alonso, M., Amaris, H., Germain, J., Galan, J., 2014. Optimal Charging Scheduling of Electric Vehicles in Smart Grids by Heuristic Algorithms. Energies 7, 2449–2475. https://doi.org/10.3390/en7042449.

Aluisio, B., Conserva, A., Dicorato, M., Forte, G., Trovato, M., 2017. Optimal operation planning of V2G-equipped Microgrid in the presence of EV aggregator. Electric Power Systems Research 152, 295–305. https://doi.org/10.1016/j.epsr.2017.07.015.

Amoroso, F.A., Cappuccino, G., 2012. Advantages of efficiency-aware smart charging strategies for PEVs. Energy Conversion and Management 54, 1–6. https://doi.org/10.1016/j.enconman.2011.09.006.

Andersen, F.M., Henningsen, G., Møller, N.F., Larsen, H.V., 2019. Long-term projections of the hourly electricity consumption in Danish municipalities. Energy 186, 115890. https://doi.org/10.1016/j.energy.2019.115890.

Aoun, A., Ibrahim, H., Ghandour, M., Ilinca, A., 2019. Supply Side Management vs. Demand Side Management of a Residential Microgrid Equipped with an Electric Vehicle in a Dual Tariff Scheme. Energies 12, 4351. https://doi.org/10.3390/en12224351.

Axsen, J., Cairns, J., Dusyk, N., Goldberg, S., 2018. What drives the Pioneers? Applying lifestyle theory to early electric vehicle buyers in Canada. Energy Research & Social Science 44, 17–30. https://doi.org/10.1016/j.erss.2018.04.015.

Axsen, J., Goldberg, S., Bailey, J., 2016. How might potential future plug-in electric vehicle buyers differ from current "Pioneer" owners? Transportation Research Part D: Transport and Environment 47, 357–370. https://doi.org/10.1016/j.trd.2016.05.015.

Azzouz, M.A., Shaaban, M.F., El-Saadany, E.F., 2015. Real-Time Optimal Voltage Regulation for Distribution Networks Incorporating High Penetration of PEVs. IEEE Trans. Power Syst. 30, 3234–3245. https://doi.org/10.1109/TPWRS.2014.2385834.

Bagher Sadati, S.M., Moshtagh, J., Shafie-khah, M., Rastgou, A., Catalão, J.P., 2019. Operational scheduling of a smart distribution system considering electric vehicles parking lot: A bi-level approach. International Journal of Electrical Power & Energy Systems 105, 159–178. https://doi.org/10.1016/j.ijepes.2018.08.021.

Bagherzade, S., Hooshmand, R.-A., Firouzmakan, P., Khodabakhshian, A., Gholipour, M., 2019. Stochastic parking energy pricing strategies to promote competition arena in an intelligent parking. Energy 188, 116084. https://doi.org/10.1016/j.energy.2019.116084.

Bailey, J., Axsen, J., 2015. Anticipating PEV buyers' acceptance of utility controlled charging. Transportation Research Part A: Policy and Practice 82, 29–46. https://doi.org/10.1016/j.tra.2015.09.004.

Barbecho Bautista, P., Lemus Cárdenas, L., Urquiza Aguiar, L., Aguilar Igartua, M., 2019. A traffic-aware electric vehicle charging management system for smart cities. Vehicular Communications 20, 100188. https://doi.org/10.1016/j.vehcom.2019.100188.

Barone, G., Brusco, G., Menniti, D., Pinnarelli, A., Polizzi, G., Sorrentino, N., Vizza, P., Burgio, A., 2020. How Smart Metering and Smart Charging may Help a Local Energy Community in Collective Self-Consumption in Presence of Electric Vehicles. Energies 13, 4163. https://doi.org/10.3390/en13164163.

Baumgartner, N., Weyer, K., Eckmann, L., Fichtner, W., 2023. How to integrate users into smart charging – A critical and systematic review. Energy Research & Social Science 100, 103113. https://doi.org/10.1016/j.erss.2023.103113.

Benalcázar, P., Samper, M.E., Vargas, A., 2019. Short-term economic dispatch of smart distribution grids considering the active role of plug-in electric vehicles. Electric Power Systems Research 177, 1–11. https://doi.org/10.1016/j.epsr.2019.105932.

Bhattarai, B., Myers, K., Bak-Jensen, B., Paudyal, S., 2017. Multi-Time Scale Control of Demand Flexibility in Smart Distribution Networks. Energies 10, 1–18. https://doi.org/10.3390/en10010037.

Bin Humayd, A.S., Bhattacharya, K., 2017. Distribution system planning to accommodate distributed energy resources and PEVs. Electric Power Systems Research 145, 1–11. https://doi.org/10.1016/j.epsr.2016.12.016.

Bishop, J.D., Axon, C.J., Bonilla, D., Banister, D., 2016. Estimating the grid payments necessary to compensate additional costs to prospective electric vehicle owners who provide vehicle-to-grid ancillary services. Energy 94, 715–727. https://doi.org/10.1016/j.energy.2015.11.029.

Blumberg, G., Broll, R., Weber, C., 2022. The impact of electric vehicles on the future European electricity system – A scenario analysis. Energy Policy 161, 112751. https://doi.org/10.1016/j.enpol.2021.112751.

Brandt, T., Wagner, S., Neumann, D., 2017. Evaluating a business model for vehicle-grid integration: Evidence from Germany. Transportation Research Part D: Transport and Environment 50, 488–504. https://doi.org/10.1016/j.trd.2016.11.017.

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qualitative Research in Psychology 3, 77–101. https://doi.org/10.1191/1478088706qp063oa.

Bryden, T.S., Hilton, G., Dimitrov, B., Ponce de Leon, C., Cruden, A., 2019. Rating a Stationary Energy Storage System Within a Fast Electric Vehicle Charging Station Considering User

Waiting Times. IEEE Trans. Transp. Electrific. 5, 879–889. https://doi.org/10.1109/TTE.2019.2910401.

Buonomano, A., 2020. Building to Vehicle to Building concept: A comprehensive parametric and sensitivity analysis for decision making aims. Applied Energy 261, 114077. https://doi.org/10.1016/j.apenergy.2019.114077.

Capasso, C., Veneri, O., 2015. Experimental study of a DC charging station for full electric and plug in hybrid vehicles. Applied Energy 152, 131–142. https://doi.org/10.1016/j.apenergy.2015.04.040.

Chadwick, K., Russell-Bennett, R., Biddle, N., 2022. The role of human influences on adoption and rejection of energy technology: A systematised critical review of the literature on household energy transitions. Energy Research & Social Science 89, 102528. https://doi.org/10.1016/j.erss.2022.102528.

Chen, C., Zarazua de Rubens, G., Noel, L., Kester, J., Sovacool, B.K., 2020a. Assessing the socio-demographic, technical, economic and behavioral factors of Nordic electric vehicle adoption and the influence of vehicle-to-grid preferences. Renewable and Sustainable Energy Reviews 121, 1–13. https://doi.org/10.1016/j.rser.2019.109692.

Chen, S., Guo, Z., Yang, Z., Xu, Y., Cheng, R.S., 2020b. A Game Theoretic Approach to Phase Balancing by Plug-In Electric Vehicles in the Smart Grid. IEEE Trans. Power Syst. 35, 2232–2244. https://doi.org/10.1109/TPWRS.2019.2946178.

Cheng, P.-H., Huang, T.-H., Chien, Y.-W., Wu, C.-L., Tai, C.-S., Fu, L.-C., 2020. Demand-side management in residential community realizing sharing economy with bidirectional PEV while additionally considering commercial area. International Journal of Electrical Power & Energy Systems 116, 105512. https://doi.org/10.1016/j.ijepes.2019.105512.

Coffman, M., Bernstein, P., Wee, S., 2017. Electric vehicles revisited: a review of factors that affect adoption. Transport Reviews 37, 79–93. https://doi.org/10.1080/01441647.2016.1217282.

Daina, N., Sivakumar, A., Polak, J.W., 2017. Electric vehicle charging choices: Modelling and implications for smart charging services. Transportation Research Part C: Emerging Technologies 81, 36–56. https://doi.org/10.1016/j.trc.2017.05.006.

Das, H.S., Rahman, M.M., Li, S., Tan, C.W., 2020. Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review. Renewable and Sustainable Energy Reviews 120, 109618. https://doi.org/10.1016/j.rser.2019.109618.

DeForest, N., Macdonald, J.S., Black, D., 2018. Day Ahead Optimization of an Electric Vehicle Fleet Providing Ancillary Services in the Los Angeles Air Force Base Vehicle-to-Grid Demonstration. Applied Energy, 987–1001. https://doi.org/10.1016/j.apenergy.2017.07.069.

DeGennaro, M., Paffumi, E., Martini, G., 2015. Customer-driven design of the recharge infrastructure and Vehicle-to-Grid in urban areas: A large-scale application for electric vehicles deployment. Energy 82, 294–311. https://doi.org/10.1016/j.energy.2015.01.039.

Deilami, S., 2018. Online Coordination of Plug-In Electric Vehicles Considering Grid Congestion and Smart Grid Power Quality. Energies 11, 2187. https://doi.org/10.3390/en11092187.

Delmonte, E., Kinnear, N., Jenkins, B., Skippon, S., 2020. What do consumers think of smart charging? Perceptions among actual and potential plug-in electric vehicle adopters in the United Kingdom. Energy Research & Social Science 60, 1–12. https://doi.org/10.1016/j.erss.2019.101318.

Dixon, J., Bukhsh, W., Edmunds, C., Bell, K., 2020. Scheduling electric vehicle charging to minimise carbon emissions and wind curtailment. Renewable Energy 161, 1072–1091. https://doi.org/10.1016/j.renene.2020.07.017.

Döbelt, S., Jung, M., Busch, M., Tscheligi, M., 2015. Consumers' privacy concerns and implications for a privacy preserving Smart Grid architecture—Results of an Austrian study. Energy Research & Social Science 9, 137–145. https://doi.org/10.1016/j.erss.2015.08.022.

Druitt, J., Früh, W.-G., 2012. Simulation of demand management and grid balancing with electric vehicles. Journal of Power Sources 216, 104–116. https://doi.org/10.1016/j.jpowsour.2012.05.033.

Earl, J., Fell, M.J., 2019. Electric vehicle manufacturers' perceptions of the market potential for demand-side flexibility using electric vehicles in the United Kingdom. Energy Policy 129, 646–652. https://doi.org/10.1016/j.enpol.2019.02.040.

Ebrahimi, M., Rastegar, M., Mohammadi, M., Palomino, A., Parvania, M., 2020. Stochastic Charging Optimization of V2G-Capable PEVs: A Comprehensive Model for Battery Aging and Customer Service Quality. IEEE Trans. Transp. Electrific. 6, 1026–1034. https://doi.org/10.1109/TTE.2020.3005875.

Eising, J.W., van Onna, T., Alkemade, F., 2014. Towards smart grids: Identifying the risks that arise from the integration of energy and transport supply chains. Applied Energy 123, 448–455. https://doi.org/10.1016/j.apenergy.2013.12.017.

Ensslen, A., Ringler, P., Dörr, L., Jochem, P., Zimmermann, F., Fichtner, W., 2018. Incentivizing smart charging: Modeling charging tariffs for electric vehicles in German and French electricity markets. Energy Research & Social Science 42, 112–126. https://doi.org/10.1016/j.erss.2018.02.013.

Erden, F., Kisacikoglu, M.C., Erdogan, N., 2018. Adaptive V2G Peak Shaving and Smart Charging Control for Grid Integration of PEVs. Electric Power Components and Systems 46, 1494–1508. https://doi.org/10.1080/15325008.2018.1489435.

Faddel, S., Youssef, T., Elsayed, A.T., Mohammed, O.A., 2018. An Automated Charger for Large-Scale Adoption of Electric Vehicles. IEEE Trans. Transp. Electrific. 4, 971–984. https://doi.org/10.1109/TTE.2018.2850526.

Fan, H., Jiang, L., Zhang, C.-K., Mao, C., 2016. Frequency regulation of multi-area power systems with plug-in electric vehicles considering communication delays. IET Generation, Transmission & Distribution 10, 3481–3491. https://doi.org/10.1049/iet-gtd.2016.0108.

Ferro, G., Laureri, F., Minciardi, R., Robba, M., 2018. An optimization model for electrical vehicles scheduling in a smart grid. Sustainable Energy, Grids and Networks 14, 62–70. https://doi.org/10.1016/j.segan.2018.04.002.

Ferro, G., Minciardi, R., Parodi, L., Robba, M., Rossi, M., 2020. Optimal Control of Multiple Microgrids and Buildings by an Aggregator. Energies 13, 1058. https://doi.org/10.3390/en13051058.

Fetene, G.M., Kaplan, S., Sebald, A.C., Prato, C.G., 2017. Myopic loss aversion in the response of electric vehicle owners to the scheduling and pricing of vehicle charging. Transportation Research Part D: Transport and Environment 50, 345–356. https://doi.org/10.1016/j.trd.2016.11.020.

Flammini, M.G., Prettico, G., Julea, A., Fulli, G., Mazza, A., Chicco, G., 2019. Statistical characterisation of the real transaction data gathered from electric vehicle charging stations. Electric Power Systems Research 166, 136–150. https://doi.org/10.1016/j.epsr.2018.09.022.

García-Villalobos, J., Zamora, I., San Martín, J.I., Asensio, F.J., Aperribay, V., 2014. Plug-in electric vehicles in electric distribution networks: A review of smart charging approaches. Renewable and Sustainable Energy Reviews 38, 717–731. https://doi.org/10.1016/j.rser.2014.07.040.

Geske, J., Schumann, D., 2018. Willing to participate in vehicle-to-grid (V2G)? Why not! Energy Policy 120, 392–401. https://doi.org/10.1016/j.enpol.2018.05.004.

Gonzalez Venegas, F., Petit, M., Perez, Y., 2021. Active integration of electric vehicles into distribution grids: Barriers and frameworks for flexibility services. Renewable and Sustainable Energy Reviews 145, 1–16. https://doi.org/10.1016/j.rser.2021.111060.

Grant, M.J., Booth, A., 2009. A typology of reviews: an analysis of 14 review types and associated methodologies. Health information and libraries journal 26, 91–108. https://doi.org/10.1111/j.1471-1842.2009.00848.x.

Hardman, S., Jenn, A., Tal, G., Axsen, J., Beard, G., Daina, N., Figenbaum, E., Jakobsson, N., Jochem, P., Kinnear, N., Plötz, P., Pontes, J., Refa, N., Sprei, F., Turrentine, T., Witkamp, B., 2018. A review of consumer preferences of and interactions with electric vehicle charging infrastructure. Transportation Research Part D: Transport and Environment 62, 508–523. https://doi.org/10.1016/j.trd.2018.04.002.

Hariri, A.-M., Hejazi, M.A., Hashemi-Dezaki, H., 2019. Reliability optimization of smart grid based on optimal allocation of protective devices, distributed energy resources, and electric vehicle/plug-in hybrid electric vehicle charging stations. Journal of Power Sources 436, 226824. https://doi.org/10.1016/j.jpowsour.2019.226824.

Hidrue, M.K., Parsons, G.R., 2015. Is there a near-term market for vehicle-to-grid electric vehicles? Applied Energy 151, 67–76. https://doi.org/10.1016/j.apenergy.2015.04.051.

Hong, J., Koo, Y., Jeong, G., Lee, J., 2012. Ex-ante evaluation of profitability and government's subsidy policy on vehicle-to-grid system. Energy Policy 42, 95–104. https://doi.org/10.1016/j.enpol.2011.11.053.

Hoog, J. de, Alpcan, T., Brazil, M., Thomas, D.A., Mareels, I., 2015. Optimal Charging of Electric Vehicles Taking Distribution Network Constraints Into Account. IEEE Trans. Power Syst. 30, 365–375. https://doi.org/10.1109/TPWRS.2014.2318293.

Huang, Y., 2019. Day-Ahead Optimal Control of PEV Battery Storage Devices Taking Into Account the Voltage Regulation of the Residential Power Grid. IEEE Trans. Power Syst. 34, 4154–4167. https://doi.org/10.1109/TPWRS.2019.2917009.

Huber, J., Schaule, E., Jung, D., Weinhardt, C., 2019. Quo Vadis Smart Charging? A Literature Review and Expert Survey on Technical Potentials and User Acceptance of Smart Charging Systems. WEVJ 10, 85. https://doi.org/10.3390/wevj10040085.

Huckebrink, D., Bertsch, V., 2021. Integrating Behavioural Aspects in Energy System Modelling—A Review. Energies 14, 4579. https://doi.org/10.3390/en14154579.

International Energy Agency, 2020. Electric Vehicles. https://www.iea.org/reports/electric-vehicles (accessed 31 August 2021).

International Energy Agency, 2021. Electric Vehicles. https://www.iea.org/reports/electric-vehicles (accessed 31 August 2022).

International Energy Agency, 2022. Global EV Outlook 2022: Securing supplied for an electric future, 221 pp.

Ioakimidis, C.S., Thomas, D., Rycerski, P., Genikomsakis, K.N., 2018. Peak shaving and valley filling of power consumption profile in non-residential buildings using an electric vehicle parking lot. Energy 148, 148–158. https://doi.org/10.1016/j.energy.2018.01.128.

Jain, P., Das, A., Jain, T., 2019. Aggregated electric vehicle resource modelling for regulation services commitment in power grid. Sustainable Cities and Society 45, 439–450. https://doi.org/10.1016/j.scs.2018.11.046.

Jargstorf, J., Wickert, M., 2013. Offer of secondary reserve with a pool of electric vehicles on the German market. Energy Policy 62, 185–195. https://doi.org/10.1016/j.enpol.2013.06.088.

Jeon, W., Cho, S., Lee, S., 2020. Estimating the Impact of Electric Vehicle Demand Response Programs in a Grid with Varying Levels of Renewable Energy Sources: Time-of-Use Tariff versus Smart Charging. Energies 13, 1–22. https://doi.org/10.3390/en13174365.

Jia, Q.-S., Long, T., 2020. A review on charging behavior of electric vehicles: data, model, and control. Control Theory Technol. 18, 217–230. https://doi.org/10.1007/s11768-020-0048-8.

Jian, L., Zechun, H., Banister, D., Yongqiang, Z., Zhongying, W., 2018. The future of energy storage shaped by electric vehicles: A perspective from China. Energy 154, 249–257. https://doi.org/10.1016/j.energy.2018.04.124.

Jiang, C., Jing, Z., Ji, T., Wu, Q., 2018. Optimal location of PEVCSs using MAS and ER approach. IET Generation, Transmission & Distribution 12, 4377–4387. https://doi.org/10.1049/iet-gtd.2017.1907.

Jin, R., Zuo, D., Zhang, X., Sun, W., 2019. An Orderly Power Utilization Scheme Based on an Intelligent Multi-Agent Apanage Management System. Energies 12, 4563. https://doi.org/10.3390/en12234563.

Kahlen, M.T., Ketter, W., van Dalen, J., 2018. Electric Vehicle Virtual Power Plant Dilemma: Grid Balancing Versus Customer Mobility. Prod Oper Manag 27, 2054–2070. https://doi.org/10.1111/poms.12876.

Kamiya, G., Axsen, J., Crawford, C., 2019. Modeling the GHG emissions intensity of plug-in electric vehicles using short-term and long-term perspectives. Transportation Research Part D: Transport and Environment 69, 209–223. https://doi.org/10.1016/j.trd.2019.01.027.

Kara, E.C., Macdonald, J.S., Black, D., Bérges, M., Hug, G., Kiliccote, S., 2015. Estimating the benefits of electric vehicle smart charging at non-residential locations: A data-driven approach. Applied Energy 155, 515–525. https://doi.org/10.1016/j.apenergy.2015.05.072.

Kavousi-Fard, A., Khodaei, A., 2016. Efficient integration of plug-in electric vehicles via reconfigurable microgrids. Energy 111, 653–663. https://doi.org/10.1016/j.energy.2016.06.018.

Kempton, W., Letendre, S.E., 1997. Electric Vehicles as a new Power Source for Eletcrtic Utilities. Transportation Research Part D: Transport and Environment, 3, 157–175.

Kempton, W., Tomić, J., 2005. Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy. Journal of Power Sources 144, 280–294. https://doi.org/10.1016/j.jpowsour.2004.12.022.

Kester, J., Noel, L., Zarazua de Rubens, G., Sovacool, B.K., 2018. Promoting Vehicle to Grid (V2G) in the Nordic region: Expert advice on policy mechanisms for accelerated diffusion. Energy Policy 116, 422–432. https://doi.org/10.1016/j.enpol.2018.02.024.

Kester, J., Zarazua de Rubens, G., Sovacool, B.K., Noel, L., 2019. Public perceptions of electric vehicles and vehicle-to-grid (V2G): Insights from a Nordic focus group study. Transportation

Research Part D: Transport and Environment 74, 277–293. https://doi.org/10.1016/j.trd.2019.08.006.

Khan, S.A., Bohnsack, R., 2020. Influencing the disruptive potential of sustainable technologies through value proposition design: The case of vehicle-to-grid technology. Journal of Cleaner Production 254. https://doi.org/10.1016/j.jclepro.2020.120018.

Kordkheili, A.R., Pourmousavi, S., Savaghebi, M., Guerrero, J., Nehrir, M., 2016. Assessing the Potential of Plug-in Electric Vehicles in Active Distribution Networks. Energies 9, 34. https://doi.org/10.3390/en9010034.

Kubli, M., Loock, M., Wüstenhagen, R., 2018. The flexible prosumer: Measuring the willingness to co-create distributed flexibility. Energy Policy 114, 540–548. https://doi.org/10.1016/j.enpol.2017.12.044.

Lee, C.-Y., Jang, J.-W., Lee, M.-K., 2020a. Willingness to accept values for vehicle-to-grid service in South Korea. Transportation Research Part D: Transport and Environment 87, 1–10. https://doi.org/10.1016/j.trd.2020.102487.

Lee, H.-J., Oh, B.-C., Kim, S.-W., Kim, S.-Y., 2020b. V2G Strategy for Improvement of Distribution Network Reliability Considering Time Space Network of EVs. Energies 13, 4415. https://doi.org/10.3390/en13174415.

Li, X., Tan, Y., Liu, X., Liao, Q., Sun, B., Cao, G., Li, C., Yang, X., Wang, Z., 2020. A cost-benefit analysis of V2G electric vehicles supporting peak shaving in Shanghai. Electric Power Systems Research 179, 106058. https://doi.org/10.1016/j.epsr.2019.106058.

Littell, J.H., Corcoran, J., Pillai, V.K., 2008. Systematic reviews and meta-analysis. Oxford University Press, Oxford, New York, vi, 202.

Liu, Z., Wang, D., Jia, H., Djilali, N., 2014. Power system operation risk analysis considering charging load self-management of plug-in hybrid electric vehicles. Applied Energy 136, 662–670. https://doi.org/10.1016/j.apenergy.2014.09.069.

Lotfy, M., Senjyu, T., Farahat, M., Abdel-Gawad, A., Matayoshi, H., 2017. A Polar Fuzzy Control Scheme for Hybrid Power System Using Vehicle-To-Grid Technique. Energies 10, 1083. https://doi.org/10.3390/en10081083.

Luh, S., Kannan, R., Schmidt, T.J., Kober, T., 2022. Behavior matters: A systematic review of representing consumer mobility choices in energy models. Energy Research & Social Science 90, 1–23. https://doi.org/10.1016/j.erss.2022.102596.

Lyon, T.P., Michelin, M., Jongejan, A., Leahy, T., 2012. Is “smart charging” policy for electric vehicles worthwhile? Energy Policy 41, 259–268. https://doi.org/10.1016/j.enpol.2011.10.045.

Maeng, K., Ko, S., Shin, J., Cho, Y., 2020. How Much Electricity Sharing Will Electric Vehicle Owners Allow from Their Battery? Incorporating Vehicle-to-Grid Technology and Electricity Generation Mix. Energies 13, 4248. https://doi.org/10.3390/en13164248.

Maigha, M., Crow, M.L., 2018. Electric Vehicle Scheduling Considering Co-optimized Customer and System Objectives. IEEE Trans. Sustain. Energy 9, 410–419. https://doi.org/10.1109/TSTE.2017.2737146.

Mayring, P., 2015. Qualitative Inhaltsanalyse: Grundlagen und Techniken, 12th ed. Beltz, Weinheim, 5 pp.

Mazza, A., Mirtaheri, H., Chicco, G., Russo, A., Fantino, M., 2020. Location and Sizing of Battery Energy Storage Units in Low Voltage Distribution Networks. Energies 13, 52. https://doi.org/10.3390/en13010052.

Moghaddam, Z., Ahmad, I., Habibi, D., Phung, Q.V., 2018. Smart Charging Strategy for Electric Vehicle Charging Stations. IEEE Trans. Transp. Electrific. 4, 76–88. https://doi.org/10.1109/TTE.2017.2753403.

Naghdizadegan Jahromi, S., Askarzadeh, A., Abdollahi, A., 2017. Modelling probabilistic transmission expansion planning in the presence of plug-in electric vehicles uncertainty by multi-state Markov model. IET Generation, Transmission & Distribution 11, 1716–1725. https://doi.org/10.1049/iet-gtd.2016.1330.

Noel, L., Papu Carrone, A., Jensen, A.F., Zarazua de Rubens, G., Kester, J., Sovacool, B.K., 2019a. Willingness to pay for electric vehicles and vehicle-to-grid applications: A Nordic choice experiment. Energy Economics 78, 525–534. https://doi.org/10.1016/j.eneco.2018.12.014.

Noel, L., Rubens, G.Z. de, Kester, Johannes, Sovacool, Benjamin K., 2019b. Vehicle-to-Grid: A Sociotechnical Transistion Beyond Electric Mobility. Palgrave Macmillan, Cham, Switzerland, 271 pp.

Noel, L., Zarazua de Rubens, G., Kester, J., Sovacool, B.K., 2018a. Beyond emissions and economics: Rethinking the co-benefits of electric vehicles (EVs) and vehicle-to-grid (V2G). Transport Policy 71, 130–137. https://doi.org/10.1016/j.tranpol.2018.08.004.

Noel, L., Zarazua de Rubens, G., Kester, J., Sovacool, B.K., 2021. Leveraging user-based innovation in vehicle-to-X and vehicle-to-grid adoption: A Nordic case study. Journal of Cleaner Production 287, 125591. https://doi.org/10.1016/j.jclepro.2020.125591.

Noel, L., Zarazua de Rubens, G., Sovacool, B.K., 2018b. Optimizing innovation, carbon and health in transport: Assessing socially optimal electric mobility and vehicle-to-grid pathways in Denmark. Energy 153, 628–637. https://doi.org/10.1016/j.energy.2018.04.076.

Nojavan, S., Zare, K., 2018. Optimal energy pricing for consumers by electricity retailer. International Journal of Electrical Power & Energy Systems 102, 401–412. https://doi.org/10.1016/j.ijepes.2018.05.013.

Noorollahi, Y., Golshanfard, A., Aligholian, A., Mohammadi-Ivatloo, B., Nielsen, S., Hajinezhad, A., 2020. Sustainable Energy System Planning for an Industrial Zone by Integrating Electric Vehicles as Energy Storage. Journal of Energy Storage 30, 1–12. https://doi.org/10.1016/j.est.2020.101553.

O'Connell, A., Flynn, D., Keane, A., 2014. Rolling Multi-Period Optimization to Control Electric Vehicle Charging in Distribution Networks. IEEE Trans. Power Syst. 29, 340–348. https://doi.org/10.1109/TPWRS.2013.2279276.

Parsons, G.R., Hidrue, M.K., Kempton, W., Gardner, M.P., 2014. Willingness to pay for vehicle-to-grid (V2G) electric vehicles and their contract terms. Energy Economics 42, 313–324. https://doi.org/10.1016/j.eneco.2013.12.018.

Pearre, N.S., Ribberink, H., 2019. Review of research on V2X technologies, strategies, and operations. Renewable and Sustainable Energy Reviews 105, 61–70. https://doi.org/10.1016/j.rser.2019.01.047.

Petticrew, M., Roberts, H., 2006. Systematic reviews in the social sciences: A practical guide / Mark Petticrew and Helen Roberts. Blackwell, Oxford, 354 pp.

Pettifor, H., Wilson, C., Axsen, J., Abrahamse, W., Anable, J., 2017. Social influence in the global diffusion of alternative fuel vehicles – A meta-analysis. Journal of Transport Geography 62, 247–261. https://doi.org/10.1016/j.jtrangeo.2017.06.009.

Ramakrishna Reddy, K., Meikandasivam, S., 2020. Load Flattening and Voltage Regulation Using Plug-In Electric Vehicle's Storage Capacity With Vehicle Prioritization Using ANFIS. IEEE Trans. Sustain. Energy 11, 260–270. https://doi.org/10.1109/TSTE.2018.2890145.

Ramakrishna Reddy, K., Meikandasivam, S., Vijayakumar, D., 2019. A novel strategy for maximization of plug-In electric vehicle's storage utilization for grid support with consideration of customer flexibility. Electric Power Systems Research 170, 158–175. https://doi.org/10.1016/j.epsr.2018.12.031.

Rogers, E.M., 1983. Diffusion of innovations, 3rd ed. Free Press; Collier Macmillan, New York, London, 236 pp.

Rostami, M.A., Raoofat, M., 2016. Optimal operating strategy of virtual power plant considering plug-in hybrid electric vehicles load. Int. Trans. Electr. Energ. Syst. 26, 236–252. https://doi.org/10.1002/etep.2074.

Sachan, S., Adnan, N., 2018. Stochastic charging of electric vehicles in smart power distribution grids. Sustainable Cities and Society 40, 91–100. https://doi.org/10.1016/j.scs.2018.03.031.

Sadeghian, O., Nazari-Heris, M., Abapour, M., Taheri, S.S., Zare, K., 2019. Improving reliability of distribution networks using plug-in electric vehicles and demand response. J. Mod. Power Syst. Clean Energy 7, 1189–1199. https://doi.org/10.1007/s40565-019-0523-8.

Schill, W.-P., 2011. Electric vehicles in imperfect electricity markets: The case of Germany. Energy Policy 39, 6178–6189. https://doi.org/10.1016/j.enpol.2011.07.018.

Schmalfuß, F., Mair, C., Döbelt, S., Kämpfe, B., Wüstemann, R., Krems, J.F., Keinath, A., 2015. User responses to a smart charging system in Germany: Battery electric vehicle driver motivation, attitudes and acceptance. Energy Research & Social Science 9, 60–71. https://doi.org/10.1016/j.erss.2015.08.019.

Schuller, A., Flath, C.M., Gottwalt, S., 2015. Quantifying load flexibility of electric vehicles for renewable energy integration. Applied Energy 151, 335–344. https://doi.org/10.1016/j.apenergy.2015.04.004.

Sharma, S., Jain, P., Bhakar, R., Gupta, P.P., 2018 - 2018. Integrated TOU Price-Based Demand Response and Dynamic G2V Charge Scheduling of Electric Vehicle Aggregator, in: 2018 8th IEEE India International Conference on Power Electronics (IICPE). 2018 8th IEEE India International Conference on Power Electronics (IICPE), JAIPUR, India. 13.12.2018 - 15.12.2018. IEEE, pp. 1–6.

Sovacool, B.K., 2014. What are we doing here? Analyzing fifteen years of energy scholarship and proposing a social science research agenda. Energy Research & Social Science 1, 1–29. https://doi.org/10.1016/j.erss.2014.02.003.

Sovacool, B.K., Axsen, J., Kempton, W., 2017. The Future Promise of Vehicle-to-Grid (V2G) Integration: A Sociotechnical Review and Research Agenda. Annu. Rev. Environ. Resour. 42, 377–406. https://doi.org/10.1146/annurev-environ-030117-020220.

Sovacool, B.K., Hirsh, R.F., 2009. Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition. Energy Policy 37, 1095–1103. https://doi.org/10.1016/j.enpol.2008.10.005.

Sovacool, B.K., Kester, J., Noel, L., Rubens, G.Z. de, 2019a. Income, political affiliation, urbanism and geography in stated preferences for electric vehicles (EVs) and vehicle-to-grid

(V2G) technologies in Northern Europe. Journal of Transport Geography 78, 214–229. https://doi.org/10.1016/j.jtrangeo.2019.06.006.

Sovacool, B.K., Kester, J., Noel, L., Rubens, G.Z. de, 2018. The demographics of decarbonizing transport: The influence of gender, education, occupation, age, and household size on electric mobility preferences in the Nordic region. Global Environmental Change 52, 86–100. https://doi.org/10.1016/j.gloenvcha.2018.06.008.

Sovacool, B.K., Kester, J., Noel, L., Zarazua de Rubens, G., 2019. Are electric vehicles masculinized? Gender, identity, and environmental values in Nordic transport practices and vehicle-to-grid (V2G) preferences. Transportation Research Part D: Transport and Environment 72, 187–202. https://doi.org/10.1016/j.trd.2019.04.013.

Sovacool, B.K., Kester, J., Noel, L., Zarazua de Rubens, G., 2020. Actors, business models, and innovation activity systems for vehicle-to-grid (V2G) technology: A comprehensive review. Renewable and Sustainable Energy Reviews 131, 109963. https://doi.org/10.1016/j.rser.2020.109963.

Sovacool, B.K., Ryan, S.E., Stern, P.C., Janda, K., Rochlin, G., Spreng, D., Pasqualetti, M.J., Wilhite, H., Lutzenhiser, L., 2015. Integrating social science in energy research. Energy Research & Social Science 6, 95–99. https://doi.org/10.1016/j.erss.2014.12.005.

Spencer, S.I., Fu, Z., Apostolaki-Iosifidou, E., Lipman, T.E., 2021. Evaluating smart charging strategies using real-world data from optimized plugin electric vehicles. Transportation Research Part D: Transport and Environment 100, 103023, 1–17. https://doi.org/10.1016/j.trd.2021.103023.

Su, J., Lie, T.T., Zamora, R., 2019. Modelling of large-scale electric vehicles charging demand: A New Zealand case study. Electric Power Systems Research 167, 171–182. https://doi.org/10.1016/j.epsr.2018.10.030.

Sufyan, M., Rahim, N.A., Muhammad, M.A., Tan, C.K., Raihan, S.R.S., Bakar, A.H.B.A., 2020. Charge coordination and battery lifecycle analysis of electric vehicles with V2G implementation. Electric Power Systems Research 184, 106307. https://doi.org/10.1016/j.epsr.2020.106307.

Sun, Y., Yue, H., Zhang, J., Booth, C., 2019. Minimization of Residential Energy Cost Considering Energy Storage System and EV With Driving Usage Probabilities. IEEE Trans. Sustain. Energy 10, 1752–1763. https://doi.org/10.1109/TSTE.2018.2870561.

Tarroja, B., Zhang, L., van Wifvat, Shaffer, B., Samuelsen, S., 2016. Assessing the stationary energy storage equivalency of vehicle-to-grid charging battery electric vehicles. Energy 106, 673–690. https://doi.org/10.1016/j.energy.2016.03.094.

Tomić, J., Kempton, W., 2007. Using fleets of electric-drive vehicles for grid support. Journal of Power Sources 168, 459–468. https://doi.org/10.1016/j.jpowsour.2007.03.010.

Toquica, D., Oliveira-De Jesus, P.M. de, Cadena, A.I., 2020. Power market equilibrium considering an EV storage aggregator exposed to marginal prices - A bilevel optimization approach. Journal of Energy Storage 28, 101267. https://doi.org/10.1016/j.est.2020.101267.

Tranfield, D., Denyer, D., Smart, P., 2003. Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. Br J Management 14, 207–222. https://doi.org/10.1111/1467-8551.00375.

Ul-Haq, A., Cecati, C., Al-Ammar, E., 2017. Modeling of a Photovoltaic-Powered Electric Vehicle Charging Station with Vehicle-to-Grid Implementation. Energies 10, 4. https://doi.org/10.3390/en10010004.

van der Kam, M., van Sark, W., Alkemade, F., 2020. Multiple roads ahead: How charging behavior can guide charging infrastructure roll-out policy. Transportation Research Part D: Transport and Environment 85, 1–19. https://doi.org/10.1016/j.trd.2020.102452.

van der Kam, M.J., Meelen, T., van Sark, W.G., Alkemade, F., 2018. Diffusion of solar photovoltaic systems and electric vehicles among Dutch consumers: Implications for the energy transition. Energy Research & Social Science 46, 68–85. https://doi.org/10.1016/j.erss.2018.06.003.

van der Kam, M.J., Peters, A., van Sark, W.G., Alkemade, F., 2019. Agent-Based Modelling of Charging Behaviour of Electric Vehicle Drivers. JASSS 22. https://doi.org/10.18564/jasss.4133.

Wang, M., Mu, Y., Jia, H., Wu, J., Yu, X., Qi, Y., 2017. Active power regulation for large-scale wind farms through an efficient power plant model of electric vehicles. Applied Energy 185, 1673–1683. https://doi.org/10.1016/j.apenergy.2016.02.008.

Webster, J., Watson, R.T., 2002. Analyzing the Past to Prepare for the Future: Writing a Literature Review. MIS Quaterly, 2, xiii–xxiii.

Will, C., Schuller, A., 2016. Understanding user acceptance factors of electric vehicle smart charging. Transportation Research Part C: Emerging Technologies 71, 198–214. https://doi.org/10.1016/j.trc.2016.07.006.

Wolsink, M., 2018. Social acceptance revisited: gaps, questionable trends, and an auspicious perspective. Energy Research & Social Science 46, 287–295. https://doi.org/10.1016/j.erss.2018.07.034.

Xu, F., Chen, X., Zhang, M., Zhou, Y., Cai, Y., Zhou, Y., Tang, R., Wang, Y., 2020. A sharing economy market system for private EV parking with consideration of demand side management. Energy 190, 116321. https://doi.org/10.1016/j.energy.2019.116321.

Yilmaz, M., Krein, P.T., 2013a. Review of Battery Charger Topologies, Charging Power Levels, and Infrastructure for Plug-In Electric and Hybrid Vehicles. IEEE Trans. Power Electron. 28, 2151–2169. https://doi.org/10.1109/TPEL.2012.2212917.

Yilmaz, M., Krein, P.T., 2013b. Review of the Impact of Vehicle-to-Grid Technologies on Distribution Systems and Utility Interfaces. IEEE Trans. Power Electron. 28, 5673–5689. https://doi.org/10.1109/TPEL.2012.2227500.

Zalzar, S., Shafiyi, M.-A., Yousefi-Talouki, A., Ghazizadeh, M.-S., 2017. A smart charging algorithm for integration of EVs in providing primary reserve as manageable demand-side resources. Int. Trans. Electr. Energ. Syst. 27, e2283. https://doi.org/10.1002/etep.2283.

Zarazua de Rubens, G., 2019. Who will buy electric vehicles after early adopters? Using machine learning to identify the electric vehicle mainstream market. Energy 172, 243–254. https://doi.org/10.1016/j.energy.2019.01.114

Paper B

User's Willingness to Participate in V2G – A comparison between German and UK Households

Nora Baumgartner [a], Niklas Klumpp [a], Tim Signer [a], Zia Wadud [b], Wolf Fichtner [a]

[a] *Chair of Energy Economics, Institute for Industrial Production (IIP), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany*

[b] *Institute for Transport Studies (ITS), University of Leeds, Leeds, United Kongdom*

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Abstract

Vehicle-to-grid (V2G) enables a smoother integration of large numbers of electric vehicles (EVs) into the electricity system by maximizing the flexibility potential. As such, EVs might emerge as new payers in the electricity market opening up new business models. Whether EVs will be available for these business models hinges on the user's willingness to participate and the monetary gains they anticipate. To shed light on users' motivations and requirements, we conducted a survey among German and UK households with N=1100. Results indicate that people are willing to participate in V2G, but compensation requirements are high in both countries (mean values for Germany= 67.54 €/month, UK= 60.96 €/month). Additionally, regression analysis reveals that psychographic characteristics positively predict the willingness to participate, while contextual factors play a subordinate role. Our results are important as they shed light on the conditions that must be met to support V2G uptake from the user's perspective.

Keywords: vehicle-to-grid (V2G), willingness to participate, V2G compensation, hierarchical multi regression analysis

B.1 Introduction

The expansion of renewable energy sources (RES) makes it necessary to increase storage capacities in the energy system, especially as sectors such as transportation are electrified and demand is further increased. This is true for Germany, where the coalition agreement of the 2021-elected Government earmarks 15 Mio. EVs by 2030 (SPD, Bündnis 90/Die Grünen and FDP, 2021). Recently, the United Kingdom (UK) Government determined ambitious EV targets as well. The Zero Emission Vehicle Mandate determines that 80% of new cars and 70% of new vans sold in the UK must be zero emission by 2030, increasing to 100% by 2035 (Department for Transport, 2023).

Using the EV's battery as short-term storage is seen as a promising technology to enable a smoother integration of increasing numbers of EVs into the electricity system. The concept of vehicle-to-grid (V2G) maximizes the flexibility potential of the EV fleet by incorporating the batteries via a two-way power flow into the system (Kempton and Tomić, 2005; Sovacool et al., 2017). Based on an average EV battery size of 50 kWh, and with aiming for a fleet of 15 million EVs by 2030 (SPD, Bündnis 90/Die Grünen and FDP, 2021), the total storage capacity would reach up to 750 GWh in Germany. To put this into context, Germany's current capacity for pumped-storage hydroelectricity, a key form of energy storage, is 40 GWh. This comparison highlights the significant potential of EV batteries as a storage solution in the energy system, far surpassing the capacity of existing pumped-storage facilities (Wissenschaftliche Dienste des Deutschen Bundestages, 2017). Many advantages are expected from V2G technology, such as integration of higher shares of RES, and a more efficient grid operation (Blumberg et al., 2022; Schuller et al., 2015). Hereby, electricity markets are critical to the success of V2G, as they generate necessary price signals for managing EV fleets and aligning EVs' electricity discharge with market demands. Yet, the participation of EVs depends on their availability for bidirectional charging and the owner's willingness to participate in V2G. A primary motivation for users to participate is monetary gain (Geske and Schumann, 2018; Huang et al., 2021; Parsons et al., 2014). The financial appeal of V2G lies in the cash flow generated from participating in electricity market segments such as ancillary and spot markets. Understanding user participation hinges on the monetary benefits they anticipate, which can be assessed by analyzing their minimum accepted compensation.

In the current study, we focus on two aspects that are crucial to the success of V2G: First, we shed light on monetary compensation requirements from a user perspective for providing flexibility to the electricity market. Second, we build a hierarchical multi-regression model to look at factors determining users' willingness to participate in V2G, among others, contextual factors (EV ownership, commuting, type of residence, etc.), barriers, and psychological factors.

The paper is structured as follows. In Section II we outline the theoretical background for our regression model. Afterward, we describe the survey design and provide some sample characteristics before delving into the results. Our results are presented in two parts. The first part looks at users' monetary compensation requirements, while the second one focuses on users' willingness to participate in V2G and its predictors. We close this paper with a discussion and conclusion.

B.2 Theoretical background

In this section, we outline the theoretical foundation for our model. Conceptually, consumer behavior, or, in our case, the willingness to participate in V2G charging, can be explained by contextual, and personal or psychological factors (Black et al., 1985; Devine-Wright, 2008; Huckebrink and Bertsch, 2021). Contextual factors include demographic or structural aspects, as well as the spatial context, while psychological factors relate to attitudes, beliefs, awareness, or norms (Black et al., 1985; Devine-Wright, 2008). Both aspects are important for a successful implementation of V2G. Psychological factors determine underlying motives for acting in a certain way, while the other enables the person to do so (Steg et al., 2015).

B.2.1 Contextual factors and barriers

Contextual factors can be defined as the "availability of products that hinder or promote a specific behavior or acceptance" (Kramer and Petzoldt, 2022, p. 2). The context defines the costs and benefits and makes some behaviors even impossible (Steg et al., 2015). With regard to V2G, research suggests that the charging infrastructure, residence type, tenure, and geographic aspects may enable or hinder V2G adoption (Axsen et al., 2016; Chadwick et al., 2022). Thus, contextual factors can be a reason for both, adoption and rejection decisions (Chadwick et al., 2022). For example, house owners can decide by their own whether to install a wallbox or not, while tenants are less independent in their decision-making. Furthermore, the travel pattern, the charging times, and parking duration are important factors that determine whether V2G is possible or not. These factors are also of special interest in a cross-country comparison, because these contextual factors can be incentivized and thus shaped by political strategies.

Another contextual factor, that is directly related to the V2G technology itself, is the EV's battery. Previous research has shown that battery degradation is a major issue for users to participate in V2G (Geske and Schumann, 2018; Huang et al., 2021; Sovacool and Axsen, 2018). This is not without a reason. Mainstream V2G literature showed, that the EV's battery is subject to additional stress due to increased numbers of charging cycles (Marongiu et al., 2015; Parsons et al., 2014; Wang et al., 2016). The amount of added degradation depends on the charging and discharging cycles used for providing V2G services. Providing an everyday frequency regulation service over the time period of 10 years, can lead to a 20% higher capacity loss depending on charging behavior and charging power (Wang et al., 2016). Although, this is an extreme scenario, as it assumes that grid services were practiced every day for 10 years, it highlights the potential stress added to a battery. On average, 0.0010% and 0.0023% capacity loss occur in each frequency regulation event depending on the dis-/charging power (1,4kw/120kw in this example). Taking the battery replacement cost into account, battery degradation cost from the 2-h frequency regulation could vary between $0,2 and $0,46 (Wang et al., 2016). Other factors influencing battery lifetime are battery type, weather, and driving behavior (Marongiu et al., 2015). Therefore, Sovacool et al. (2017) and Huber et al. (2019) consider battery degradation to be an important part of the financial dimension of V2G. Hence, revenues to EV owners should include compensation to cover additional battery degradation costs (Bishop et al., 2016).

B.2.2 Environmental self-identity and innovativeness

Complementary to contextual factors that create an outer environment that enable or hinder a person to adopt a technology, psychological factors determine interest in and underlying motivations for innovative technologies, i.e., V2G.

One factor that has been shown to predict environmental behavior is environmental self-identity (van der Werff et al., 2013). Environmental elf-identity can be defined as the "extent to which one sees oneself as a type of person whose actions are environmentally-friendly." (van der Werff et al., 2013, p. 1258). These persons act environmentally-friendly due to intrinsic motivations and the feeling of moral obligations. This concept has also been translated to smart energy behavior. Research showed that environmental self-identity was strengthened when the behavior was costly, e.g., required an investment (van der Werff et al., 2016).

Additionally, new products and services are more likely to be adopted by people who are by disposition more innovative or novelty-seeking (Wolske et al., 2017). Innovativeness, as part of the diffusion of innovation theory (Rogers, 1983), is a common psychographic characteristic to explain adoption intention. For example, Arts et al. (2011) showed that innovativeness was among the most important drivers to explain adoption intention.

B.2.3 Research questions and hypothesis

In our paper we look at two different indicators for V2G acceptance and their predictors, which are users' monetary compensation requirements and the willingness to participate in a V2G charging service. In the following we aim to answer the following two research questions:

i. What is the expected compensation in Germany and the UK for providing flexibility to the electricity market, including battery degradation?
ii. To what extent do contextual and psychological factors predict the intention to participate in V2G in Germany and the UK?

Regarding research question i, we expect high compensation requirements, as mobility might be restricted, and investments for V2G are anticipated to be costly, as are the expected additional costs for increased battery degradation.

Merging the elements from Section II, we hypothesize that the effects of contextual factors differ between countries, whereas we expect no differences between countries regarding barriers and psychological factors. Yet, we expect battery degradation to negatively predict acceptance, while innovativeness and environmental self-identity have a positive influence.

B.3 Methods

To address the research question, we conducted an online survey in December 2023 to analyze V2G acceptance in relation to mobility behavior. In the following, we describe the survey design, sampling strategy and characteristics.

B.3.1 Data sampling

The survey was distributed with a commercial panel company among German and UK households. We targeted persons older than 17 with a driving license, using a randomized sampling strategy. We achieved a sample size of N= 1334 participants. Complete responses included participants who passed the attention check item, straight-lining checks and were not identified as speeders. The final sample included N= 1100 valid responses.

B.3.2 Survey design

The survey is organized into six distinct sections, encompassing a total of 56 questions. The initial section of the survey is about socio-demographic information. The second section primarily explores specific vehicle characteristics within a household (fuel type, no. of cars, usage, etc.). The questions asked in our survey not only focus on the most frequently used car, but also on the second most frequently used car. Additionally, the participants were asked about the ownership of an EV. The third section delves into personal mobility patterns. Specific questions for EV users were asked regarding their charging behavior, i.e., when and under which circumstances they charge their EV. Prior to introducing the concept of V2G in the fourth section, participants were queried about their pre-existing knowledge regarding V2G similar to Geske and Schumann (2018). Following the introduction, the survey probes into potential barriers to participation, including battery degradation, potential benefits that could foster the implementation of V2G, and users' willingness to participate and monetary compensation requirements. The fifth chapter assessed personal factors, i.e., environmental awareness and variables connected with the theory of diffusion of innovation. The sixth part included household characteristics.

Table 1 Measures

Scales	Source
Mobility Behavior	Nobis and Kuhnimhof (2018)
Environmental Awareness	van der Werff et al. (2013)
Willingness to participate, concerns, incentives	Geske and Schumann (2018)
Diffusion of Innovation	Wolske et al. (2017)

B.3.3 Measures

We used several scales, already tested in previous studies. Table 1 provides an overview of the measures' sources that are relevant to the following analysis. In general, all questions had to be answered on a Likert scale, coded from 1 to 7, with 1 always being the negative and 7 the positive extremum.

B.3.4 Sample characteristics

For all following analyzes, we divided our sample into two groups – Germany and UK. Table 1 in the Appendix displays the sample characteristics for both groups. The respondents were 50,7% female in Germany and 50,4% female in the UK and fairly educated as 46,1% in Germany and 80,6% in the UK had their A-Levels or a higher degree. Most of the respondents are working full time (Germany= 64,2%; UK= 64,5%). Interestingly, 69,2% own their house/flat if they are living in the UK, whereas only 47,7% in Germany do so. Another aspect that must be considered in the analyzes, is the number of households having a car. Only 0,3% of German and 0,2% of UK households do not have a car, which is significantly less than the actual numbers are. In 2021 77% of all households in Germany owned at least one car and about 79% of the households in UK did so in 2022 (National Travel Survey Statistics, 2023; Statistisches Bundesamt).

B.4 Results

In the following section, we present the preliminary results of our study. We start with the results from descriptive statistics and proceed with the results from the regression analyses. All following analyses was conducted using SPSS version 29.0.1.0.

B.4.1 Compensation requirements

B.4.1.1 Expected V2G compensation

The expected monetary compensation requirement conveys the (in-)convenience of participating in V2G. Respondents provided their expected compensation in an open-ended question, with values ranging from 0-100 (Euros and Pounds per month)[1]. In order to provide respondents with as realistic a situation as possible and thus enable them to estimate the monetary costs in the context of V2G, respondents were previously informed about the costs of a V2G wallbox and asked about their attitude toward it. The same procedure was carried out with the issue of battery degradation. Thus, we expected the required compensation to be rather high in both countries. The results are displayed in Fig.1. Interestingly, the mean value is higher for the German sample than for the UK sample, even though the values for the UK sample were converted from Pound to Euro. For Germany the mean value is 67.54 € per month, while the mean value for the UK is with 60.96 € per month significantly lower. Furthermore, Figure 1 shows that the interquartile range for Germany is very close to the upper bound of 100€, while it is much lower located for the UK sample.

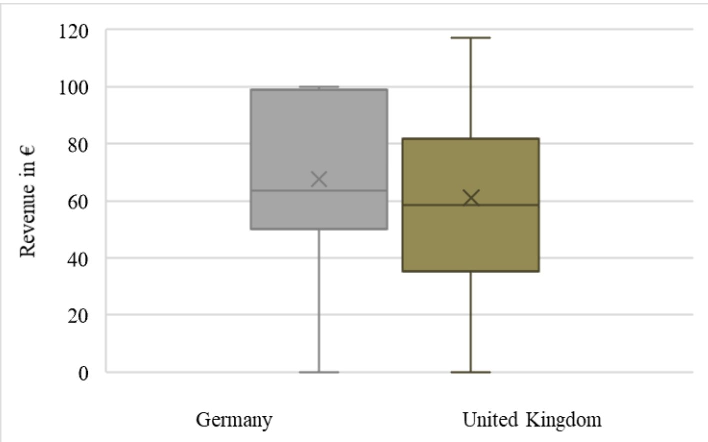

Figure 1 Expected compensation in € per month in Germany and UK

Results indicate, that, as expected, compensation requirements are high for both countries. Though, it has to be noted, that these values have to be read with caution as the open-ended question gave room to subjective perceptions people have. Yet, the aim was not to determine realistic values for V2G compensation, but to reflect the (in-)convenience of this technology, especially when considering

[1] For all further analyzes including monetary aspects, currency was converted into euros (exchange rate on March 15th 2024: 1 GBP= 1.17 EUR (British Pound (GBP) to Euro (EUR)).

the high upfront investments that are necessary for V2G and the additional costs due to a shortened battery life.

B.4.1.2 Relevance of battery aging on compensation requirements

Among all barriers, faster battery aging due to V2G charging proved to be the most important barrier in our study. Battery degradation is highly relevant for the participants, with a mean of 5.25[2] for the German and 5.57 for the UK sample. As previous studies argue that battery degradation is an important part of the financial dimension of V2G charging, we expected that this barrier would have a significant impact on users' compensation requirements. We tested this hypothesis by regressing the importance of battery degradation on the compensation requirements. The influence on the revenue requirements is for both samples significant with ß= .086, *p*= .034 for the German and ß= .104, *p*= .020 for the UK sample. The effect of battery degradation is marginally stronger for the UK sample. This implies that the stronger people believe battery degradation to be a problem, the higher the revenue requirements are in both countries.

B.4.2 Willingness to participate

B.4.2.1 User's willingness to participate in V2G

Apart from monetary compensation requirements, V2G acceptance can also be measured in terms of behavior, i.e., the intention to participate in V2G. Our results reveal that the general willingness to participate in V2G is rather high in both countries, with mean values of 5.01 (Germany) and 4.92 (UK). The value is slightly but significantly higher in Germany (χ^2= 6, N= 1100)= 12.84, *p*= .046). What is interesting is that previous knowledge about V2G is higher in the UK than in Germany. Thus, we expected the results to be the other way around. Moreover, after introducing respondents to the V2G concept and its challenges regarding battery aging, we asked respondents again whether they would still be willing to participate. Astonishingly, while nearly half of all respondents were undecided (Germany= 39.4%; UK= 44.0%), the other half would still participate (Germany= 37.4%; UK= 42.7%). Thus, we can conclude that there seems to be a generally high willingness to participate among German and UK households, also when considering battery aging.

B.4.2.2 Hierarchical multi-regression anayses

In the following, we present the results from our regression model for Germany and the UK. The model is set up in three steps, and the variables are entered hierarchically. In step 1, we entered the contextual variables (rent vs. ownership, type of region, EV ownership, commuting). In step 2 we entered two variables capturing battery degradation (battery aging and compensation for

[2] Relevance of battery degradation was measured on a 7-point Likert scale.

battery aging), before entering in step 3 the psychographic variables (environmental self-identity, consumer novelty seeking and consumer independent judgment making). We dummy-coded the variables rent vs. ownership and type of region. *Rent* is the reference category for the first variable, while it is *big city* for the latter.

Results for both countries are displayed in Table 2. What can be observed is that contextual factors play a subordinate role in both countries (step 1). The explained variance is significant but low with R=.045 for Germany and R=.037 for the UK. The effects of contextual factors diminish when entering barriers in a second and psychographics characteristics in a third step. For example, EV ownership significantly, and positively, predicts participation for the German sample in step 1 (ß= .162, $p< .001$) and step 2 (ß= .118, $p< .01$), but the effect is outweighed by psychographic characteristics in step 3. The same is true for people living in the countryside compared to people in big cities and for commuting. Both predictors have a negative effect on participation, but disperse in step 3.

Model 3 is significantly improved compared to model 2 and 1. Results show, that barriers and psychographic variables significantly predict the willingness to participate in Germany and the UK (model 3), except for consumer independent judgment making in Germany. The ß-values are high, and battery aging has a negative effect on the outcome variable, while the other predictors positively regress on it. In the UK, battery aging has a lower effect on the willingness to participate in Germany. Moreover, EV ownership turns significant in the 3rd step for the UK model. Interestingly, the coefficient is negative, meaning that people with EV experience have a lower willingness to participate in V2G than people with less EV experience, which is counterintuitive. The 3rd model can explain significantly more variance than models 2 and 3. With R^2= .330, $p< .001$ the model is better for the German sample than for the UK sample (R^2= .220, $p< .001$).

Results indicate that barriers and psychographic variables seem to play a much bigger role in explaining the willingness to participate in V2G than contextual variables, which partly confirms our hypothesis. It was shown that battery aging negatively affects users‘ willingness to participate, but that compensation for battery aging is even more important. Moreover, people who are more innovative, are also more likely to participate in V2G.

B.5 Discussion and conclusion

The willingness of users to participate in V2G is a prerequisite for utilizing the flexibility potential for the electricity market. Hence, our analysis provided insights into the user perspective to participate in V2G charging. Two different measures were used – first, the required compensation for providing flexibility under consideration of increased battery aging, and second, the users' willingness to participate in V2G. While the first one provides insights into users' (in-)convenience to participate in V2G charging in monetary terms, the latter is a reflection of a more general acceptance of the concept.

The results have disclosed that people show a high participation willingness in V2G with mean values of 5.01 (Germany) and 4.92 (UK). This finding holds even when incorporating the uncertainty of battery degradation as an essential cost component. This is contrasted by high monetary compensation requirements.

Interestingly, the compensation requirements are lower in the UK (60.96 €/month) than in Germany (67 €/month). One possible reason for this could be the higher income level in Germany compared to the UK (Eurostat, 2024). Moreover, results showed that battery aging has a positive effect on the compensation requirements, meaning the more battery aging is perceived as a potential barrier, the higher the compensation requirement. This underlines previous research showing that users associate battery aging with substantial expenses (Huang et al., 2021; Huber et al., 2019; Schmalfuß et al., 2015), indicating that battery aging should be taken into account in the development of future V2G services. Thus, V2G requires providers of V2G services to design specialized charging tariffs that are attractive to users in monetary terms, as recommended by Signer et al. (Signer et al., 2024). In this study we solely focused on battery degradation as one main predictor of compensation requirements. Yet, socio-demographic characteristics, specifically income and education can have an influence on compensation requirements as well. Thus, future research could analyze compensation requirements in more detail, considering, e.g., sociodemographic characteristics, the degree to which people are willing to participate, or their previous EV experience and V2G knowledge.

Having said this, it must be pointed out that our approach only shows the user's viewpoint, with a focus on users' compensation requirements. This work does not address the extent to which current market conditions allow for such compensation. Though, the question of how much compensation is necessary and how much revenue is possible from a market perspective underlies some uncertainty (Signer et al., 2024).

Furthermore, we analyzed users' willingness to participate in V2G using hierarchical multi-regression analysis. The results unveil the importance of barriers and psychographic characteristics above contextual factors. Along with the fear of battery aging and the compensation thereof, a person's innovativeness and perceived environmental identity strongly predict participation in V2G. This is an important finding as it highlights that the circumstances people live in are far less decisive for people to adopt innovative technologies than their interest in new technologies and their attitude towards the environment. Interestingly, this finding holds for both countries, Germany and the UK, implying that political strategies, as well as business models, could promote

V2G by stressing its novelty and added value for fostering RES. Contextual factors, on the other hand, were not significantly related to users' willingness to participate, which suggests that diverse household positions are not a potential hindrance to a general acceptance. Yet, this might change when looking at adoption, requiring specific infrastructure. Therefore, it would be interesting to study further contextual, infrastructure-related factors, that can be directly influenced and promoted by political strategies and that would enable barrier-free access to this technology.

Concerning V2G barriers, the hierarchical multi-regression analyses reaffirm the relevance of battery aging and its effect not only on compensation requirements but also on the general acceptance. Reducing the effect of V2G on battery aging can thus increase the willingness of users to participate in V2G and reduce the necessary compensation (cf., Maigha and Crow, 2018; Sufyan et al., 2020).

Next to the user perspective of V2G, the electricity market perspective plays a decisive role as well. A successful integration of V2G necessitates the interplay between market conditions and user expectations and requirements. Our results highlighted the user perspective of V2G and can inform electricity market models and support the development of successful business models.

Table 2 Hierarchical multi-regression analysis predicting willingness to participate.

Germany									
Step	Predictors	R^2	R^2 change	F change	df	p	Step 1ß	Step 2ß	Step 3ß
Step 1 Contextual factors	Rent vs. property	.045	.045	4.629	595	<.001	.051	.005	-.009
	Country						-.056	-.024	-.003
	Town						-.011	-.008	.007
	City						-.069	-.059	-.044
	EV ownership						.162***	.118**	.053
	Commuting						-.055	-.045	-.014
Step 2 Battery degradation	Battery aging	.221	.176	67.078	593	<.001		-.151***	-.139***
	Compensation for battery aging							.426***	.304***
Step 3 Psychographic characteristics	Environ. Self-ID	.330	.109	31.872	590	<.001			.168***
	Consumer novelty seeking								.257***
	Consumer ind. judgment								.028
UK									
Step	Predictors	R^2	R^2 change	F change	df	p	Step 1ß	Step 2ß	Step 3ß
Step 1 Contextual factors	Rent vs. property	.037	.037	3.134	488	.005	.044	.024	.045
	Country						-.160**	-.115*	-.074
	Town						-.089	-.047	-.016
	City						-.035	-.017	-.012
	EV ownership						-.039	-.062	-.143***
	Commuting						-.128**	-.115**	-.059
Step 2 Battery degradation	Battery aging	.113	.076	20.810	486	<.001		-.086*	-.094*
	Compensation for battery aging							.290***	.254***
Step 3 Psychographic characteristics	Environ. Self-ID	.220	.107	21.973	483	<.001			.204***
	Consumer novelty seeking								.119***
	Consumer ind. judgment								.105*

Appendix

Table 3 Sample characteristics

Descriptive analyses of socio-demographics	Country	
	Germany (N= 604)	UK (N= 496)
Gender		
Male	306	250
Female	295	237
Non-binary / Other	3	9
Household members		
1 person	137	93
2 persons	200	139
3 persons	145	100
4 persons	94	125
5 persons and more	28	39
No. of cars per household		
No car	2	1
1 car	349	292
2 cars	218	157
3 cars	26	32
4 cars and more	9	14
Rent/Ownership		
Rent	306	140
Ownership	288	343
Other	10	13
Living area:		
Not specified	5	5
Rural region (<5,000 inhabitants)	136	97
Small town (>5,000 inhabitants)	109	167
City (>20,000 inhabitants)	167	115
Large city (>100,000 inhabitants)	187	112

References

Arts, J.W., Frambach, R.T., Bijmolt, T.H., 2011. Generalizations on consumer innovation adoption: A meta-analysis on drivers of intention and behavior. International Journal of Research in Marketing 28, 134–144. https://doi.org/10.1016/j.ijresmar.2010.11.002.

Axsen, J., Goldberg, S., Bailey, J., 2016. How might potential future plug-in electric vehicle buyers differ from current "Pioneer" owners? Transportation Research Part D: Transport and Environment 47, 357–370. https://doi.org/10.1016/j.trd.2016.05.015.

Baumgartner, N., Klumpp, N., Signer, T., Wadud, Z., Fichtner, W., 2024. Users' Willingness to Participate in V2G – A Comparison Between German and UK Households, in: 2024 20th International Conference on the European Energy Market (EEM). 2024 20th International Conference on the European Energy Market (EEM), Istanbul, Turkiye. 10.06.2024 - 12.06.2024. IEEE, pp. 1–8.

Bishop, J.D., Axon, C.J., Bonilla, D., Banister, D., 2016. Estimating the grid payments necessary to compensate additional costs to prospective electric vehicle owners who provide vehicle-to-grid ancillary services. Energy 94, 715–727. https://doi.org/10.1016/j.energy.2015.11.029.

Black, J.S., Stern, P.C., Elworth, J.T., 1985. Personal and contextual influences on househould energy adaptations. Journal of Applied Psychology 70, 3–21. https://doi.org/10.1037/0021-9010.70.1.3.

Blumberg, G., Broll, R., Weber, C., 2022. The impact of electric vehicles on the future European electricity system – A scenario analysis. Energy Policy 161, 112751. https://doi.org/10.1016/j.enpol.2021.112751.

Chadwick, K., Russell-Bennett, R., Biddle, N., 2022. The role of human influences on adoption and rejection of energy technology: A systematised critical review of the literature on household energy transitions. Energy Research & Social Science 89, 102528. https://doi.org/10.1016/j.erss.2022.102528.

Department for Transport, 2023. Zero emission vehicle (ZEV) mandate consultation: summary of responses and joint government response (print version).

Devine-Wright, P., 2008. Reconsidering public acceptance of renewable energy technologies: A critical review, in: Grubb, M., Jamasb, T., Pollitt, M.G. (Eds.), Delivering a low carbon electricity system: Technologies, economics, and policy, 1st ed. Cambridge Univ. Press, Cambridge.

Eurostat, 2024. Durchschnittlicher Bruttomonatsverdienst von Vollzeitbeschäftigten¹ in den Ländern der Europäischen Union (EU) im Jahr 2018. https://de.statista.com/statistik/daten/studie/183571/umfrage/bruttomonatsverdienst-in-der-eu/#:~:text=Durchschnittsgehalt%20in%20Europa%20nach%20L%C3%A4ndern&text=Der%20durchschnittliche%20Bruttomonatsverdienst%20betrug%20rund%205.005%20Euro.

Geske, J., Schumann, D., 2018. Willing to participate in vehicle-to-grid (V2G)? Why not! Energy Policy 120, 392–401. https://doi.org/10.1016/j.enpol.2018.05.004.

Huang, B., Meijssen, A.G., Annema, J.A., Lukszo, Z., 2021. Are electric vehicle drivers willing to participate in vehicle-to-grid contracts? A context-dependent stated choice experiment. Energy Policy 156, 112410. https://doi.org/10.1016/j.enpol.2021.112410.

Huber, J., Schaule, E., Jung, D., Weinhardt, C., 2019. Quo Vadis Smart Charging? A Literature Review and Expert Survey on Technical Potentials and User Acceptance of Smart Charging Systems. WEVJ 10, 85. https://doi.org/10.3390/wevj10040085.

Huckebrink, D., Bertsch, V., 2021. Integrating Behavioural Aspects in Energy System Modelling—A Review. Energies 14, 4579. https://doi.org/10.3390/en14154579.

Kempton, W., Tomić, J., 2005. Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy. Journal of Power Sources 144, 280–294. https://doi.org/10.1016/j.jpowsour.2004.12.022.

Kramer, J., Petzoldt, T., 2022. A matter of behavioral cost: Contextual factors and behavioral interventions interactively influence pro-environmental charging decisions. Journal of Environmental Psychology 84, 101878. https://doi.org/10.1016/j.jenvp.2022.101878.

Maigha, M., Crow, M.L., 2018. Electric Vehicle Scheduling Considering Co-optimized Customer and System Objectives. IEEE Trans. Sustain. Energy 9, 410–419. https://doi.org/10.1109/TSTE.2017.2737146.

Marongiu, A., Roscher, M., Sauer, D.U., 2015. Influence of the vehicle-to-grid strategy on the aging behavior of lithium battery electric vehicles. Applied Energy 137, 899–912. https://doi.org/10.1016/j.apenergy.2014.06.063.

National Travel Survey Statistics, 2023. National Travel Survey 2022: Household car availability and trends in car trips.

Nobis, C., Kuhnimhof, T., 2018. Mobilität in Deutschland – MiD. Ergebnisbericht. infas, DLR, IVT, infas 360, Bonn, Berlin, 136 pp. http://www.mobilitaet-in-deutschland.de/pdf/MiD2017_Ergebnisbericht.pdf (accessed 27 July 2021).

Parsons, G.R., Hidrue, M.K., Kempton, W., Gardner, M.P., 2014. Willingness to pay for vehicle-to-grid (V2G) electric vehicles and their contract terms. Energy Economics 42, 313–324. https://doi.org/10.1016/j.eneco.2013.12.018.

Rogers, E.M., 1983. Diffusion of innovations, 3rd ed. Free Press; Collier Macmillan, New York, London, 236 pp.

Schmalfuß, F., Mair, C., Döbelt, S., Kämpfe, B., Wüstemann, R., Krems, J.F., Keinath, A., 2015. User responses to a smart charging system in Germany: Battery electric vehicle driver motivation, attitudes and acceptance. Energy Research & Social Science 9, 60–71. https://doi.org/10.1016/j.erss.2015.08.019.

Schuller, A., Flath, C.M., Gottwalt, S., 2015. Quantifying load flexibility of electric vehicles for renewable energy integration. Applied Energy 151, 335–344. https://doi.org/10.1016/j.apenergy.2015.04.004.

Signer, T., Baumgartner, N., RUPPERT, M., Sandmeier, T., Fichtner, W., 2024. Modeling V2G spot market trading: The impact of charging tariffs on economic viability. Energy Policy 189, 114109. https://doi.org/10.1016/j.enpol.2024.114109.

Sovacool, B.K., Axsen, J., 2018. Functional, symbolic and societal frames for automobility: Implications for sustainability transitions. Transportation Research Part A: Policy and Practice 118, 730–746. https://doi.org/10.1016/j.tra.2018.10.008.

Sovacool, B.K., Axsen, J., Kempton, W., 2017. The Future Promise of Vehicle-to-Grid (V2G) Integration: A Sociotechnical Review and Research Agenda. Annu. Rev. Environ. Resour. 42, 377–406. https://doi.org/10.1146/annurev-environ-030117-020220.

SPD, Bündnis 90/Die Grünen and FDP, 2021. Koalitionsvertrag: Daring more progress. Alliance for freedom, justice and sustainability, 178 pp.

Statistisches Bundesamt. Pkw-Dichte im Jahr 2021 auf Rekordhoch.

Steg, L., Perlaviciute, G., van der Werff, E., 2015. Understanding the human dimensions of a sustainable energy transition. Frontiers in Psychology (Front. Psychol.).

Sufyan, M., Rahim, N.A., Muhammad, M.A., Tan, C.K., Raihan, S.R.S., Bakar, A.H.B.A., 2020. Charge coordination and battery lifecycle analysis of electric vehicles with V2G implementation. Electric Power Systems Research 184, 106307. https://doi.org/10.1016/j.epsr.2020.106307.

van der Werff, E., Perlaviciute, G., Steg, L., 2016. Transition to Smart Grids: A Psychological Perspective, in: Beaulieu, A., Wilde, J. de, Scherpen, J.M. (Eds.), Smart Grids from a Global Perspective, vol. 18. Springer International Publishing, Cham, pp. 43–62.

van der Werff, E., Steg, L., Keizer, K., 2013. It is a moral issue: The relationship between environmental self-identity, obligation-based intrinsic motivation and pro-environmental behaviour. Global Environmental Change 23, 1258–1265. https://doi.org/10.1016/j.gloenvcha.2013.07.018.

Wang, D., Coignard, J., Zeng, T., Zhang, C., Saxena, S., 2016. Quantifying electric vehicle battery degradation from driving vs. vehicle-to-grid services. Journal of Power Sources 332, 193–203. https://doi.org/10.1016/j.jpowsour.2016.09.116.

Wissenschaftliche Dienste des Deutschen Bundestages, 2017. Entwicklung der Stromspeicherkapazitäten in Deutschland von 2010 bis 2016: WD 8 - 3000 - 083/16. https://www.bundestag.de/resource/blob/496062/759f6162c9fb845aa0ba7d51ce1264f1/wd-8-083-16-pdf-data.pdf (accessed 27 March 2024), 16 pp.

Wolske, K.S., Stern, P.C., Dietz, T., 2017. Explaining interest in adopting residential solar photovoltaic systems in the United States: Toward an integration of behavioral theories. Energy Research & Social Science 25, 134–151. https://doi.org/10.1016/j.erss.2016.12.023.

Paper C

Does experience matter? Assessing user motivatons to accept a vehicle-tog-grid charging tariff

Nora Baumgartner [a], Franziska Kellerer [b], Manuel Ruppert [a], Sebastian Hirsch [b], Stefan Mang [b], Wolf Fichtner [a]

[a] *Chair of Energy Economics, Institute for Industrial Production (IIP), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany*
[b] *CENTOURIS, University of Passau, Passau, Germany*

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Corrigendum to ['Does experience matter? Assessing user motivations to accept a vehicle-to-grid charging tariff'] [Transportation Research Part D 113 (2022) 103528]

Nora Baumgartner, Franziska Kellerer, Manuel Ruppert, Sebastian Hirsch, Stefan Mang, Wolf Fichtner
Chair of Energy Economics, Karlsruhe Institute of Technology (KIT)
CENTOURIS, University of Passau

The authors regret to point out and correct the following mistakes to the article.
In the article we state that EV owners require a higher SoC_{min} compared to people having no EV experience when pursuing a cost-minimized charging strategy (p.10, 13-15). Yet, the results indicate the opposite. The minimum range requirements decrease for EV owners compared to people having no EV experience when offering a cost-minimized charging strategy. Moreover, like for the climate-neutral charging strategy, WTP_{exp} values increase.

This leads to the conclusion that, like the climate-neutral charging strategy, SoC_{min} requirements of EV owners, who pursue a cost-minimizing charging strategy, decrease while their WTP_{exp} increases, i.e., EV users require lower compensation compared to inexperienced users. Form an aggregator's perspective, both charging strategies are recommendable, as the aggregator receives more flexibility while lower compensation is required.

The authors would like to apologise for any inconvenience caused.

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<Nora Baumgartner>
<nora.baumgartner@kit.edu>

Abstract

Vehicle-to-grid (V2G) could be a cornerstone to ensure the efficient integration of a large number of electric vehicles (EVs) and the resulting electricity demand into the energy system. However, successful V2G adoption requires direct interaction with the EV user. To explore user preferences and requirements in the context of a V2G charging tariff, we conducted a survey (N= 1196). We assess users' minimum range requirements and willingness to pay for a V2G charging tariff and relate them to users' experience with EVs. By building a mediation model, we evaluate the importance of three charging strategies to guide users' minimum range requirements and expected monetary savings. The results reveal EV owners' preference for a climate-neutral charging strategy, leading to a higher readiness to accept lower minimum ranges and lower monetary savings. These results are especially important to aggregators, aiming to design profitable business models, while accounting for user requirements and preferences.

Keywords: EV experience, Vehicle-to-grid (V2G), Charging tariff, Willingness to pay (WTP), Price sensitivity meter (PSM), Charging strategies

C.1 Introduction

Electric vehicles (EVs) are one essential element of worldwide political strategies to reduce CO_2 emissions in the transport sector and thus tackle climate change. Since the transport sector is responsible for about 25% of CO_2 emissions worldwide and about 20% in Germany (German Federal Ministry of Economic Affairs and Energy, 2021; IEA, International Energy Agency), the coalition agreement of the newly elected German government aims for 15 million EVs by 2030 (SPD, Bündnis 90/Die Grünen and FDP, 2021). However, the further adoption of EVs will lead to increased electricity demand and consequently poses new challenges to the grid (Babrowski et al., 2014; Blumberg et al., 2022; Das et al., 2020). Yet, utilizing EV storage has the potential to provide additional decentralized flexibility for the electricity system (Blumberg et al., 2022; Doluweera et al., 2020; European Association for Storage of Energy, 2019; Gunkel et al., 2020).

Vehicle-to-grid (V2G) as a particular form of smart charging is increasingly seen as a promising technology. Due to the quick response time (Kempton and Tomić, 2005a) and the geographic and temporal flexibility of EVs (Knezovic et al., 2017), V2G allows for more efficient EV integration in the energy system (Blumberg et al., 2022; Kempton and Letendre, 1997; Kempton and Tomić, 2005b). With the aid of V2G, the battery of EVs can serve as mobile storage and have the ability to feed electricity back into the grid. Numerous advantages are expected from V2G, such as more reliable and efficient grid operation and, consequently, higher potential for integrating renewable energy sources (RES) into the grid (Blumberg et al., 2022; Dixon et al., 2020; Schuller et al., 2015). With this, V2G is envisioned to contribute to a more decentralized, secure, and flexible energy system (Sovacool and Hirsh, 2009).

This study focuses, in particular, on the user perspective of V2G, as the technology in question directly involves the EV user, requiring a certain level of user compliance to be successfully implemented (Bühler et al., 2014). The amount of flexibility that is provided is dependent on the user's decision to plug in the EV (Bailey and Axsen, 2015). Moreover, V2G charging might involve reduced flexibility or increased planning (Franke et al., 2018; Franke and Krems, 2013), as the charging process could interfere with the user's lifestyle and driving behavior (Sovacool et al., 2017). Besides this interference, V2G also yields a perceived loss of control over the charging process (Delmonte et al., 2020; Krueger and Cruden, 2020; Yilmaz et al., 2021). Another relevant constraint impacting users' willingness to participate in V2G is the concern of a shortened battery life due to V2G (Krueger and Cruden, 2020). Thus, V2G requires an adjusted charging behavior and, most importantly, acceptance by the user. Consequently, to promote the launch and uptake of this technology, it is necessary not only to investigate the technical feasibility, but also the preferences and requirements of future users.

Given these perceived barriers to V2G, it is important to examine under what circumstances users will accept and engage with them. Previous studies investigate adequate compensation and requirements from a user perspective by assessing the discomfort costs to provide flexibility in the context of a power supply contract (Kubli et al., 2018) or by determining the willingness to accept

V2G (Lee et al., 2020). Moreover, a further common approach is to assess the monetary value of V2G attributes, such as the minimum range (Bailey and Axsen, 2015; Geske and Schumann, 2018; Huang et al., 2021). These studies allow a quantified assessment of consumer preferences for specific EV attributes and their monetary valuation. By contrast, we approach this topic by assessing users' willingness to pay (WTP) in terms of a two-level charging tariff[1]. Users' WTP not only reflects an acceptable price for providing flexibility, but also on users' expectations in respect to possible savings due to V2G. We consider the actual net-charging cost, which is the primary mechanism of the aggregator[2] to compensate for V2G (Ensslen et al., 2018). By including an individually chosen minimum range[3], we furthermore account for minimum requirements regarding a V2G charging tariff. Minimum range and WTP are essential parameters to both EV users and aggregators as they define user conditions and requirements on the one hand and flexibility potentials on the other.

However, stating one's own WTP for a V2G charging tariff presupposes a certain prior knowledge and interest. Since knowledge and interest with regard to the energy system are in general limited (Huber et al., 2019), results of previous studies suggest that users' experience with EVs represents a critical factor in creating an informed decision about issues in the realm of V2G (Chen et al., 2020; Noel et al., 2019a) and is one relevant variable explaining adoption (Bühler et al., 2014; Chen et al., 2020; Kubli, 2022; Larson et al., 2014; Schmalfuß et al., 2015; Sovacool et al., 2019a; Sovacool et al., 2018, 2019a). While these studies solely focus on one stakeholder group, we believe that precisely the comparison between non-experienced users and EV-experienced users might be the key to drawing conclusions on how to motivate these different target groups. We argue that it makes a difference whether individuals regularly use their EV and are familiar with the technological peculiarities, already have gained experience in driving an EV in solitary events, or have no experience at all with EVs.

Just like the level of EV experience, motivations and benefits can guide users' evaluation of minimum range and WTP for a V2G charging tariff. Previous literature highlights several factors motivating the user to participate in or accept V2G. One of the most prominent motivations is a higher integration of RES and reduced CO_2 emissions (Geske and Schumann, 2018; Kubli, 2022; Noel et al., 2018). Moreover, contributing to grid stability is another motive to consider V2G (Kubli, 2022), despite potentially higher battery degradation or loss of flexibility (van Heuveln et al., 2021). Finally, existing literature highlights the importance of monetary benefits to participate in V2G (Geske and Schumann, 2018; van Heuveln et al., 2021). From a grid operator's

1 Emodi et al. (2022) highlight the fact, that an EV charging tariff constitutes the interface between the EV owner and the aggregator. (Potential) EV owners conclude an electricity tariff to charge their EV at home. Depending on the tariff conditions, these tariffs incentivize a specific charging behavior and thus enable the operator to raise flexibility potentials.

2 Aggregators can be defined as a third party, combining individual EVs to participate in the electricity market (Das et al., 2020; Noel et al., 2019b). By doing so, EVs can provide complex electricity grid services (Noel et al., 2021). Thus, the main task of the aggregator is to "gather (…) information about the market situation, schedule (…) charging and discharging according to the bargained rules and expected revenues" (Geske and Schumann, 2018).

3 According to Bauman et al. (2016), setting a minimum range is a necessary condition to users, especially in the early adoption stage, to accept controlled charging. We base our definition of the minimum range on Ensslen et al. (2018) and define it as the minimum necessary range, that EVs must always be able to cover in unpredictable cases, i.e. for example an emergency case.

perspective, grid stability and RES complement each other well, especially since expensive energy storage or backup capacities for balancing intermittent RES would (mostly) be redundant (Bailey and Axsen, 2015; Lund and Kempton, 2008; Sovacool et al., 2017). These findings are supported by energy system modelling approaches including V2G as a flexibility option. Utilizing flexibility in order to manage grid congestion decreases the necessary curtailment of RES and consequently leads to a more economical and less carbon-intensive result (Staudt et al., 2018; Szinai et al., 2020).

While there is evidence that different motives (environmental, grid-beneficial, financial) exist to foster participation in V2G, the question remains whether and to what extent these aspects relate to user experience with EVs. Moreover, we are not aware of any study which has tested these motives with regard to users' WTP and minimum range requirements. Thus, we designed three charging strategies based on the most important motives, i.e. climate-neutral, grid-beneficial, and cost-minimized charging. Charging strategies are described as a bargain between the vehicle user and the aggregator (Geske and Schumann, 2018). Assessing whether and how these motives influence users' WTP and the evaluation of the minimum range can be an important first step towards guiding prospective business models.

The novelty of our approach lies in investigating the role of user experience and underlying motivations to evaluate WTP and minimum range requirements for a V2G charging service. Based on the findings of our paper, it is thus possible to derive stakeholder-specific recommendations. With our study, we aim to contribute to the existing body of research by answering the following research question:

How does EV experience influence user requirements with respect to minimum range and required savings within a V2G charging tariff and to what extent do underlying motives influence this relationship?

This paper offers a quantitative comparative assessment, including the perspectives of 264 EV owners, 241 people with medium EV experience, and 691 respondents with no EV experience on a V2G charging tariff. Thereby, we present one of the few studies including a comparatively large share of EV owners in Germany. It is assumed that the perceptions and knowledge of individuals with different levels of user experience differ for the V2G systems. In other words, V2G is evaluated differently by those who own an EV and those who did not yet buy or got the chance to test an EV and thus do not necessarily have an updated and informed perception of this technology and its usage. Finally, besides experience, we also test different motivations that have the potential to guide users' WTP preferences in a V2G tariff.

The remainder of this paper is structured as follows: In Section C.2, we provide a literature background on previous studies assessing user's WTP. Section C.2.3 describes the research design, including data collection, study design and the data analysis strategy. In Section 3, we present our results, which will be discussed in Section C.4. We conclude with an outlook for possible future research (Section C.5).

C.2 Literature background

In this section, we review the most important empirical studies determining users' WTP for V2G. Especially in the context of a V2G tariff, the relevance of the minimum range (SoC_{Min}) is emphasized.

In future, the purchase price for an EV that will be able to feed electricity back into the grid, as well as the possible earnings that could be generated with V2G, will be of high importance to consumers. A summary of past studies investigating users' WTP in the context of V2G is shown in Table 1. We identified two research streams: The first stream deals with the vast majority of papers investigating users' WTP for specific V2G attributes, thus assessing the importance of these attributes. The second stream focuses on the compensation that users claim in order to provide flexibility.

Table 1: Review of past WTP studies in the context of V2G

Reference	Method	Target group	Country	Sample size	WTP
Assessing WTP for EV attributes in the context of V2G					
Geske and Schumann, 2018	Discrete choice experiment	Vehicle users	Germany	611	WTP for one km of minimum range between €3.88 - €6.45 / km
Bailey and Axsen, 2015	Stated choice experiment	New vehicle buyers	Canada	1470	Increased guaranteed minimum charge by 10% was valued at CAD-$47 / year (€33 / year.)[1]
Huang et al., 2021	Stated choice experiment	EV drivers	The Netherlands	148	WTP for a guaranteed minimum battery level increase of 1% / month: €5.91; quick recharge: €2.73; additional discharge cycle: €6.81
Noel et al., 2019a	Stated preference survey	Representative randomized and non-randomized sample	Nordic region	4762	€3802 – €5209 WTP for V2G capability in EV
Hidrue and Parsons, 2015	Contingent valuation survey	Car buyers	United States	3029	Median WTP ranges from $10,200 (€9005) for a V2G EV without range extender to $22,900 (€20,219) for the Civic model with range extender
Compensation for providing flexibility and accepting V2G					
Parsons et al., 2014	Stated preference survey	Representative sample	United States	243	Median cash-back: $2368 - $8622 / year (€2091 - €7613 / year)

[1] To better compare the values, we translate all currencies into EUR and place these values in brackets behind the original value and currency. We base the translation on the exchange rate (31st of December 2021) from the European Central Bank (German Central Bank, 2022).

Kubli et al., 2018	Choice experiment	PV owners, EV owners, heat pump owners	Switzerland	300	Discomfort costs due to V2G: CHF 3.85 - CHF 45.16 (€3.72 - €43.71)
Lee et al., 2020	Contingent valuation approach	Stratified random sample	South Korea	1007	Willingness to accept (WTA) $8.83 / month and vehicle (€7.79 / month and vehicle)
Kubli, 2022	Choce experiment	Current and potential EV adopters	Switzerland	202	Net willingness to accept (WTA): Charging location: -CHF 6.45 (-€6.24) (charging from work compared to home-charging) and -CHF 10.36 (-€10.03) (charge at public space compared to home-charging) Charging duration +CHF 3.57 (+€3.46) (4h compared to 6h) and +CHF 6.95 (+€6.73) (2h compared to 6h) Guaranteed charging (eco charging compared to standard charging): -CHF 4.33 (-€4.19)

C.2.1 Assessing WTP for EV attributes in the context of V2G

Most of the studies applied stated preference methods, such as discrete or stated choice experiments to assess users' preferences and monetary valuation for different EV attributes in the context of V2G. In this regard, a sizeable body of research discusses the EV range. The vehicle range is by far the most common attribute and received high monetary values. Minimum and maximum EV ranges are thus still perceived as a possible hindrance to flexible mobility behavior and, therefore, one essential feature in order to participate in a V2G service (Geske and Schumann, 2018; Hidrue et al., 2011; Huang et al., 2021). A theoretical explanation of this circumstance is provided by Bühler et al. (2014), highlighting that range will remain important for accepting EVs and specifically V2G due to persisting perceptions of mobility requirements[2]. This insight is taken up by Bailey and Axsen (2015), who use a latent class model to identify trade-offs between different attributes (percentage of green electricity, source of green electricity, guaranteed minimum charge, monthly electricity bill) of a utility-controlled charging program. The authors find a high WTP for an increase of the guaranteed minimum charge. The high WTP for extra ranges is reconfirmed by Geske and Schumann (2018), who conclude that fear of restrictions of freedom and independence negatively affect users' willingness to participate in V2G. They acknowledge that immobility due to V2G poses, by far, the greatest risk to consumers. Similarly, a recent study by

[2] Bühler et al. (2014) describe this phenomenon as societal resistance to change. According to the authors, users have a very specific understanding of car characteristics and features. Range is one of these must-have characteristics that significantly varies from that of cars with internal combustion engines.

Huang et al. (2021) emphasizes that the acceptance of the minimum battery level is largely influenced by the recharge time and the availability of fast charging for the EV.

Literature thus demonstrates the significant role of the minimum range for V2G. To account for this, we included the minimum range as a feature in our two-level charging tariff (Section 3.2.1). Contrary to the previously mentioned literature, we did not assess the monetary value thereof, but a specific range. Doing so is particularly important when designing a V2G charging contract, as it marks the accepted upper limit of the flexibility potential that can be used by the aggregator. Likewise, flexibility in V2G contracts can be restricted due to contract terms that commit a certain number of hours to the aggregator (Al-Obaidi et al., 2021; Hidrue and Parsons, 2015). In both ways, flexibility can be harnessed, potentially contributing to integrating higher shares of RES into the electricity system.

One of the few studies that related preferences for V2G attributes to EV user experience was conducted by Noel et al. (2019a). This comparative study in the Nordic region elaborates on the WTP for several EV attributes and found i.a. a high marginal WTP for additional range. Even for high ranges, the marginal WTP was high. The study shows that EV experience impacts EV choice, but that previous knowledge of V2G technology does not influence users WTP for V2G (Noel et al., 2019a). By focusing on different levels of user experience with EVs, our study design allows a more detailed investigation of this aspect.

C.2.2 Compensation for providing flexibility and accepting V2G

There is abundant technical research investigating EV user revenues, for example for vehicle-to-home and arbitrage trading (e.g., Kern et al., 2022), ancillary services (e.g., Bishop et al., 2016; Gough et al., 2017), primary frequency regulation market (e.g., Bañol Arias et al., 2020) and peak-shaving (e.g., Li et al., 2020). However, investigating the adequacy of these revenues from a user perspective has been researched far less often.

When investigating adequate compensation and requirements for providing flexibility from a user perspective, empirical studies applied mostly stated choice experiments. While Lee et al. (2020) assess EV owners' willingness to accept (WTA) a V2G service, Kubli et al. (2018) focus on the co-creation of flexibility and thus compare the three technologies photovoltaic (PV) with battery storage, electric mobility, and heat pumps. One remarkable result of the latter study is that the sensitivity for the flexibility attribute is low and that the part-worth utility function dropped for guaranteed charging levels below 60%. Moreover, the authors find high discomfort costs to provide flexibility in a power supply contract (Kubli et al., 2018). In a recent study by the same author, the question of how much compensation is required to adjust the charging location, duration and range to facilitate smart charging is pursued (Kubli, 2022). The author summarizes that an attractive remuneration has to be paid to incentivize users to chose another option when home-charging is available. The same could be observed by Parsons et al. (2014), who found very high cash-back values, i.e. very high discount rates, implying that buyers attach high importance to flexibility and lifestyles. Thus, the authors recommend either offering up-front price discounts on

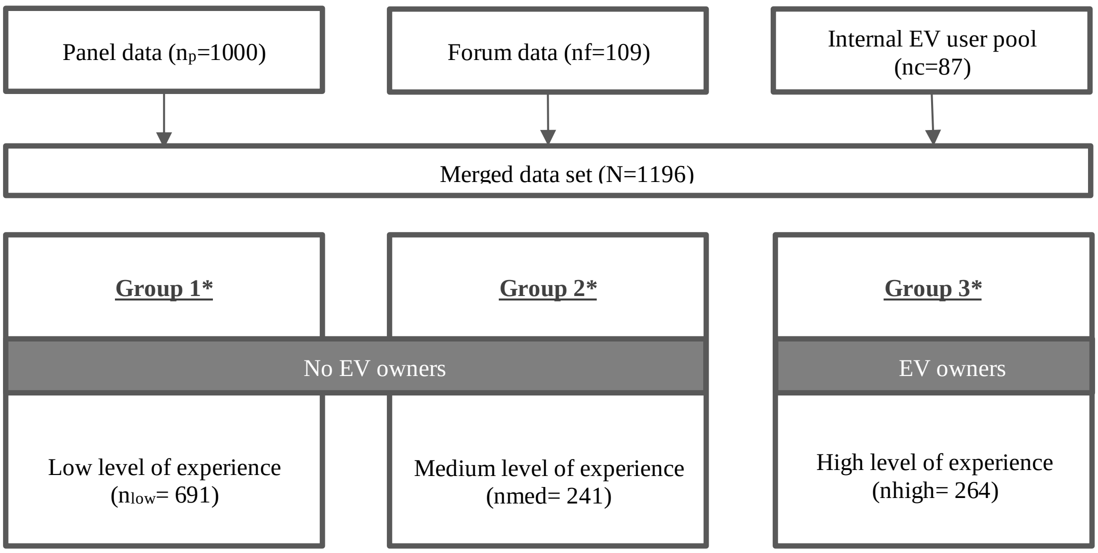
V2G vehicles or offering a pay-as-you-go contract (Parsons et al., 2014). These studies show that potential users demand very high discounts or overestimate the value of specific attributes, such as range. It is unclear whether this circumstance is due to individual inexperience with V2G or whether buyers simply value freedom of mobility that high.

C.2.3 Materials and methods

To address the research question raised in the introduction, a study was conducted to evaluate the user perspective on tariff options and business models for V2G. In the following section, the data sampling process and the research design is presented. Moreover, we describe the methodological approach we used to assess users' willingness to pay.

C.2.4 Data collection and sources

We conducted an online survey in January and February 2021. For data collection, we combined randomized and purposive sampling to increase the share of EV experienced people and EV owners. These target groups are still underrepresented and thus harder to reach in Germany (cf. Sovacool et al., 2019b). In 2021, the share of EVs accounted for only ~1.2% of the German car fleet (Federal Motor Transport Authority, 2022), and thus, we expected little experience with EVs in the overall population. As Sovacool et al. (2019a) argue, previous studies in the context of EVs or V2G build their research on randomized samples, potentially biasing the results or limiting the validity due to the lack of experience with the technology in focus. We addressed this potential limitation by using purposive sampling (Maxwell, 2009).



*SD04: Is an electric vehicle available in your household? Yes - No AND SD05: Have you already driven an electric vehicle (e.g., test drives, etc.)? Yes – No.

Figure 1: Data sources

The survey was designed to provide insights from people with different levels of EV experience and distributed anonymously online. Only people older than 17 years owning a driving license participated in the survey. The sample is based on three data sources: First, data was recruited from a German market research company, offering a representative national panel. Respondents were admitted to complete the questionnaire until we received a population-representative sample regarding age, gender, and federal state. Moreover, as noted previously, we expected EV owners to differ from people with little to no EV experience regarding their awareness and understanding of V2G technology (cf. Axsen et al., 2016). To test this assumption, we also placed the survey in e-mobility forums. Furthermore, the survey was distributed among the internal CENTOURIS[3] pool of potential participants who own an EV, which has been successively built up through corresponding projects. We provided an incentive to respondents participating via these pools. A list of the forums can be found in Appendix A. It is important to note that this additional data is not population-representative. After the survey period was completed, data control was conducted, eliminating data according to previously determined quality standards. A reliable indicator of low response quality is speeding (Conrad et al., 2017; Leiner, 2019). We, therefore, excluded all respondents who could be identified as speeders. Moreover, we checked all responses regarding their plausibility. The final sample is comprised of 1000 valid responses originating from the panel data, 109 valid responses from the EV online forums, and 87 valid responses from the internal CENTOURIS EV user pool (see Figure 1).

C.2.5 Survey design

The survey consisted of four parts: In the first part, we assessed sociodemographic characteristics of the respondents, including questions relating to their EV experience (see Section C.2.4). We evaluated the respondents' previous experience with EVs[4] based on two questions: *Is an electric vehicle available in your household?* and *Have you already driven an electric vehicle (e.g. test drives)?*. Based on the answers, we grouped all respondents according to their level of EV experience into three groups: "low user experience", "medium user experience" and "high user experience" (see Figure 1). We conducted all of our further analyses for these three groups.

In the second part, a short explanatory video clip introduced the concept of V2G to the respondents, explaining the interplay between the energy system, V2G charging and the possibility to generate revenues due to flexibility provision. Afterwards, we introduced the term minimum range and outlined the V2G tariff design (see Section C.2.5.2). We included several quality checks to assess whether participants understood the V2G concept and the charging tariff design, before asking participants about their preferred minimum range (see Section C.2.5.1) and their willingness to pay (see Section C.2.5.3) in open-ended questions. Moreover, we assessed participants' preferences concerning their preferred charging strategy (see Section C.2.5.4). Furthermore, questions in the study addressed users' preferences regarding the design of possible business cases and tariff models. These questions included accepted investment cost and amortization periods

3 CENTOURIS – center for data-based insights is a proper noun and is an institute of the University of Passau.

4 In this study, the term EV refers exclusively to an externally chargeable passenger car that is operated purely on battery power or in combination with an internal combustion engine as a plug-in hybrid.

and preferred compensation models and contracting parties. These results are elaborated in more detail in Kellerer et al. (2022). In the final part, we introduced five-point Likert scales to evaluate participants' environmental concern, self-efficacy and technological affinity. We closed the survey by asking questions related to household characteristics.

C.2.5.1 Determining the preferred minimum range

In the framework of V2G, previous research assigns particular importance to the minimum range (see Section C.2.1). Therefore, in a first step, respondents provided their minimum range requirements in an open-ended question:

How many kilometers should your electric car always be able to cover in unpredictable cases, for example, in emergency situations? Please think of the range with which you would just feel safe.

The answers were provided in km (see also Appendix B for the exact wording). For assessing users' WTP, this range determined the basis for the second tariff level.

C.2.5.2 V2G tariff design

A special two-level charging tariff was developed and outlined to the participants to evaluate users' preferences regarding possible business models and electricity prices in the V2G scenario (Table 2). This tariff was inspired by an EV-specific controlled charging tariff developed by Ensslen et al. (2018) and solely focuses on the net-purchasing price of electricity[5] to charge the EV in an AC charging mode.

Table 2: Two-level charging tariff design

Charging level	Charging mode	Definition
1st tariff level	Uni-directional charging	Instant charging until the individually chosen SoC_{Min} is reached. The price for this mode is €5.20 / 100 km.
2nd tariff level	Bi-directional (V2G) charging	Charging in the bidirectional charging mode until the individually chosen maximum range is reached.

The tariff design that we created is comprised of two levels: At the first tariff level, the EV will be promptly charged until reaching a self-selected "minimum"- state-of-charge (SoC_{Min}), which can be set individually. The electricity price for the first tariff level was predetermined to be €5.20 / 100 km, based on the average electricity price in Germany in January 2021 (€0.34 / kWh) and the Worldwide Harmonized Light-duty Vehicles Test Procedure (WLTP) consumption of a

[5] Recently, a law in Germany has become effective that regulates the feeding in of electricity from the EV into the grid (Federal Ministry of Ecomonic Affairs and Climate Action, in charge, 2022). However, at the time of data collection, this law was only discussed in Germany and no law was effective in the European Union, which is why considering selling electricity in the framework of a V2G charging tariff was, from a regulatory perspective, not possible (European Association for Storage of Energy, 2019).

BMW i3 (15.3 kWh / 100 km). The second tariff level described the V2G phase. At this level, plugged EVs can be charged and de-charged within the individual settings for the desired range and time of departure.

C.2.5.3 Willingness to pay for a V2G charging tariff

Determining a customer's WTP is an essential step in the pricing process when introducing a new product. This is the case for new vehicle technologies and concepts, such as V2G. Yet, determining customers' WTP for a V2G charging tariff is a hypothetical setting where the respondents express their WTP without any actual experience with the product (cf. Jensen et al., 2013). Bühler et al. (2014) point to the fact that users tend to inaccurately predict the value of the product if no experience is available. To approach this issue, we chose a mixed-randomized and non-randomized sampling technique (see Section C.2.4).

Different methods to determine users' WTP can be found in existing literature. The main methodological distinction is made by direct or indirect measurement of customers' WTP and by the context which asks for a hypothetical or actual WTP (Miller et al., 2011). We chose to apply the price sensitivity meter (PSM) by van Westendorp, an indirect method to identify users' WTP (van Westendorp, 1976). The primary advantage of this method is that the focus is set on the price of a product and not on other attributes (Breidert et al., 2006). Moreover, the method is based on the assumption that a price range exists, which is bounded by the maximum and minimum that users are willing to pay (cf. Larson et al., 2014). However, a downside of this method is that respondents might over- or underestimate their WTP (Breidert et al., 2006; Hofstetter and Miller, 2009). One reason might be the lack of knowledge to estimate a price. In particular, complex and unfamiliar products lead to over- or underestimations of prices (Brown et al., 1996). In the literature, these theoretical disadvantages have been examined. Yet, the superiority of indirect methods such as the conjoint analysis could not be proven (Völckner, 2006).

Following the PSM approach, participants in the web-based survey were asked the following four open-ended questions (cf. Appendix C) to evaluate the second tariff level of the previously determined two-level charging tariff design: *At what average price per 100 km of range would you consider V2G charging...*

…too expensive, i.e. you would definitely look for a cheaper tariff?
…expensive, i.e. you would only conclude the contract after careful consideration?
…cheap, i.e. the tariff would be a bargain?
…too cheap, i.e. you have doubts about the seriousness of the tariff?

The answers were aggregated. The intercepts between the different curves determine the different price points, which will be discussed in Section C.3.3 - indifference price point (IDP), optimal price point (OPP), point of marginal cheapness (MGP) and point of marginal expensiveness (MDP).

C.2.5.4 Charging strategies

Finally, we assessed respondents preferred charging strategies for the second charging level. By doing so, we elaborate on underlying motivations, guiding users' WTP and SoC_{Min} requirements. Specifically, we were interested in elaborating, whether the charging strategy explains the relationship between user experience and stated SoC_{Min} and WTP. Respondents thus had to distribute a total of 100 points, mirroring their preferences for the three charging strategies – cost-minimized charging, climate-neutral charging and grid-beneficial charging. The exact questions can be found in Appendix D.

We performed a mediation analysis by using Process in SPSS, a methodology that is based on Hayes and Preacher (2014). With this method, the overall relationship between the predictor (X) and the outcome variable (Y) can be explained by both of their relationships with a third variable, the mediator (M), thus reflecting a causal sequence (Field, 2018). Mediation occurs when the effect of the independent variable X on the dependent variable Y is reduced by integrating the mediator variable M (Baron and Kenny, 1986; Dudenhöffer, 2015). To test for inference in mediation analysis, several tests can be performed. For example, one can test the occurrence of the indirect effect by using the Sobel test (Hayes and Scharkow, 2013), which performs a significance test to reject or accept the null-hypothesis (Tibbe and Montoya, 2022). Another possibility is to perform percentile or bias-corrected bootstrap confidence intervals (CIs), where a CI test is formed to see whether zero falls outside its confidence limits (Tibbe and Montoya, 2022). For an overview and comparison of these tests see Hayes and Scharkow (2013) or Tibbe and Montoya (2022). As recommended, we applied the bias-corrected bootstrap CIs (Field, 2018; Hayes and Preacher, 2014; Hayes and Scharkow, 2013; Zhao et al., 2010).

To test the sequences of interest, we used the bias-corrected bootstrap procedure with multilevel categorical variables (Haye's Model No. 4, N= 10.000) (cf. Hayes and Preacher, 2014) to estimate the direct, total and indirect (standardized) effects of the linear model. Since the mediators are derived from a constant sum query, we created a separate model for each mediator[6]. The mediation model is based on the equations below.

$$c = c' + ab \tag{1}$$

Equation (1) defines the relative total effect c, which corresponds to the sum of the relative direct effect c' and the product of the coefficients a and b.

$$M = \beta_M + a_1 X_1 + a_2 X_2 + \varepsilon_M \tag{2}$$
$$Y = \beta'_Y + c'_1 X_1 + c'_2 X_2 + bM + \varepsilon_Y \tag{3}$$

The indirect effect of X on Y through M is estimated as the product of ab from equations (2) and (3). With equation (2) we measure the effect of X on M. With β_M the standardized (regression)

[6] As described in Section C.2.5.4 respondents had to distribute a total of 100 points to the three charging strategies – cost-minimized charging, climate-neutral charging, grid-beneficial charging – to express their preferences. Therefore, a linear dependency exists between the three charging strategies. We solved this issue by building a separate model for each mediator. Of course, this has the drawback that dependencies between the mediators are not reflected and accounted for.

coefficient is included and ε_M defines the error. As the study setup results in a multicategorical predictor (user experience), dummy coding is applied. Consequently, we have two predictor variables a_1 and a_2 in the model. Equation (3) defines the direct effect.

$$Y = \beta_Y + c_1 X_1 + c_2 X_2 + \varepsilon_Y \tag{4}$$

Finally, equation (4) defines the total effect of X on Y, which is the observed difference of group means on Y. A detailed description of statistical mediation analysis with multicategorical independent variables can be found in Hayes and Preacher (2014).

C.3 Results

In this section, we present the most important results of our study. First, we provide a sample characterization of the three groups low, medium and high user experience. Second, we present the results of the SoC_{Min} and the WTP for a V2G charging tariff, and based on these results, discuss the role of user experience and underlying motivations.

C.3.1 Sample characterization

Table 3: Sample characterization

		Total sample (N= 1196)	**Low user experience (n_{low}= 691)**	**Medium user experience (n_{med}= 241)**	**High user experience (n_{high}= 264)**	**German average [a]**
Age	17-29 years	17.0%	17.9%	19.5%	12.1%	20.0%
	30-39 years	16.4%	15.6%	18.3%	17.7%	17.8%
	40-49 years	18.3%	16.2%	20.3%	22.0%	16.6%
	50-59 years	23.7%	24.2%	21.6%	24.6%	22.2%
	60-74 years	24.6%	26.0%	20.3%	24.6%	23.4%
Gender	Female	43.3%	54.6%	38.6%	18.2%	50.6%
	Male	56.6%	45.4%	61.0%	81.8%	49.4%
	Other	0.1%	0.0%	0.4%	0.0%	0.0%
Level of education	Not yet graduated	0.2%	0.3%	0.0%	0.0%	3.5%
	Secondary school graduate	7.2%	10.0%	3.7%	3.0%	28.6%
	General certificate of secondary education	26.1%	30.5%	24.5%	15.9%	30.0%
	General higher education qualification	66.3%	59,0%	71.8%	80.3%	33.5%
	Other	0.3%	0.1%	0.0%	0.8%	4.2%

[a] Own calculations based on data for 2019 of the Federal Statistical Office of Germany (2019)

Table 3 displays the sample characteristics and compares the sample with data from the German Census (Federal Statistical Office of Germany, 2019). The sample consists of 1196 valid responses from the dataset presented in Section C.2.4, grouped into three groups based on the participants' levels of experience with electromobility. The first group, with a sample size of n_{low}= 691, has had no experience yet with EVs. The second group (n_{med}= 241) gained experience with EVs during test drives, car sharing, and other non-frequent forms of interaction. The third group represents EV owners (n_{high}= 264).

The sample is partially representative of Germany. With regard to age, the sample distribution is similar between the three groups, with the exception of the age group 18-29 years old for the group with high user experience (12.1%), which is underrepresented compared to the other groups and the German average (20.0%). Moreover, males (56.6%) are slightly overrepresented in the total sample. The overrepresentation becomes more significant in the two groups where experience with EVs already exists. This difference can most likely be traced back to the fact that, besides the panel data, we used multiple additional sources to collect the overall dataset. Finally, a difference between the sample and the representative Census data regarding the level of education can be observed. While the share within the Census sample is nearly equally distributed between the three graduation levels, a higher percentage of the sample in this study attained a general higher education qualification (66.3%). This bias can be observed among all three groups of our sample.

Finally, we also collected data on monthly net income per household[1]. The results show, that EV experienced people (26.9% with a monthly net income of €4.600 - €7.499) have significantly higher monthly net incomes than people with medium EV experience (20.3% with a monthly net income per household in the range of €3.600 - €4.599), or without EV experience (23.3% with a monthly net income of €1.600 - €2.599 followed by 22% with a monthly net income per household of €2.600 - €2.599). Our analysis indicates that respondents of the group with higher EV experience tend to be male, have a higher level of education and have a higher monthly net income per household. Thus, our sample is biased towards early adopters (Chen et al., 2020; cf. Ozaki and Sevastyanova, 2011; Plötz et al., 2014).

C.3.2 Minimum range requirements for a V2G charging tariff

In this study, we were interested in elaborating on whether different levels of user experience with EVs have an impact on the evaluation of the SoC_{Min}. Respondents were asked about their minimum range requirements that must always be available during the charging process. In order to prevent highly unrealistic responses, the maximum value that could be named by the respondents was set to 500 km. In the following, we present the results of the survey.

The results shown in Figure 2 reveal that approx. 30% of the respondents would accept a SoC_{Min} of 50 km and approx. 70% of the respondents a SoC_{Min} of 100 km. The saturation begins at a SoC_{Min} of about 200 km, which covers about 90% of the respondents (cf. Figure 2). Table 4 gives an overview of the minimum range requirements over the whole sample. The mean value over

[1] We report these results only in the text but not in the table, since the categories we retrieved are not comparable with the categories from the data from the Federal Statistical Office of Germany (2019).

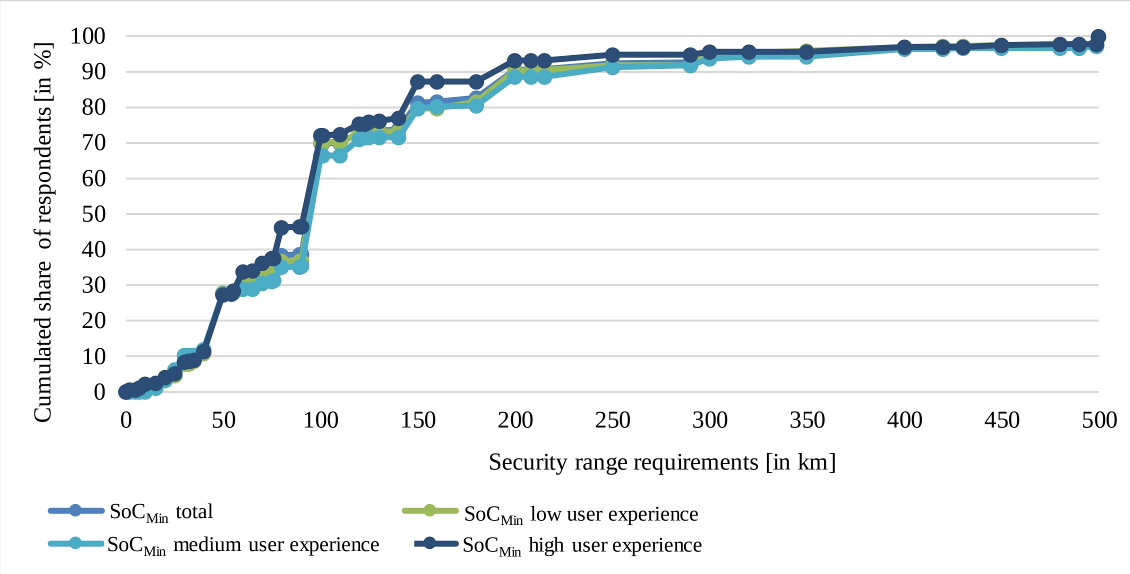


Figure 2: Cumulated share of answers regarding the minimum range according to the level of user experience, N= 1195.

the total sample is 119 km. These numbers appear to be high considering that this range should suffice in emergency cases.

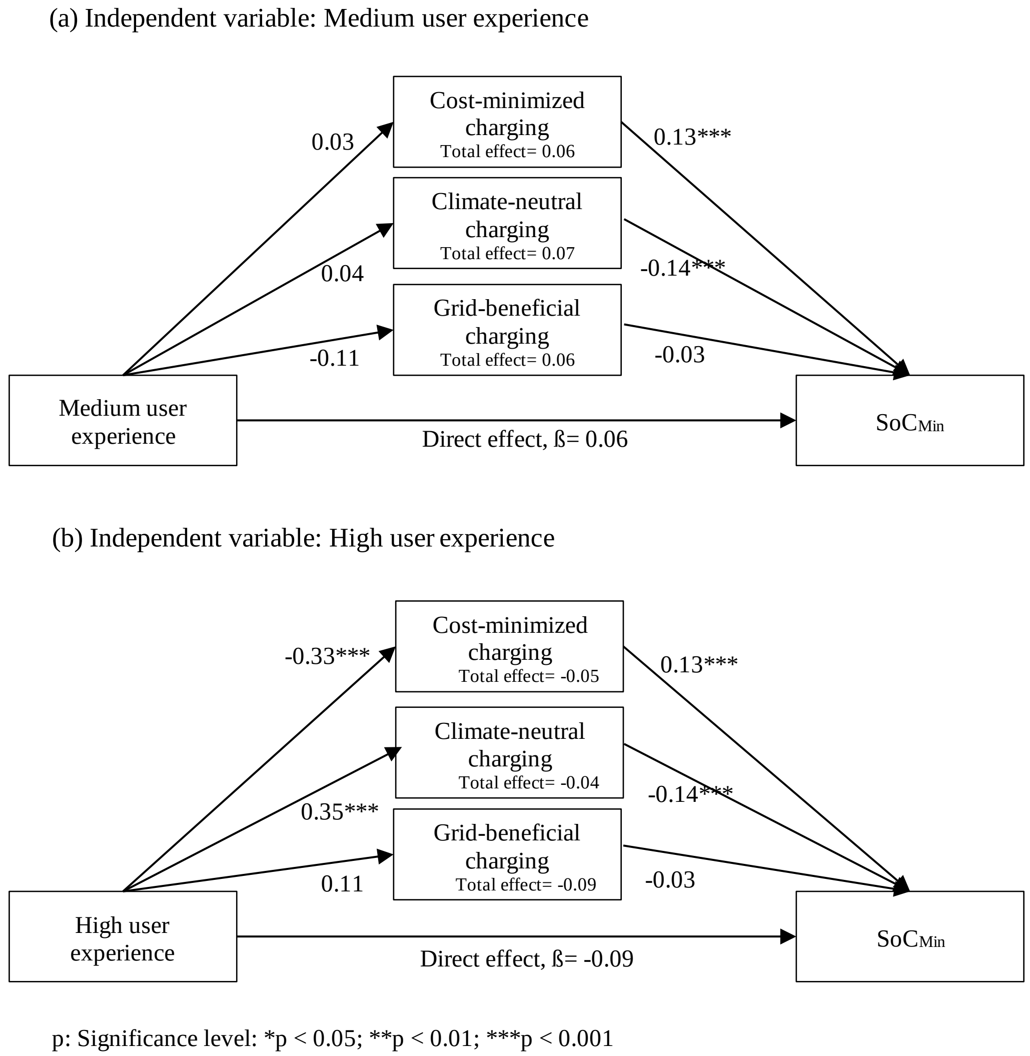
What can also be observed from Figure 2 is that EV experience does not seem to have a significant impact on participants' evaluation of the SoC_{Min}. An analysis of variance (ANOVA) confirmed that group means are not significantly different. In order to elaborate the relationship between the SoC_{Min} and the level of user experience in more detail, we performed a mediation analysis. Specifically, we were interested in investigating on whether the charging strategy, which can be seen as one possible motivation for higher or lower SoC_{Min}, explains the relationship between user experience and stated SoC_{Min}.

Table 4: Minimum range requirements in total

Sample	[in km]							
	M	SD	SE	Min	Max	$q_{0,25}$	$q_{0,5}$	$q_{0,75}$
N=1195	119.01	98.37	2.84	0	500	50.0	100.0	150.0

We tested the following sequence: level of user experience -> charging strategy -> SoC_{Min}. We chose the group of low user experience as the reference group, meaning all following results are interpreted in comparison to this reference group. Table 5 presents the indirect effects of the mediation analysis and Figure 3 (a-b) the standardized B-values of the mediation analysis.

We can observe from Figure 3 b that the effect of high user experience on climate-neutral charging (ß= 0.35) is positive. The effect on cost-minimized charging is negative and slightly smaller (ß= -0.33). This indicates that the importance of climate-neutral charging increases and of the cost-minimizing charging strategy declines for EV owners when compared to users with no EV experience. Both values are moreover highly significant, whereas the effect of high user experience on grid-beneficial charging is not significant. High user experience thus significantly predicts cost-minimized and climate-neutral charging. Medium user experience, however, does not significantly predict one of the charging strategies. When analyzing the relationship between the charging strategies and the SoC_{Min}, we can see that these relationships are highly significant, except for the relationship between grid-beneficial charging and SoC_{Min}. Moreover, the effect of cost-minimized charging on SoC_{min} is negative, while the opposite is true for the relationship between climate-neutral charging and SoC_{min}, emphasizing that minimum range requirements increase for a higher preference for cost-minimized charging, while they decrease in case of a higher preference to charge the EV in a climate-neutral manner. Finally, the direct effects of medium (ß= -



Note: Even though the mediators are displayed in one model, we carried out three separate models – for each mediator one model.

Figure 3: (a-b) Mediation analysis for X= level of user experience, M= charging strategy, Y= minimum range; N= 1196

0.06, 95% CI [-8.13; 20.73], p= 0.392) and high (ß= -0.09, 95% CI [-23.07; 4.85], p= 0.201) user experience on the SoC_{Min} are not significant.

To account for a possible bias due to diverging sociodemographic characteristics between the groups (see Section C.3.1), we tested the mediation analysis with the three covariates: gender, income and education. Gender was significant, yet, including sociodemographic variables as covariates didn't change the results of the indirect effects. The results can be found in Appendix E.

Table 5 shows that pursuing a climate-neutral and a cost-minimizing charging strategy both mediate the relationship between high user experience and minimum range requirements. By contrast, the indirect effect due to grid-beneficial charging is not significant, nor could we identify any indirect effect that significantly mediates the relationship between medium user experience and minimum range requirements. Thus, there seem to be significant differences between users with a high EV experience and without experience, but no differences between those having medium and no user experience with EVs.

Table 5: Indirect effect of level of user experience, on SoC_{Min}, mediated by the three charging strategies

	Cost minimized-charging			Climate-neutral charging			Grid-beneficial charging		
		Bootstrap 95% CIs			Bootstrap 95% CIs			Bootstrap 95% CIs	
	ß (*SE*)	Lower to	Upper	ß (*SE*)	Lower to	Upper	ß (*SE*)	Lower to	Upper
Medium user experience	0.003 (*0.010*)	-0.016	0.025	-0.006 (*0.012*)	-0.029	0.017	0.004 (*0.005*)	-0.004	0.016
High user experience	-0.042 (*0.014*)	-0.075	-0.018	-0.050 (*0.015*)	-0.082	-0.024	-0.004 (*0.005*)	-0.016	0.0037

Note: Confidence Intervals (CIs) are bias corrected; 10.000 bootstrap samples.

Interestingly, pursuing a climate-neutral charging strategy increases the willingness of high experienced users to accept lower SoC_{Min} values. We can thus conclude that the promise to charge in a climate-neutral way leads to decreasing minimum range requirements, thus allowing for the exploitation of higher flexibility potentials. Pursuing a cost-minimizing charging strategy has the opposite effect. Charging in a cost-minimizing manner does not motivate users to require lower ranges, i.e., to provide more flexibility in order to generate higher revenue potentials.

C.3.3 WTP for a two-level V2G charging tariff

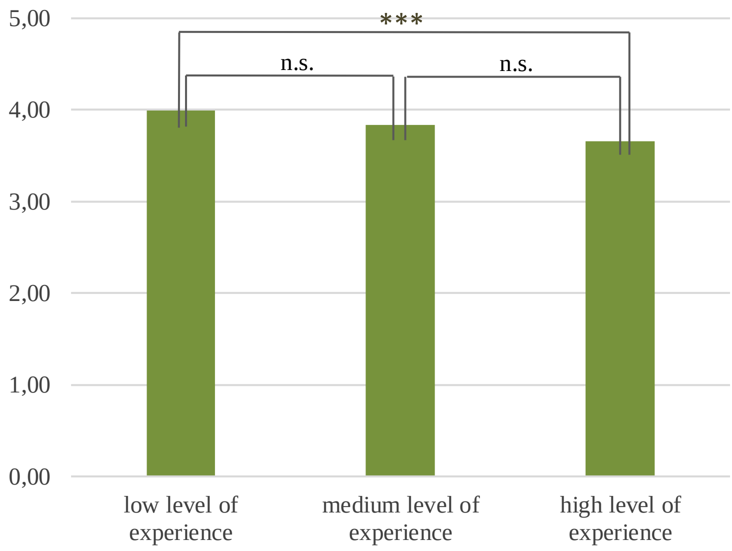
The second goal of our survey was to determine users' WTP for a V2G charging tariff. The results of the PSM are displayed in Table 6. The graphical presentation of the results of the PSM can be found in Appendix F. Table 6 shows that the optimal price for a V2G tariff is €3.05 / 100 km. Compared to the reference price, this is relatively low (-42%), i.e. users demand a high price reduction when charging in a V2G mode.

Table 6: Price for a bidirectional charging tariff depending on the level of user experience

Sample	**2nd price level of a two-price level tariff [in EUR/100km]**			
	IDP[1]	OPP[2]	MPG[3]	MDP[4]
Reference price (uncontrolled charging) €5.20 / 100km				
Total (N= 1169)	3.50 (-33%)	3.05 (-42%)	2.01	4.60
Low experience (n_{low}= 678)	3.60 (-31%)	3.40 (-35%)	2.00	5.00
Medium experience (n_{med}= 233)	3.20 (-39%)	3.00 (-43%)	2.00	5.00
High experience (n_{high}= 258)	3.10 (-41%)	3.00 (-43%)	2.00	4.16

[1] Indifference price point (IDP): Equal number of respondents rate the price point as either "cheap" or "expensive".
[2] Optimal price point (OPP): The price exceeds either the upper or lower limits of an equal number of respondents.
[3] Point of marginal cheapness (MGP): Number of respondents experiencing the tariff as "too cheap" is larger than the number of those who experience it as cheap.
[4] Point of marginal expensiveness (MDP): Number of respondents experiencing the tariff as "too expensive" is larger than the number of those who experience it as expensive.

Moreover, the WTP decreases with higher levels of user experience, while the price sensitivity, which is the difference between the IDP and the OPP, increases. The points of marginal cheapness and of marginal expensiveness describe the acceptable price range. Corresponding to the price sensitivity, the acceptable price range is greater for low and medium experienced participants (€2.00 - €5.00) than for highly experienced participants (€2.00 - €4.16). These results neglect our assumption that EV experienced participants would be willing to pay more for a V2G service, since they would be aware of possible advantages.



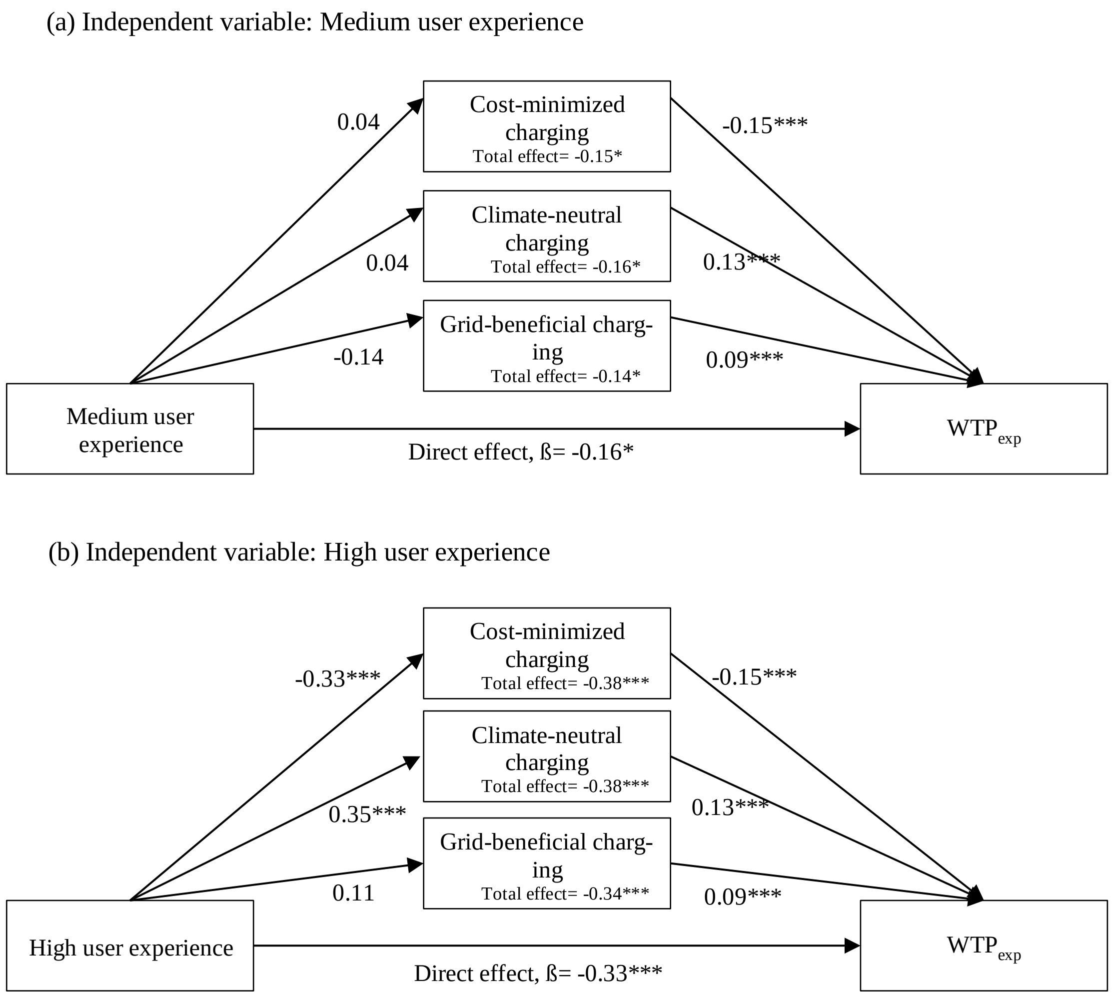
Note: p: Significance level: *$p < 0.5$; **$p < 0.01$; ***$p < 0.001$
Analysis of variance (Post-Hoc-Test: Hochberg): $F(2, 1175)= 10.93$, $p= < 0.001$

Figure 4: Willingness to pay for bidirectional charging tariff (N= 1178)

To test the hypothesis that the WTP can be explained by the level of user experience, we performed an analysis of variance (ANOVA). We tested this relationship for the value of WTP expensive (WTP_{exp}) originating from the PSM. This value reflects the users' upper limit to buy the service even though it is perceived as being expensive. The

ANOVA showed that there is only a significant effect (p= < 0.001) for high user experience on the WTP_{exp} for a V2G tariff compared to those having a low level of user experience with EVs. Moreover, the F-statistic shows with F (2, 1175)= 10.93, p= < 0.001 that this relationship can significantly be explained by the level of user experience.

To elaborate on the relationship between WTP and the level of user experience in more detail, we performed a second mediation analysis, following the procedure described in Section C.3.2. We tested the following sequence: level of user experience -> charging strategy -> WTP_{exp}. Note: Even though the mediators are displayed in one model, we carried out three separate models, for each mediator one model.



p: Significance level: *p < 0.05; **p < 0.01; ***p < 0.001

Note: Even though the mediators are displayed in one model, we carried out three separate models, for each mediator one model.

Figure 5: (a-b) Mediation analysis for X= level of user experience, M= charging strategy, Y= willingness to pay (expensive) for N= 1178

Figure 5 (a-b) depicts the effects of the mediation analysis as ß-values and values and Table 7 the indirect effects of the mediation analysis.

The standardized B-values in Note: Even though the mediators are displayed in one model, we carried out three separate models, for each mediator one model.

Figure 5 (a-b), which demonstrate the relationship between the levels of user experience and the charging strategies, were analyzed in Section C.3.2. When analyzing the relationship between the charging strategies and WTP_{exp}, we can see that this relationship is highly significant for all three charging strategies. While increasing interest for the cost-minimizing charging strategy leads to lower WTP, i.e. the wish for higher compensation, an increase in interest in a climate-neutral or grid-beneficial charging strategy leads to a higher WTP. As such, offering a cost-minimizing charging strategy raises expectations of higher revenues. There is a clear tendency that climate-neutral, and, to a lesser extent, grid-beneficial charging strategies both foster the willingness of users to pay more for such a service.

Table 7 Indirect effect of level of user experience on WTP_{exp} mediated by the three charging strategies

	Cost minimized-charging			Climate-neutral charging			Grid-beneficial charging		
		Bootstrap 95% CIs			Bootstrap 95% CIs			Bootstrap 95% CIs	
	ß (*SE*)	Lower to Upper		ß (*SE*)	Lower to Upper		ß (*SE*)	Lower to Upper	
Medium user experience	-0.006 (*0.012*)	-0.030	0.017	0.006 (*0.011*)	-0.015	0.027	-0.013 (*0.008*)	-0.033	0.001
High user experience	0.049 (*0.016*)	0.021	0.083	0.045 (*0.015*)	0.020	0.076	0.011 (*0.008*)	-0.003	0.030

Note: Confidence Intervals (CIs) are bias corrected; 10.000 bootstrap samples.

The indirect effects of the three mediation models show that two out of three charging strategies mediate the relationship between user experience and WTP_{exp}. Like the previous model (cf. Table 6), the cost-minimized (ß= 0.05, 95% BCa CI [0.02, 0.08]), as well as the climate-neutral charging strategy (ß= 0.05, 95% BCa CI [0.02, 0.08]), both appear to be significant mediators for the relationship between high user experience and WTP_{exp}. The grid-beneficial charging strategy, however, neither mediates the relationship between medium user experience and WTP_{exp}, nor for high user experience. Since we identified a sociodemographic bias between and within the groups (Section C.3.1), we tested the models under consideration of these variables as covariates. Noteworthy, while the covariates did not have any considerable effect on the mediation by the climate-neutral and the cost-minimizing charging strategy, the inclusion of gender, education and income separately as covariates impacted the indirect effect of the grid- beneficial charging strategy. The coefficients improve and the confidence intervals indicate that mediation takes place. The results are displayed in Appendix E.

C.4 Discussion

Although users' WTP for V2G and the SoC_{Min} have been examined by past studies, so far, hardly any studies have differentiated between levels of user experience and analyzed users' underlying motivations. Doing so provides information on users' expectations towards this new service, thus indicating minimum requirements. Underlying motivations assist in creating business models for future V2G tariffs. To close this gap, the paper aimed to answer the following research question: *How does EV experience influence user requirements with respect to minimum range and required savings within a V2G charging tariff and to what extent do underlying motives influence this relationship?*

The initial assumption that differences between the levels of user experience would be apparent could not be validated by the study's results. The results revealed that the SoC_{Min} values are, with an average of 199 km over the complete sample, high. Thus, expectations for the minimum charging level were high, independently of the level of user experience. The values appear especially high against the background that the average driving ranges in Germany range from 22 km in urban to 37 km in rural areas (Nobis and Kuhnimhof, 2018). On the one hand, these results are in line with previous studies, demonstrating that potential EV users are willing to pay more for additional ranges (Geske and Schumann, 2018; Hidrue and Parsons, 2015; Huang et al., 2021), emphasizing the SoC_{Min} as a precondition for participation in V2G tariffs (Ensslen et al., 2018; Huang et al., 2021). On the other hand, it raises the question as to what underlying factors drive these high estimates. We can think of four explanations: First, people expressed their objection towards V2G by stating very high values. Second, people clearly overestimated their SoC_{Min} requirements or were not able to estimate realistic values. This explanation is especially in line with the observed societal resistance to change in Bühler et al. (2014) (see Section 2.1). Third, people truly have very high SoC_{Min} requirements, or fourth, people did not understand the concept of the SoC_{Min} Independent of the possible reasons for these high values, from an aggregator's point of view, considering users' minimum range requirements implies that only low flexibility potentials can be raised due to generally high minimum range requirements.

While user experience itself cannot explain differences in SoC_{Min}, underlying motivations do. Pursuing a climate-neutral charging strategy or a cost-minimizing charging strategy mediate high user experience compared to low user experience. While a climate-neutral charging strategy leads to accepting lower SoC_{Min} values, a cost-minimizing charging strategy has the opposite effect. Whether survey participants realized the interconnection between higher flexibility potentials due to lower minimum ranges and monetary or environmental benefits is unclear. Regardless of the interconnection, environmental benefits are much more valued by EV owners, while financial benefits are less attractive to this group.

Previous studies provide different insights on the importance of the various motives that we tested to increase the user acceptance of V2G (Geske and Schumann, 2018; cf. Will and Schuller, 2016). Besides environmental, monetary or grid-related motives, the possibility to fast charge the EV can be a means to significantly achieve acceptance of lower guaranteed minimum ranges (Huang et al., 2021). This may increase the acceptance of V2G. Yet, it may also antagonize the overall objective of V2G to provide flexibility for a future reliable energy system. Complementary, Ardeshiri and Rashidi (2020) show a high acceptance, i.e. high WTP for a state-initiated fee to accelerate the installation of fast charging stations. The study by Ardeshiri and Rashidi (2020), however, did not consider V2G and the results are relevant on a policy-level, while our results are a primary concern for the energy system. Our results thus complement the existing body of literature by demonstrating that more flexibility potentials can be raised by offering a climate-neutral charging strategy which motivates EV users to accept lower minimum ranges. This insight is especially relevant from an aggregator's perspective.

Besides range requirements, we also assessed user's WTP for a V2G charging service. Assessing users' WTP for an innovative, not-yet-available service is always limited by its hypothetical character. We tried to overcome this shortcoming by including EV-experienced people in the sample, expecting more realistic estimations from this target group. Regarding WTP, the results revealed that the WTP over the complete sample is with an optimal price of €3.05 low compared to the reference price of €5.20 / 100 km. The generally low WTP (-42% over the whole sample compared to the reference price) is in line with previous research, assessing WTP for V2G attributes, finding high WTP for extra services, such as longer minimum ranges (Axsen et al., 2016; cf. Bailey and Axsen, 2015; Geske and Schumann, 2018; Huang et al., 2021). This suggests that users assign a great value to flexibility, leading to a significantly lower WTP or to a higher readiness to pay more in order to gain additional flexibility.

However, when assessing compensation to provide flexibility, the results of existing research are less consistent. In an early study, Parsons et al. (2014) found very high cash-back demands ranging from $2368 - $8622 / year (€2091 - €7613 / year) depending on the contract conditions, whereas a recent study by Lee et al. (2020) estimate a willingness to accept of $8.83 / month (€7.79 / month). A comparison of these results with our findings is limited, as vast improvements in EV and (smart) charging technology have taken place in the past years. Additionally, electricity prices and regulations differ enormously between countries. A more direct comparison is possible with the study by Kubli et al. (2018). Their results show implicit discomfort costs for varying degrees of flexibility between CHF 3.85 - CHF 45.16 / month (€3.72 - €43.71 / month) compared to an option without flexibility. The authors classify these results as moderate, which are lower than our findings for Germany.

Additionally, with regard to user experience, the results were unexpected, in that proficient users were willing to pay significantly lower electricity prices (-43%) to charge their EV than inexperienced users (-35%). EV users thus required higher compensation or, to turn the argument around, EV users expect the monetary benefits arising from V2G to be higher than inexperienced users. Bailey and Axsen (2015) obtained similar results, and point out that experienced users might be better able to estimate the value of engaging in such a charging program.

To put our results in context, a review by Sovacool et al. (2017) highlight that economic modeling studies specify monetary benefits to vary between $100 - $300 / year (€88 - €264 / year) and vehicle. Studies estimating earnings for providing regulation services state values from $85 - $2500 (€75 - €2207) (Bailey and Axsen, 2015), up to $5000 / year (€4414 / year) and vehicle (Sovacool et al., 2017). A recent study estimated a yearly revenue of €530 by combining vehicle-to-home and arbitrage trading (Kern et al., 2022). Thus, there seems to be a wide range regarding possible monetary benefits depending on the application and underlying assumptions (for a meta-analysis see Heilmann and Friedl, 2021), implying that the amount of monetary benefits harbors a great deal of uncertainty. The expectation horizon of our respondents is with regard to monetary compensation rather at the lower end, not accounting for taxes and fees, compared to the previously mentioned literature.

Furthermore, the mediation analysis revealed that a climate-neutral and a cost-minimizing charging strategy can significantly influence EV users' WTP_{exp} for a V2G charging tariff. EV users are thus willing to pay more when a climate-neutral charging strategy is pursued, while the opposite effect can be observed for a cost-minimizing charging strategy. EV users' WTP thus decreases when applying a cost-minimizing charging strategy, i.e. EV users require higher compensation compared to inexperienced users. A grid-beneficial strategy proves to be non-significant for all groups. Given these results, the question arises, how can aggregators in the future energy system account for these preferences? Generally, as Krueger and Cruden (2020) point out, accounting for user requirements puts further constraints on the aggregator, and even more so when user requirements are high, which is the case when considering the effect of the cost-minimizing charging strategy on both the SoC_{min} and WTP_{exp}. This indicates a potential conflict for aggregators to fulfill user requirements on one hand, and master the increased complexity of the power grid on the other.

Yet, fostering a climate-neutral charging strategy is preferable for both parties. EV owners clearly prefer to charge in a climate-neutral way. Moreover, this strategy incentivizes this user group to provide more flexibility and simultaneously accept lower revenues. From the perspective of an aggregator, these conditions provide more flexibility to develop a suitable business model. Moreover, from a system perspective charging in a climate-neutral way is preferable to a cost-minimizing charging strategy. This is especially due to the fact that explicit consideration of grid constraints on the transmission grid level results in less curtailment of RES compared to an economically oriented tariff design and to an economically and ecologically improved system outcome (Gunkel et al., 2020; Szinai et al., 2020). Our findings thus support previous literature suggesting to communicate and promote more intuitive advantages which subsequently benefit the grid, such as environmental benefits (Bailey and Axsen, 2015; Gunkel et al., 2020; Sloot et al., 2022; Sovacool et al., 2017; Szinai et al., 2020; Will et al., 2022).

C.5 Conclusion. Policy implications and future work

Our study aimed to improve our understanding of how user experience with EVs influences users' WTP for a V2G charging tariff and SoC_{Min} requirements in Germany. Moreover, we investigated the role of underlying motivations, guiding users' evaluation thereof. Our research design allowed us to compare the perspectives of EV-experienced users, medium-experienced users, and people who did not have any experience yet with EVs.

Our results show that SoC_{Min} requirements are high compared to average daily driving distances in Germany. Furthermore, WTP values were low compared to the reference price. These results are true for all three levels of user experience. In general, people seem to have high mobility requirements on the one hand and high discount expectations on the other, making it difficult for aggregators to offer profitable business models. Differences between the levels of user experience and WTP and SoC_{Min} became visible, when including underlying motivations as a mediating variable in our analysis. While charging in a climate-neutral way leads to a higher readiness of EV owners compared to people with no EV experience to accept higher prices and lower minimum ranges, charging in a cost-minimized manner has the opposite effect. We thus recommend that future charging tariffs should especially promote climate-neutral charging strategies, as these are clearly the most accepted strategies by users and provide the best possible benefit and highest flexibility potential to aggregators. Moreover, by pursuing climate-neutral charging strategies, operators would be able to better align the integration of RES and grid stability.

Our results thus provide further insights into user motivations to participate in a V2G tariff, highlighting the importance of fostering RES integration to agree to lower SoC_{Min} and higher WTP. Concerning the grid-beneficial charging strategy, no mediating effects are observable. Yet, this charging strategy is of high importance to increase the overall system reliability, which is especially true against the background of the government's plans to further increase the RES capacity in Germany within the next decade. The users' indifference towards the grid-beneficial charging strategy, however, challenges policy makers who aim to foster system-integrative and sustainable solutions to meet the government's goals. The same is true for other countries pursuing the pathway to decarbonisation. Therefore, raising awareness of V2G's potential to benefit grid congestion and carbon intensity appears essential. Based on our results, we recommend communication and promotion of more intuitive advantages that indirectly also benefit the grid infrastructures, such as environmental benefits. A lot of effort is required to challenge the balancing act to fulfil system services and comply with regulatory frameworks while meeting user requirements when designing convincing charging strategies. To this end, stakeholder-specific communication and services are needed, as well as clear regulatory frameworks.

To overcome the hypothetical character of assessing V2G charging tariffs, we specifically targeted EV-experienced people, expecting more realistic estimations. To assess users' real WTP for a V2G charging tariff, future research could conduct field studies with pilot customers.

Moreover, considering battery aging within a V2G service would be another interesting aspect for future research when assessing questions on range and willingness to pay. Finally, due to a regulatory gap in Germany on selling electricity within a V2G service, we solely focused on the net-purchasing price to charge the EV. Recently, as part of a newly passed law to promote RES in Germany, the German parliament also decided on §14a EnWG, which regulates how to deal with the grid-serving control of controllable consumer devices and controllable grid connections, including bidirectionally chargeable EVs (Federal Ministry of Ecomonic Affairs and Climate Action, in charge, 2022). Future work could thus integrate and evaluate this new regulatory framework in a V2G tariff scheme.

Finally, our results revealed that experienced EV users' motivations could be raised by offering a climate-neutral charging strategy. Further research needs to specifically target the group of people without EV experience in order to achieve the ambitious EV goals worldwide. Moreover, the importance of different charging strategies could be evaluated in more detail. The question of which benefits could be raised from an aggregator's perspective by pursuing different V2G charging strategies while accounting for user requirements with low EV experience could be subject for further research.

CRediT author statement:

Nora Baumgartner: Conceptualization; Formal analysis; Methodology; Software; Validation; Visualization; Writing - original draft; **Franziska Kellerer**: Conceptualization; Data curation; Investigation; Methodology; Validation; Writing - review & editing; **Manuel Ruppert**: Project administration; Supervision; Writing - review & editing; **Sebastian Hirsch**: Methodology, Writing - review & editing; **Stefan Mang**: Funding acquisition; Project administration; Resources; Supervision; Writing - review & editing; **Wolf Fichtner**: Funding acquisition; Project administration; Supervision; Writing - review & editing;

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

APPENDIX A Forums and platforms for purposive sampling

Forum and platform	Group name	Web address
GoingElectric		https://www.goingelectric.de/forum/
Motor Talk		https://www.motor-talk.de/
Tesla Fahrer und Freunde		https://tff-forum.de/
Elektromobilität Diskussionsforum		https://www.elektromobilitaet-forum.de/
Elektroauto Community		https://www.elektroauto.community/
Elektroauto Forum		https://elektroauto-forum.de/
Photovoltaik Forum		https://www.photovoltaik-forum.com/
Facebook	BMW i3 Freunde Elektromobilität D/A/CH Elektromobilität heute Ich fahre Elektroauto Pro Elektromobilität. Pro BEV Elektroauto 2.0	https://www.facebook.com/
AutoExtrem		https://www.autoextrem.de/forums/
Forum für alternative Antriebe		https://forum-alternative-antriebe.de/
eVW-Forum - E-Fahrzeuge von VW		https://evw-forum.de/
XING	Neue Mobilität Europäisches Netzwerk Elektromobilität Elektromobilität - Die Zukunft fährt elektrisch Ladeinfrastruktur Elektromobilität Elektromobilität	https://goto.xing.com/mach-dein-xing?experiment=abacus-108
BHKW-Forum - Das Prosumer Netzwerk für mehr Effizienz im Heizungskeller		https://www.bhkw-forum.de/diskussion/

APPENDIX B. Survey questions for assessing users' minimum range (SoCSR) requirements

Question F01. Mr. Meier now sets the desired minimum range using his charging app.

Please put yourself in Mr. Meier's position. How many kilometers should your electric car always be able to cover in unpredictable cases, for example in emergency situations?

Please think of the range with which you would just feel safe.

…Kilometer

Appendix C. Survey questions for assessing users' willingness to pay for a V2G charging tariff according to the Price Sensitivity Meter (PSM)

Question F02. Please put yourself in Mr. Meier's place at contract conclusion. In the first charging phase (uncontrolled immediate charging), the price for charging your electric car is 5.20 euros per 100 km range. You are now considering how much charging in the second charging phase, bidirectional charging, will cost you.

Please enter a price in the format *.** € below. Assume that the maximum costs per 100 km range can be as high as in the first charging phase (€5.20).

At what average price per 100 km of range would you consider bi-directional charging...

... find it too expensive, i.e., you would definitely look for a cheaper tariff? ☐ € per 100 km range (charging phase 2)
...feel expensive and you would only conclude the contract after careful consideration? ☐ € per 100 km range (charging phase 2)
... feel cheap, i.e., the tariff would be a bargain? ☐ € per 100 km range (charging phase 2)
... feel too cheap, i.e., you have doubts about the seriousness of the tariff? ☐ € per 100 km range (charging phase 2)

Appendix D. Survey questions for assessing users' preferred charging strategy

Question F03. Mr. Meier has the additional option, as part of the tariff agreement, of specifying criteria to be used for charging in the second, bidirectional phase.

Please decide how important the following criteria would be to you.

Please allocate a total of 100 points to the corresponding aspects. Give the most points to the criterion that you consider most important.

- ❒ Charging as cost-minimized as possible __ Points
- ❒ Charging as climate-neutral as possible (= high share of renewable energy sources) __ Points

Making the greatest possible contribution to grid stabilization __ Points

Appendix E. Comparison of results of mediation analysis with and without covariates

Variable names

X	user experience (SD05_auf)
x1	medium user experience
x2	high user experience
Y	min SoC (F01)
M	cost-minimized charging (F03_1), climate-neutral charging (F03_2), grid-beneficial charging (F03_3)
Covariate	salary (SD10), education (SD08_neu), gender (SD01)

p: Significance level: *p < 0.05; **p < 0.01; ***p < 0.001

Mediation analysis for cost-optimized charging

	ß without Covariate		**Mediation with covariate SD10**		**Mediation with covariate SD08_neu**		**Mediation with covariate SD01**	
Model summary: outcome variable M								
	R^2=0.019, F=11.657, p<0.000		R^2=0.019, F=7.824, p<0.000		R^2=0.019, F=7.768, p<0.000		R^2=0.025, F=10.328, p<0.000	
	ß	p	ß	p	ß	p	ß	p
x1	0.026	0.726	0.026	p=0.725	0.026	p=0.726	0.001	p=0.989
x2	-0.326***	0.000	-0.326***	p=<0.000	-0.326***	p<0.000	-0.386***	p<0.000
Covariate			0.012	p=0.678	-0.003	p=0.923	-0.082**	p=0.006
Model summary: outcome variable Y								
	R^2=0.019, F=7.673, p<0.000		R^2=0.020, F=5.985, p<0.000		R^2=0.019, F=5.763, p<0.000		R^2=0.225, F=6.857, p<0.000	
	ß	p	ß	p	ß	p	ß	p
x1	0.061	p=0.414	0.061	p=0.412	0.061	p=0.415	0.042	p=0.576
x2	-0.051	p=0.485	-0.051	p=0.478	-0.052	p=0.476	-0.098	p=0.196
M	0.129***	p<0.000	0.129***	p<0.000	0.129***	p<0.000	0.124***	p<0.000
Covariate			0.028	p=0.337	0.070	p=0.818	-0.063*	p=0.037

Total effect model

	R^2=0.003, F=1.593, p=0.204		R^2=0.0035, F=1.3997, p=0.2413		R^2=0.0027, F=1.0769, p=0.3578		R^2=0.0075, F=3.0082, p=0.0294	
	ß	p	ß	p	ß	p	ß	p
x1	0.064	p=0.3924	0.064	p=0.390	0.064	p=0.393	0.042	p=0.578
x2	-0.093	p=0.201	-0.093	p=0.197	-0.094	p=0.197	-0.146*	p=0.054
Covariate			0.029	p=0.315	0.006	p=0.829	-0.073*	p=0.016

Indirect effect

	ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper	
x1	0.003	-0.016	0.025	0.003	-0.016	0.024	0.003	-0.016	0.024	0.000	-0.019	0.079
x2	-0.042	-0.075	-0.018	-0.419	-0.073	-0.017	-0.042	-0.073	-0.017	-0.048	-0.083	-0.020

Mediation analysis for climate-neutral charging

	ß without Covariate		**Mediation with covariate SD10**		**Mediation with covariate SD08_neu**		**Mediation with covariate SD01**	
Model summary: outcome variable M								
	R^2=0.020, F=11.892, p<0.000		R^2=0.020, F=7.956, p<0.000		R^2=0.020, F=8.077, p<0.000		R^2=0.025, F=10.347, p<0.000	
	ß	p	ß	p	ß	p	ß	p
x1	0.040	p=0.592	0.040	p=0.591	0.040	p=0.594	0.064	p=0.390
x2	0.345***	p<0.000	0.345***	p<0.000	0.342***	p<0.000	0.404***	p<0.000
Covariate			0.009	p=0.750	0.019	p=0.503	0.080**	p=0.008

Model summary: outcome variable Y

	R^2=0.023, F=9.372, p<0.000		R^2=0.024, F=7.312, p=0.000		R^2=0.023, F=7.049, p<0.000		R^2=0.265, F=8.011, p=0.000	
	ß	p	ß	p	ß	p	ß	p
x1	0.067	p=0.346	0.070	p=0.344	0.070	p=0.347	0.051	p=0.496
x2	-0.043	p=0.554	-0.044	p=0.548	-0.044	p=0.450	-0.089	p=0.237
M	-0.144***	p<0.000	-0.145***	p<0.000	-0.144***	p<0.000	-0.140***	p<0.000
Covariate			0.034	p=0.288	0.009	p=0.753	-0.062*	p=0.040

Total effect model

	R^2=0.003, F=1.593, p=0.204		R^2=0.004, F=1.400, p=0.241		R^2=0.003, F=7.077, p=0.358		R^2=0.008, F=3.008, p=0.029	
	ß	p	ß	p	ß	p	ß	p
x1	0.064	p=0.321	0.064	p=0.390	0.064	p=0.393	0.042	p=0.578
x2	-0.093	p=0.201	-0.093	p=0.197	-0.094	p=0.197	-0.146*	p=0.054
Covariate			0.029	p=0.315	0.006	p=0.829	-0.073*	p=0.016

Indirect effect

	ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper	
x1	-0.006	-0.029	0.017	-0.002	-0.029	0.016	-0.006	-0.029	0.017	-0.009	-0.031	0.012
x2	-0.050	-0.082	-0.024	-0.050	-0.082	-0.024	-0.049	-0.081	-0.023	-0.056	-0.092	-0.028

Mediation analysis for grid-beneficial charging

	ß without Covariate		**Mediation with covariate SD10**		**Mediation with covariate SD08_neu**		**Mediation with covariate SD01**	
Model summary: outcome variabel M								
	R^2=0.005, F=3.103, p=0.045		R^2=0.007, F=2.594, p=0.051		R^2=0.006, F=2.279, p=0.080		R^2=0.007, F=2.62, p=0.049	
	ß	p	ß	p	ß	p	ß	p
x1	-0.108	p=0.147	-0.109	p=0.146	-0.108	p=0.148	-0.097	p=0.200
x2	0.113	p=0.118	0.114	p=0.115	0.117	p=0.106	0.141	p=0.061
Covariate			-0.036	p=0.210	-0.023	p=0.426	0.039	p=0.198
Model summary: outcome variable Y								
	R^2=0.004, F=1.489, p=0.216		R^2=0.005, F=1.350, p=0.249		R^2=0.004, F01.125, p=0.343		R^2=0.008, F=2.529, p=0.039	
	ß	p	ß	p	ß	p	ß	p
x1	0.061	p=0.419	0.061	p=0.416	0.060	p=0.420	0.039	p=0.605
x2	-0.089	p=0.230	-0.090	p=0.216	-0.090	p=0.216	-0.142	p=0.061
M	-0.033	p=0.258	-0.032	p=0.274	-0.033	p=0.261	-0.030	p=0.297
Covariate			0.028	p=0.334	0.006	p=0.849	-0.072*	p=0.018
Total effect model								
	R^2=0.003, F=1.593, p=0.204		R^2=0.004, F=1.400, p=0.241		R^2=0.003, F=1.077, p=0.358		R^2=0.008, F=3.008, p=0.029	
	ß	p	ß	p	ß	p	ß	p
x1	0.064	p=0.392	0.064	p=0.390	0.064	p=0.393	0.042	p=0.58
x2	-0.093	p=0.201	-0.093	p=0.197	-0.094	p=0.196	-0.146*	p=0.054
Covariate			0.029	p=0.315	0.006	p=0.829	-0.073*	p=0.016

Indirect effect

	ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper	
x1	0.004	-0.004	0.016	0.004	-0.004	0.016	0.004	-0.004	0.016	0.003	-0.460	0.015
x2	-0.004	-0.016	0.004	-0.004	-0.016	0.004	-0.003	-0.016	0.004	-0.004	-0.018	0.005

Variable names

X	user experience (SD05_auf)
x1	medium user experience
x2	high user experience
Y	WTP expensive (F02_2)
M	cost-minimized charging (F03_1), climate-neutral charging (F03_2), grid-beneficial charging (F03_3)
Covariate	salary (SD10), education (SD08_neu), gender (SD01)

p: Significance level: *p < 0.05; **p < 0.01; ***p < 0.001

Cost-optimized charging

	ß without Covariate		**Mediation with covariate SD10**		**Mediation with covariate SD08_neu**		**Mediation with covariate SD01**	
Model summary: outcome variable M								
	R^2=0.020, F=11.913, p<0,000		R^2=0.020, F=7.956, p<0,000		R^2=0.020 F=7.938, p<0,000		R^2=0.026, F=10.516, p<0,000	
	ß	p	ß	p	ß	p	ß	p
x1	0.042	p=0.576	0.042	p=0.576	0.042	p=0.560	0.017	p=0.818
x2	-0.326***	p<0.000	-0.326***	p<0.000	-0.325***	p<0.000	-0.387***	p<0.000
Covariate			0.007	p=0.804	-0.003	p=0.932	-0.083**	p=0.006

Model summary: outcome variable Y

	R^2=0.040, F=16.405, p<0,000		R^2=0.041, F=12.678, p<0.000		R^2=0.040, F=12.358, p<0.000		R^2=0.050, F=15.487, p<0.000	
	ß	p	ß	p	ß	p	ß	p
x1	-0.152*	p=0.041	-0.152*	p=0.041	-0.151*	p=0.042	-0.121	p=0.105
x2	-0.380***	p<0.000	-0.378***	p<0.000	-0.377***	p<0.000	-0.300***	p<0.000
M	-0.150***	p<0.000	-0.149***	p<0.000	-0.150***	p<0.000	-0.142***	p=0.000
Covariate			-0.035	p=0.224	-0.014	p=0.617	0.105***	p<0.000

Total effect model

	R^2=0.018, F=10.938, p<0.000		R^2=0,020, F=7.807, p<0.000		R^2=0.019, F=7.365, p<0.000		R^2=0.031, F=12.371, p<0.000	
	ß	p	ß	p	ß	p	ß	p
x1	-0.158*	p=0.036	-0.158*	p=0.036	-0.158*	p=0.036	-0.123	p=0.101
x2	-0.331***	p<0.000	-0.330***	p<0.000	-0.328***	p<0.000	-0.246***	p=0.001
Covariate			-0.036	p=0.215	-0.014	p=0.630	0.115***	p<0.000

Indirect effect

	ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper	
x1	-0.006	-0.303	0.017	-0.006	-0.031	0.016	-0.006	-0.031	0.0162	-0.002	-0.025	0.0194
x2	0.049	0.022	0.083	0.049	0.022	0.082	0.049	0.021	0.082	0.055	0.026	0.0923

Climate-neutral charging

	ß without Covariate		**Mediation with covariate SD10**		**Mediation with covariate SD08_neu**		**Mediation with covariate SD01**	
Model summary: outcome variable M								
	R^2=0.020, F=11.808, p<0.000		R^2=0.020, F=7.924, p<0.000		R^2=0.020, F08.011, p<0.000		R^2=0.025, F=10.215, p<0.000	
	ß	p	ß	p	ß	p	ß	p
x1	0.042	p=0.576	0.042	p=0.576	0.042	p=0.578	0.066	p=0.385
x2	0.346***	p<0.000	0.346***	p<0.000	0.343***	p<0.000	0.404***	p<0.000
Covariate			0.012	p=0.678	0.079	p=0.513	0.079**	p=0.009
Model summary: outcome variable Y								
	R^2=0.035, F=14.145, p<0.000		R^2=0.036, F=11.040, p<0.000		R^2=0.035, F=10.684, p<0.000		R^2=0.045, F=13.887, p<0.000	
	ß	p	ß	p	ß	p	ß	p
x1	-0.163*	p=0.028	-0.163*	p=0.028	-0.163*	p=0.029	-0.131	p=0.079
x2	-0.376***	p<0.000	-0.375***	p<0.000	-0.373***	p<0.000	-0.295***	p<0.000
M	0.130***	p<0.000	0.131***	p<0.000	0.131***	p<0.000	0.122***	p<0.000
Covariate			-0.037	p=0.192	-0.017	p=0.567	0.0107***	p<0.000
Total effect model								
	R^2=0.018, F=10.938, p<0.000		R^2=0.020, F=7.807, p<0.000		R^2=0.019, F=7.365, p<0.000		R^2=0.031, F=12.371, p<0.000	
	ß	p	ß	p	ß	p	ß	p
x1	-0.158*	p=0.036	-0.158*	p=0.036	-0.158*	p=0.036	-0.123	p=0.101
x2	-0.331***	p<0.000	-0.330***	p<0.000	-0.328***	p<0.000	-0.246***	p=0.001
Covariate			-0.036	p=0.215	-0.014	p=0.630	0.116***	p<0.000

Indirect effect

	ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper	
x1	0.006	-0.015	0.027	0.006	-0.015	0.028	0.005	-0.016	0.0273	0.008	-0.011	0.030
x2	0.045	0.020	0.076	0.045	0.020	0.077	0.045	0.019	0.076	0.049	0.022	0.083

Grid-beneficial charging

	ß without Covariate		**Mediation with covariate SD10**		**Mediation with covariate SD08_neu**		**Mediation with covariate SD01**	
Model summary: outcome variable M								
	R^2=0.007, F=4.051, p=0018		R^2=0,020, F=7.956, p<0.000		R^2=0.020, F=7.938, p<0.000		R^2=0.026, F=10.516, p<0.000	
	ß	p	ß	p	ß	p	ß	p
x1	-0.142	p=0.060	0.042	p=0.576	0.042	p=0.576	0.017	p=0.818
x2	0.113	p=0.120	-0.326***	p<0.000	-0.325***	p<0.000	-0.387***	p<0.000
Covariate			0.007	p=0.804	-0.003	p=0.932	-0.083**	p=0.006

Model summary: outcome variable Y

	R^2=0.027, F=10.795, p<0.000		R^2=0.041, F=12.678, p<0.000		R^2=0.040, F=12.358, p<0.000		R^2=0.050, F=15.487, p<0.000	
	ß	p	ß	p	ß	p	ß	p
x1	-0.145*	p=0.054	-0.152*	p=0.041	-0.151*	p=0.043	-0.121	p=0.105
x2	-0.341***	p<0.000	-0.378***	p<0.000	-0.377***	p<0.000	-0.300***	p<0.000
M	0.093***	p=0.001	-0.149***	p<0.000	-0.150***	p<0.000	-0.142***	p<0.000
Covariate			-0.035	p=0.224	-0.0144	p=0.617	0.105***	p<0.000

Total effect model

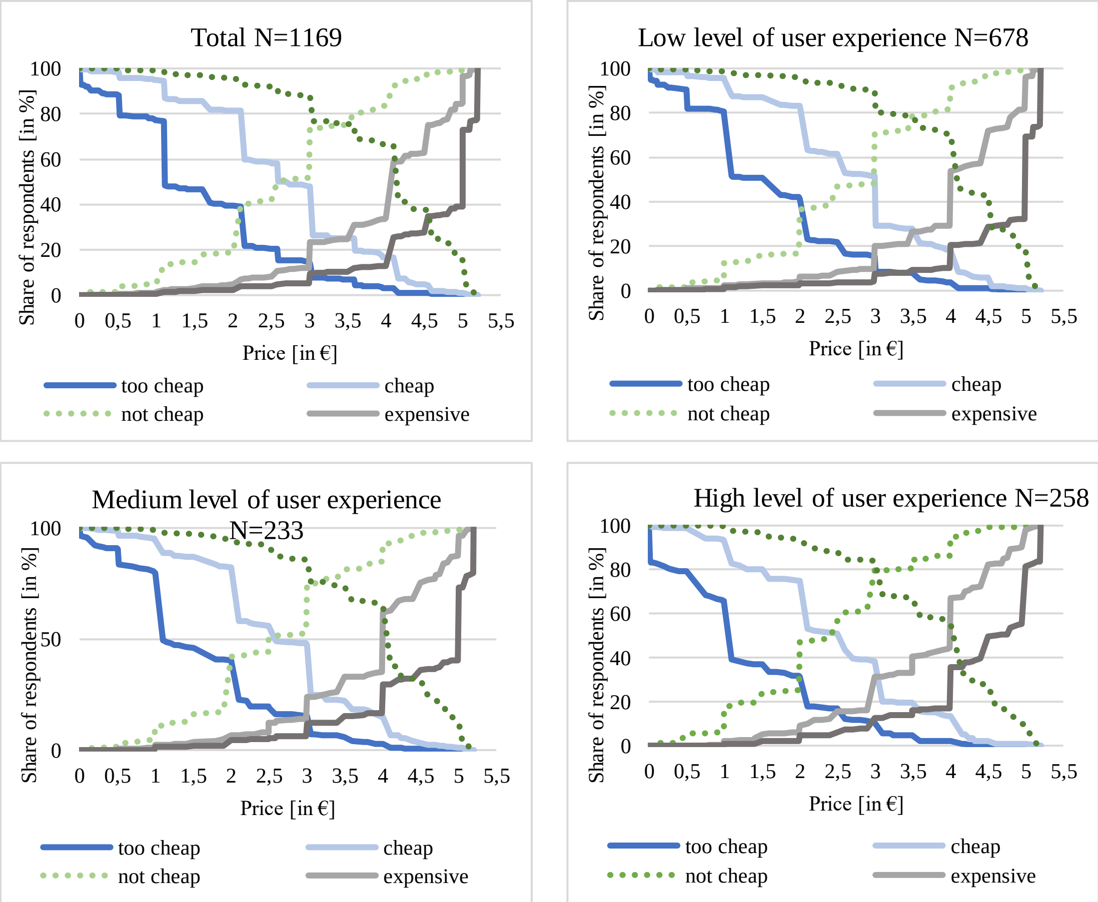
	R^2=0.018, F=10.938, p<0.000		R^2=0.020, F=7.0807, p<0.000		R^2=0.019, F=7.365, p=0,001		R^2=0.031, F=12.371, p<0.000	
	ß	p	ß	p	ß	p	ß	p
x1	-0.158*	p=0.036	-0.158*	p=0.036	-0.158*	p=0.036	-0.123	p=0.101
x2	-0.331***	p<0.000	-0.330***	p<0.000	-0.326***	p<0.000	-0.246***	p=0.001
Covariate			-0.036	p=0.215	-0.014	p=0.630	0.116***	p<0.000

Indirect effect

	ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper		ß	Bootstrap 95% CIs Lower to Upper	
x1	-0.013	-0.033	0.0013	-0.006	-0.030	0.016	-0.006	-0.031	0.017	-0.003	-0.025	0.019
x2	0.011	-0.003	0.0302	0.049	0.022	0.083	0.049	0.021	0.083	0.055	0.026	0.092

APPENDIX F. Willingness to pay for a V2G charging tariff according to the Price Sensitivity Meter (PSM)

Willingness to Pay (WTP) for a bidirectional charging tariff



References

Al-Obaidi, A., Khani, H., Farag, H.E., Mohamed, M., 2021. Bidirectional smart charging of electric vehicles considering user preferences, peer to peer energy trade, and provision of grid ancillary services. International Journal of Electrical Power & Energy Systems 124, 106353. https://doi.org/10.1016/j.ijepes.2020.106353.

Ardeshiri, A., Rashidi, T.H., 2020. Willingness to pay for fast charging station for electric vehicles with limited market penetration making. Energy Policy 147, 111822. https://doi.org/10.1016/j.enpol.2020.111822.

Axsen, J., Goldberg, S., Bailey, J., 2016. How might potential future plug-in electric vehicle buyers differ from current "Pioneer" owners? Transportation Research Part D: Transport and Environment 47, 357–370. https://doi.org/10.1016/j.trd.2016.05.015.

Babrowski, S., Heinrichs, H., Jochem, P., Fichtner, W., 2014. Load shift potential of electric vehicles in Europe. Journal of Power Sources 255, 283–293. https://doi.org/10.1016/j.jpowsour.2014.01.019.

Bailey, J., Axsen, J., 2015. Anticipating PEV buyers' acceptance of utility controlled charging. Transportation Research Part A: Policy and Practice 82, 29–46. https://doi.org/10.1016/j.tra.2015.09.004.

Bañol Arias, N., Hashemi, S., Bach Andersen, P., Træholt, C., Romero, R., 2020. Assessment of economic benefits for EV owners participating in the primary frequency regulation markets. International Journal of Electrical Power & Energy Systems 120, 1–26. https://doi.org/10.1016/j.ijepes.2020.105985.

Baron, R.M., Kenny, D.A., 1986. The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. Journal of Personality and Social Psychology 51, 1173–1182. https://doi.org/10.1037/0022-3514.51.6.1173.

Bauman, J., Stevens, M.B., Hacikyan, S., Tremblay, L., Mallia, E., Mendes, C.J., 2016. Residential Smart-Charging Pilot Program in Toronto: Results of a Utility Controlled Charging Pilot. WEVJ 8, 531–542. https://doi.org/10.3390/wevj8020531.

Baumgartner, N., Kellerer Franziska, RUPPERT, M., HIRSCH, S., Mang, Stefan, Fichtner, Wolf, 2022. Does experience matter? Assessing user motivations to accept a vehicle-to-grid charging tariff. Transportation Research Part D: Transport and Environment 113, 103528. https://doi.org/10.1016/j.trd.2022.103528.

Bishop, J.D., Axon, C.J., Bonilla, D., Banister, D., 2016. Estimating the grid payments necessary to compensate additional costs to prospective electric vehicle owners who provide vehicle-to-grid ancillary services. Energy 94, 715–727. https://doi.org/10.1016/j.energy.2015.11.029.

Blumberg, G., Broll, R., Weber, C., 2022. The impact of electric vehicles on the future European electricity system – A scenario analysis. Energy Policy 161, 112751. https://doi.org/10.1016/j.enpol.2021.112751.

Breidert, C., Hahsler, M., Reutterer, T., 2006. A Review of Methods for Measuring Willingness-to-Pay. Innovative Marketing 2, 8–31.

Brown, T.C., Champ, P.A., Bishop, R.C., McCollum, D.W., 1996. Which Response Format Reveals the Truth about Donations to a Public Good? Land Economics 72, 152. https://doi.org/10.2307/3146963.

Bühler, F., Cocron, P., Neumann, I., Franke, T., Krems, J.F., 2014. Is EV experience related to EV acceptance? Results from a German field study. Transportation Research Part F: Traffic Psychology and Behaviour 25, 34–49. https://doi.org/10.1016/j.trf.2014.05.002.

Chen, C., Zarazua de Rubens, G., Noel, L., Kester, J., Sovacool, B.K., 2020. Assessing the socio-demographic, technical, economic and behavioral factors of Nordic electric vehicle adoption and the influence of vehicle-to-grid preferences. Renewable and Sustainable Energy Reviews 121, 1–13. https://doi.org/10.1016/j.rser.2019.109692.

Conrad, F.G., Couper, M.P., Tourangeau, R., Zhang, C., 2017. Reducing speeding in web surveys by providing immediate feedback. Survey research methods 11, 45–61. https://doi.org/10.18148/srm/2017.v11i1.6304.

Das, H.S., Rahman, M.M., Li, S., Tan, C.W., 2020. Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review. Renewable and Sustainable Energy Reviews 120, 109618. https://doi.org/10.1016/j.rser.2019.109618.

Delmonte, E., Kinnear, N., Jenkins, B., Skippon, S., 2020. What do consumers think of smart charging? Perceptions among actual and potential plug-in electric vehicle adopters in the United Kingdom. Energy Research & Social Science 60, 1–12. https://doi.org/10.1016/j.erss.2019.101318.

Dixon, J., Bukhsh, W., Edmunds, C., Bell, K., 2020. Scheduling electric vehicle charging to minimise carbon emissions and wind curtailment. Renewable Energy 161, 1072–1091. https://doi.org/10.1016/j.renene.2020.07.017.

Doluweera, G., Hahn, F., Bergerson, J., Pruckner, M., 2020. A scenario-based study on the impacts of electric vehicles on energy consumption and sustainability in Alberta. Applied Energy 268, 114961. https://doi.org/10.1016/j.apenergy.2020.114961.

Dudenhöffer, K., 2015. Akzeptanz von Elektroautos in Deutschland und China: Eine Untersuchung von Nutzungsintentionen im Anfangsstadium der Innovationsdiffusion. Zugl.: Duisburg-Essen, Univ., Diss., 2014. Springer Gabler, Wiesbaden, 398 pp.

Emodi, N.V., Dwyer, S., Nagrath, K., Alabi, J., 2022. Electromobility in Australia: Tariff Design Structure and Consumer Preferences for Mobile Distributed Energy Storage. Sustainability 14, 6631. https://doi.org/10.3390/su14116631.

Ensslen, A., Ringler, P., Dörr, L., Jochem, P., Zimmermann, F., Fichtner, W., 2018. Incentivizing smart charging: Modeling charging tariffs for electric vehicles in German and French electricity markets. Energy Research & Social Science 42, 112–126. https://doi.org/10.1016/j.erss.2018.02.013.

European Association for Storage of Energy, 2019. Energy Storage: A Key Enabler for the Decarbonisation of the Transport Sector. EASE Position Paper on Energy Storage and Mobility, Brussels, 27 pp.

Federal Ministry of Ecomonic Affairs and Climate Action, 2022. Amendment of the Energy Industry Act (EnWG), in: German Government (Ed.), Act on Immediate Measures for Accelerated Expansion of Renewable Energies and Further Measures in the Electricity Sector. Federal Gazette Publisher, Bonn, pp. 1304–1306.

Federal Motor Transport Authority, 2022. Share of electric cars in the passenger car fleet in Germany from 2012 to 2022. https://de.statista.com/statistik/daten/studie/784986/umfrage/marktanteil-von-elektrofahrzeugen-in-deutschland/ (accessed 22 March 2022).

Federal Statistical Office of Germany, 2019. GENESIS database: Tables 12411-0005, 12411-0003, 12411-0005. https://www-genesis.destatis. (accessed 23 March 2022).

Field, A., 2018. Discovering statistics using IBM SPSS statistics, 5th ed. SAGE, Los Angeles, London, New Delhi, Singapore, Washington DC, Melbourne, 1070 pp.

Franke, T., Krems, J.F., 2013. Interacting with limited mobility resources: Psychological range levels in electric vehicle use. Transportation Research Part A: Policy and Practice 48, 109–122. https://doi.org/10.1016/j.tra.2012.10.010.

Franke, T., Schmalfuß, F., Rauh, N., 2018. Human Factors and Ergonomics in the Individual Adoption and Use of Electric Vehicles, in: Thatcher, A., Yeow, P.H. (Eds.), Ergonomics and Human Factors for a Sustainable Future. Springer Singapore, Singapore, pp. 135–160.

German Central Bank, 2022. Exchange rate statistic. https://www.bundesbank.de/resource/blob/804114/c8ba38f87cc0bde396b81fa5ac9b755c/mL/ii-euro-referenzkurse-der-ezb-data.pdf (accessed 2 November 2022).

German Federal Ministry of Economic Affairs and Energy, 2021. Gesamtausgabe der Energiedaten - Datensammlung des BMWi. https://www.bmwi.de/Redaktion/EN/Artikel/Energy/energy-data.html (accessed 14 July 2021).

Geske, J., Schumann, D., 2018. Willing to participate in vehicle-to-grid (V2G)? Why not! Energy Policy 120, 392–401. https://doi.org/10.1016/j.enpol.2018.05.004.

Gough, R., Dickerson, C., Rowley, P., Walsh, C., 2017. Vehicle-to-grid feasibility: A techno-economic analysis of EV-based energy storage. Applied Energy 192, 12–23. https://doi.org/10.1016/j.apenergy.2017.01.102.

Gunkel, P.A., Bergaentzlé, C., Græsted Jensen, I., Scheller, F., 2020. From passive to active: Flexibility from electric vehicles in the context of transmission system development. Applied Energy 277, 115526. https://doi.org/10.1016/j.apenergy.2020.115526.

Hayes, A.F., Preacher, K.J., 2014. Statistical mediation analysis with a multicategorical independent variable. The British journal of mathematical and statistical psychology 67, 451–470. https://doi.org/10.1111/bmsp.12028.

Hayes, A.F., Scharkow, M., 2013. The relative trustworthiness of inferential tests of the indirect effect in statistical mediation analysis: does method really matter? Psychological science 24, 1918–1927. https://doi.org/10.1177/0956797613480187.

Heilmann, C., Friedl, G., 2021. Factors influencing the economic success of grid-to-vehicle and vehicle-to-grid applications—A review and meta-analysis. Renewable and Sustainable Energy Reviews 145, 111115. https://doi.org/10.1016/j.rser.2021.111115.

Hidrue, M.K., Parsons, G.R., 2015. Is there a near-term market for vehicle-to-grid electric vehicles? Applied Energy 151, 67–76. https://doi.org/10.1016/j.apenergy.2015.04.051.

Hidrue, M.K., Parsons, G.R., Kempton, W., Gardner, M.P., 2011. Willingness to pay for electric vehicles and their attributes. Resource and Energy Economics 33, 686–705. https://doi.org/10.1016/j.reseneeco.2011.02.002.

Hofstetter, R., Miller, K.M., 2009. Precision pricing: Measuring consumers' willingness to pay accurately. Zugl.: Bern, Univ., Diss., 2008. Books on Demand, Norderstedt, 280 pp.

Huang, B., Meijssen, A.G., Annema, J.A., Lukszo, Z., 2021. Are electric vehicle drivers willing to participate in vehicle-to-grid contracts? A context-dependent stated choice experiment. Energy Policy 156, 112410. https://doi.org/10.1016/j.enpol.2021.112410.

Huber, J., Schaule, E., Jung, D., Weinhardt, C., 2019. Quo Vadis Smart Charging? A Literature Review and Expert Survey on Technical Potentials and User Acceptance of Smart Charging Systems. WEVJ 10, 85. https://doi.org/10.3390/wevj10040085.

IEA, International Energy Agency. Global EV Outlook 2021: Accelerating ambitions despite the pandemic, 101 pp. https://iea.blob.core.windows.net/assets/ed5f4484-f556-4110-8c5c-4ede8bcba637/GlobalEVOutlook2021.pdf (accessed 27 July 2021).

Jensen, A.F., Cherchi, E., Mabit, S.L., 2013. On the stability of preferences and attitudes before and after experiencing an electric vehicle. Transportation Research Part D: Transport and Environment 25, 24–32. https://doi.org/10.1016/j.trd.2013.07.006.

Kellerer, F., Zimmermann, J., Hirsch, S., forthcoming, 2022. Creating and sustaining user engagement in bidirectional charging., in: Powertrains and Energy Systems of Tomorrow. 16th International MTZ Congress Powertrains and Energy Systems of Tomorrow 2022, Berlin, Germany. 10th - 11th of May.

Kempton, W., Letendre, S.E., 1997. Electric Vehicles as a new Power Source for Electric Utilities. Transportation Research Part D: Transport and Environment 2, 157–175.

Kempton, W., Tomić, J., 2005a. Vehicle-to-grid power fundamentals: Calculating capacity and net revenue. Journal of Power Sources 144, 268–279. https://doi.org/10.1016/j.jpowsour.2004.12.025.

Kempton, W., Tomić, J., 2005b. Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy. Journal of Power Sources 144, 280–294. https://doi.org/10.1016/j.jpowsour.2004.12.022.

Kern, T., Dossow, P., Morlock, E., 2022. Revenue opportunities by integrating combined vehicle-to-home and vehicle-to-grid applications in smart homes. Applied Energy 307, 118187. https://doi.org/10.1016/j.apenergy.2021.118187.

Krueger, H., Cruden, A., 2020. Integration of electric vehicle user charging preferences into Vehicle-to-Grid aggregator controls. Energy Reports 6, 86–95. https://doi.org/10.1016/j.egyr.2020.02.031.

Kubli, M., 2022. EV drivers' willingness to accept smart charging: Measuring preferences of potential adopters. Transportation Research Part D: Transport and Environment 109, 103396. https://doi.org/10.1016/j.trd.2022.103396.

Kubli, M., Loock, M., Wüstenhagen, R., 2018. The flexible prosumer: Measuring the willingness to co-create distributed flexibility. Energy Policy 114, 540–548. https://doi.org/10.1016/j.enpol.2017.12.044.

Larson, P.D., Viáfara, J., Parsons, R.V., Elias, A., 2014. Consumer attitudes about electric cars: Pricing analysis and policy implications. Transportation Research Part A: Policy and Practice 69, 299–314. https://doi.org/10.1016/j.tra.2014.09.002.

Lee, C.-Y., Jang, J.-W., Lee, M.-K., 2020. Willingness to accept values for vehicle-to-grid service in South Korea. Transportation Research Part D: Transport and Environment 87, 1–10. https://doi.org/10.1016/j.trd.2020.102487.

Leiner, D.J., 2019. Too Fast, too Straight, too Weird: Non-Reactive Indicators for Meaningless Data in Internet Surveys. Woorking Paper from 02/2016. Survey research methods 13, 1–59. https://doi.org/10.18148/srm/2018.v13i3.7403.

Li, X., Tan, Y., Liu, X., Liao, Q., Sun, B., Cao, G., Li, C., Yang, X., Wang, Z., 2020. A cost-benefit analysis of V2G electric vehicles supporting peak shaving in Shanghai. Electric Power Systems Research 179, 106058. https://doi.org/10.1016/j.epsr.2019.106058.

Lund, H., Kempton, W., 2008. Integration of renewable energy into the transport and electricity sectors through V2G. Energy Policy 36, 3578–3587. https://doi.org/10.1016/j.enpol.2008.06.007.

Maxwell, J., 2009. Designing a Qualitative Study, in: Bickman, L., Rog, D.J. (Eds.), The SAGE handbook of applied social research methods, 2nd ed. SAGE, Los Angeles, pp. 214–253.

Miller, K.M., Hofstetter, R., Krohmer, H., Zhang, Z.J., 2011. How Should Consumers' Willingness to Pay be Measured? An Empirical Comparison of State-of-the-Art Approaches. Journal of Marketing Research 48, 172–184. https://doi.org/10.1509/jmkr.48.1.172.

Nobis, C., Kuhnimhof, T., 2018. Mobilität in Deutschland – MiD. Ergebnisbericht. infas, DLR, IVT, infas 360, Bonn, Berlin, 136 pp. http://www.mobilitaet-in-deutschland.de/pdf/MiD2017_Ergebnisbericht.pdf (accessed 27 July 2021).

Noel, L., Papu Carrone, A., Jensen, A.F., Zarazua de Rubens, G., Kester, J., Sovacool, B.K., 2019a. Willingness to pay for electric vehicles and vehicle-to-grid applications: A Nordic choice experiment. Energy Economics 78, 525–534. https://doi.org/10.1016/j.eneco.2018.12.014.

Noel, L., Rubens, G.Z. de, Kester, Johannes, Sovacool, Benjamin K., 2019b. Vehicle-to-Grid: A Sociotechnical Transistion Beyond Electric Mobility. Palgrave Macmillan, Cham, Switzerland, 271 pp.

Noel, L., Zarazua de Rubens, G., Kester, J., Sovacool, B.K., 2018. Beyond emissions and economics: Rethinking the co-benefits of electric vehicles (EVs) and vehicle-to-grid (V2G). Transport Policy 71, 130–137. https://doi.org/10.1016/j.tranpol.2018.08.004.

Noel, L., Zarazua de Rubens, G., Kester, J., Sovacool, B.K., 2021. Leveraging user-based innovation in vehicle-to-X and vehicle-to-grid adoption: A Nordic case study. Journal of Cleaner Production 287, 125591. https://doi.org/10.1016/j.jclepro.2020.125591.

Ozaki, R., Sevastyanova, K., 2011. Going hybrid: An analysis of consumer purchase motivations. Energy Policy 39, 2217–2227. https://doi.org/10.1016/j.enpol.2010.04.024.

Parsons, G.R., Hidrue, M.K., Kempton, W., Gardner, M.P., 2014. Willingness to pay for vehicle-to-grid (V2G) electric vehicles and their contract terms. Energy Economics 42, 313–324. https://doi.org/10.1016/j.eneco.2013.12.018.

Plötz, P., Schneider, U., Globisch, J., Dütschke, E., 2014. Who will buy electric vehicles? Identifying early adopters in Germany. Transportation Research Part A: Policy and Practice 67, 96–109. https://doi.org/10.1016/j.tra.2014.06.006.

Schmalfuß, F., Mair, C., Döbelt, S., Kämpfe, B., Wüstemann, R., Krems, J.F., Keinath, A., 2015. User responses to a smart charging system in Germany: Battery electric vehicle driver motivation, attitudes and acceptance. Energy Research & Social Science 9, 60–71. https://doi.org/10.1016/j.erss.2015.08.019.

Schuller, A., Flath, C.M., Gottwalt, S., 2015. Quantifying load flexibility of electric vehicles for renewable energy integration. Applied Energy 151, 335–344. https://doi.org/10.1016/j.apenergy.2015.04.004.

Sloot, D., Lehmann, N., Ardone, A., 2022. Explaining and promoting participation in demand response programs: The role of rational and moral motivations among German energy consumers. Energy Research & Social Science 84, 102431, 1–15. https://doi.org/10.1016/j.erss.2021.102431.

Sovacool, B.K., Abrahamse, W., Zhang, L., Ren, J., 2019a. Pleasure or profit? Surveying the purchasing intentions of potential electric vehicle adopters in China. Transportation Research Part A: Policy and Practice 124, 69–81. https://doi.org/10.1016/j.tra.2019.03.002.

Sovacool, B.K., Axsen, J., Kempton, W., 2017. The Future Promise of Vehicle-to-Grid (V2G) Integration: A Sociotechnical Review and Research Agenda. Annu. Rev. Environ. Resour. 42, 377–406. https://doi.org/10.1146/annurev-environ-030117-020220.

Sovacool, B.K., Hirsh, R.F., 2009. Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition. Energy Policy 37, 1095–1103. https://doi.org/10.1016/j.enpol.2008.10.005.

Sovacool, B.K., Kester, J., Noel, L., Rubens, G.Z. de, 2019a. Income, political affiliation, urbanism and geography in stated preferences for electric vehicles (EVs) and vehicle-to-grid (V2G) technologies in Northern Europe. Journal of Transport Geography 78, 214–229. https://doi.org/10.1016/j.jtrangeo.2019.06.006.

Sovacool, B.K., Kester, J., Noel, L., Rubens, G.Z. de, 2018. The demographics of decarbonizing transport: The influence of gender, education, occupation, age, and household size on electric mobility preferences in the Nordic region. Global Environmental Change 52, 86–100. https://doi.org/10.1016/j.gloenvcha.2018.06.008.

Sovacool, B.K., Kester, J., Noel, L., Zarazua de Rubens, G., 2019b. Are electric vehicles masculinized? Gender, identity, and environmental values in Nordic transport practices and vehicle-to-grid (V2G) preferences. Transportation Research Part D: Transport and Environment 72, 187–202. https://doi.org/10.1016/j.trd.2019.04.013.

SPD, Bündnis 90/Die Grünen and FDP, 2021. Koalitionsvertrag: Daring more progress. Alliance for freedom, justice and sustainability, 178 pp.

Staudt, P., Schmidt, M., Gärttner, J., Weinhardt, C., 2018. A decentralized approach towards resolving transmission grid congestion in Germany using vehicle-to-grid technology. Applied Energy 230, 1435–1446. https://doi.org/10.1016/j.apenergy.2018.09.045.

Szinai, J.K., Sheppard, C.J., Abhyankar, N., Gopal, A.R., 2020. Reduced grid operating costs and renewable energy curtailment with electric vehicle charge management. Energy Policy 136, 111051, 1–19. https://doi.org/10.1016/j.enpol.2019.111051.

Tibbe, T.D., Montoya, A.K., 2022. Correcting the Bias Correction for the Bootstrap Confidence Interval in Mediation Analysis. Frontiers in Psychology (Front. Psychol.) 13, 810258.

van Heuveln, K., Ghotge, R., Annema, J.A., van Bergen, E., van Wee, B., Pesch, U., 2021. Factors influencing consumer acceptance of vehicle-to-grid by electric vehicle drivers in the Netherlands. Travel Behaviour and Society 24, 34–45. https://doi.org/10.1016/j.tbs.2020.12.008.

van Westendorp, P.H., 1976. NSS-Price Sensitivity Meter (PSM): A New Approach to Study Consumer Perceptions of Prices, in: Proceedings of the 29th ESOMAR Congress: Research That Works For Today's Marketing Problems. 5-9 September, pp. 139–167.

Völckner, F., 2006. Methoden zur Messung individueller Zahlungsbereitschaften: Ein Überblick zum State of the Art. JfB 56, 33–60. https://doi.org/10.1007/s11301-006-0002-y.

Will, C., Lehmann, N., Baumgartner, N., Feurer, S., Jochem, P., Fichtner, W., 2022. Consumer understanding and evaluation of carbon-neutral electric vehicle charging services. Applied Energy 313, 118799, 1–20. https://doi.org/10.1016/j.apenergy.2022.118799.

Will, C., Schuller, A., 2016. Understanding user acceptance factors of electric vehicle smart charging. Transportation Research Part C: Emerging Technologies 71, 198–214. https://doi.org/10.1016/j.trc.2016.07.006.

Yilmaz, S., Cuony, P., Chanez, C., 2021. Prioritize your heat pump or electric vehicle? Analysing design preferences for Direct Load Control programmes in Swiss households. Energy Research & Social Science 82, 102319. https://doi.org/10.1016/j.erss.2021.102319.

Zhao, X., Lynch, J.G., Chen, Q., 2010. Reconsidering Baron and Kenny: Myths and Truths about Mediation Analysis. J Consum Res 37, 197–206. https://doi.org/10.1086/651257.

Paper D

Development and test of a dual-pathway model of personal and community factors driving new energy technology adoption - The case of V2G in three European countries

Nora Baumgartner [a,b], Daniel Sloot [a,b], Anne Günther [c], Ulf J. J. Hahnel [c]

[a] *French-German Institute for Environmental Research, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany*
[b] *Chair of Energy Economics, Institute for Industrial Production (IIP), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany*
[c] *Psychology of Sustainability and Behavior Change, Faculty of Psychology, University of Basel, Missionsstrasse 62A, 4055 Basel, Switzerland*

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Abstract

Understanding the drivers that underpin the adoption of new energy technologies is key to fostering a successful energy transition. Increasingly, studies focus on non-economic factors but are often limited to personal motivations such as ecological values. While there is increasing recognition that community factors can be key for behavioral change, the role of these factors with regard to energy technology acceptance is so far not well understood. To address this gap, we propose a new theoretical model to explain adoption interest of innovative energy technologies, such as vehicle-to-grid technology. Our model comprises two levels and suggests that both a personal-motivation route and a community-motivation route can uniquely explain adoption interest. We further propose an interplay between personal and community factors. We test this model through an empirical study based on representative samples from three European countries (Germany, France, Switzerland, total *N*= 979). Our results support the notion that different motivational routes can drive adoption interest. In particular, we find that initiative membership predicted adoption interest directly and indirectly via personal norm. Finally, we test our model for differences between countries, finding evidence that community factors might differentially affect adoption interest across national contexts.

Keywords: Community energy initiative, personal norm, technology adoption, country comparison, structural equation model, Vehicle-to-grid (V2G)

D.1 Introduction

Many countries worldwide aim to decarbonize their energy system in order to combat climate change and protect the environment. To this end, a fundamental system transformation is needed that is based on renewable and decentralized energy production, as well as flexible energy consumption (Koirala et al., 2018b). As novel technologies emerge within this transformation, the role of individuals shifts away from being mere passive consumers. In their new role, individuals are becoming active energy citizens in the energy transition by adopting and using new energy production or distribution technologies (Sintov and Schultz, 2015; Steg et al., 2018). The increase of rooftop photovoltaic systems during the last years is a prominent example, and bears witness of consumers becoming prosumers, by producing their own electricity while feeding in the surplus (Hahnel et al., 2020; Hahnel and Fell, 2022). Empowered with these new opportunities, an individual's behavior can drive or hinder the energy system transformation (Nielsen et al., 2024), which makes it necessary to investigate the factors driving individuals' adoption decisions in the context of novel energy technologies.

Research increasingly points to the notion that economic factors and rational self-interest are not the only factors that determine individual behavior in the energy transition, but non-economic factors often play an important role as well (Dreyer et al., 2022; Nilsson et al., 2018). This builds on more general insights on decision-making and bounded rationality from psychology and behavioral economics (e.g., Kahneman, 2003a, 2003b). Previous research has highlighted the importance of individual energy behavior in this transition and focused on identifying personal motivations beyond economic and self-interest motives such as ecological or altruistic motives, that underlie sustainable energy use or technology adoption (Steg et al., 2015; Steg, 2016). In addition, individuals often act within particular social contexts or groups, which can influence their decision-making (e.g., Fielding and Hornsey, 2016; Fritsche et al., 2018; Sloot et al., 2019). This suggests that not only individual behavior but also collective efforts can drive the system transformation. In particular, recent research has pointed to the role of community energy initiatives as one type of collective to facilitate the sustainable energy transition (Schwanitz et al., 2023). Community energy initiatives can raise their members' awareness of renewable energy technologies and create acceptance for these technologies (Seyfang and Smith, 2007; Sloot et al., 2018). Moreover, by facilitating collective investments in energy technologies, these initiatives enable individuals to take on a more active role in this transformation (Hamann et al., 2023). By fostering collective ecological efforts over individual actions, they enable citizenship practices (Hamann et al., 2023) and can uniquely motivate sustainable energy behavior (Sloot et al., 2018). Importantly, however, little is known about the extent to which membership in these initiatives has the potential to motivate the adoption and use of *novel* technological innovations that have not been widely established yet. Equally important, more research is needed to understand the process by which the community context, alongside personal values of citizens, can motivate technology adoption.

In this study, we address these research gaps by examining the potential of community factors — in particular, membership in community energy initiatives — as drivers of novel technology adoption. We propose a new theoretical model that considers both personal and community factors as potential drivers of technology adoption, suggesting that adoption can be driven jointly by personal values and norms, and membership in community energy initiatives. Specifically, we present an empirical study based on nationally representative data collected in three European countries, namely Germany, France, and Switzerland, to explain whether membership in a community energy initiative increases the likelihood to engage in additional energy transition practices. Our sample comprises 229 energy initiative members and 690 non-members across all three countries. Energy systems differ between countries, and there is a variety of initiatives, varying in their organizational form, amount of members, success rate, and strategies (Koirala et al., 2018a; Oteman et al., 2014), which results in a 'patchwork of definitions' (Schwanitz et al., 2023, p.7). To acknowledge this diversity, we use the term *community energy initiative* to emphasize the locally-rooted dedication to fostering the energy transition, which does not necessarily have to adhere to existing legal structures and definitions.

Our empirical test of the theoretical model focuses on the adoption of vehicle-to-grid (V2G) technology for electric vehicles (EVs). V2G can be defined as a storage technology with a bidirectional power flow (Kempton and Tomić, 2005; Sovacool and Hirsh, 2009). That is, EVs that are connected to the grid can both be charged and feed electricity back into the grid when necessary. On a household level, people may benefit financially by providing flexibility (Sovacool et al., 2017). On a system level, V2G provides temporal and distributed flexibility (Knezovic et al., 2017), and thus can be seen as an approach to balance short-term production and consumption based on renewable energy sources (Hargreaves et al., 2013; Hossain, 2016). On a regional level, this technology can specifically benefit local communities that generate renewable energy and promote autonomous energy systems, by allowing for different energy services (Koirala et al., 2018b; Proka et al., 2020; Reis et al., 2021; Schram et al., 2021), or by providing flexibility to enable electricity sharing (e.g., peer-to-peer-trading) within a community (Hahnel et al., 2020; Huber et al., 2019). While this technology holds many advantages and benefits for the system and the user, V2G comes along with disadvantages, too, especially for the EV owner. One of the main disadvantages is that mobility needs may be restricted (Franke et al., 2018; Franke and Krems, 2013). Another relevant constraint is higher costs, also due to a potentially shortened battery life (Krueger and Cruden, 2020).

We aim at understanding the role that community energy initiatives can have in promoting additional energy transition practices, namely the adoption of V2G technology for EVs. We thus consider the complex interplay between personal and social motivations in influencing citizenship behavior and sustainable practices, beyond mere monetary motivations assumed by classic models of ecological economics (Schlüter et al., 2019; Verburg et al., 2016). We additionally examine how those motivational factors are shaped by the local and national environment in which individuals operate, thus accounting for the important role of contextual factors in driving sustainable practices. Specifically, this paper has two main objectives:

i. Proposing a theoretical model that considers both personal and community factors as potential drivers of novel technology adoption
ii. Testing the theoretical model through an empirical study based on nationally representative data collected in three European countries – Germany, France, and Switzerland – for the case of vehicle-to-grid technology.

The paper is structured into five parts. The first part focuses on the theoretical foundations and introduces the novel theoretical model. We derive our hypotheses and then proceed with the description of the study design, data, and analysis method. Based on this, we present our findings, starting with the results of the model before delving into the multigroup analysis, comparing the effects between the three target countries. Finally, we discuss and reflect upon the theoretical implications and limitations of our research.

D.2 Personal and community factors

D.2.1 Values and personal norm

The energy transition with its goals as defined by the Paris Agreement requires a system transformation, which will only succeed with citizens actively engaging in the transition, for example through changing their behavior and adopting novel energy technologies (Steg, 2016). To date, a variety of different models exist that have been used to explain technology adoption. One prominent model that is widely used to understand decision-making processes within an environmental context is the theory of planned behavior (TPB) (Azjen, 1991), introduced as an expectancy-value model of attitude-behavior relationships (Conner and Armitage, 1998). The model explains behavior mainly based on attitudes and perceived behavioral control, and was adapted and applied to various contexts, for example to explain EV adoption (Haustein et al., 2021; Lee et al., 2023), V2G acceptability (van Heuveln et al., 2021), or engagement in environmental activism (Fielding et al., 2008). Yet, this theory remains grounded in the assumptions of rational choices and self-interest, and is limited in capturing social contexts, such as the influence of particular groups (Jackson, 2005; López-Mosquera and Sánchez, 2012). Behavioral economics emphasizes that decision-making often departs from the rational actor model, shaped by cognitive shortcuts like heuristics, emotional influences, and biases that simplify complex choices. Beyond these processes, intrinsic motivations, such as values and norms, play a critical role, particularly in the context of sustainability (Simon, 1955; Simon, 1982; Kahneman, 2003b; Evans, 2008; Gigerenzer and Gaissmaier, 2011). An alternative model giving more weight to these normative factors is the value-belief-norm theory (VBN) developed by Stern et al. (1999), which assumes (pro-environmental) behavior to be based on environmental and altruistic values (Dietz, 2015; Jackson, 2005; López-Mosquera and Sánchez, 2012). Previous empirical research has highlighted the role that personal factors, such as the values and moral obligations captured by the VBN theory, play in explaining ecological behavior (Steg, 2016; Steg et al., 2015; van der Werff and Steg, 2016). Specifically, individuals who pursue biospheric (i.e., ecological) values are more likely to engage in sustainable energy behavior, as these values reflect an intrinsic personal motivation to protect the environment and thus engage in behaviors consistent with this goal (de Groot and Steg, 2008). Next to biospheric values, egoistic values might underpin the adoption of novel energy technologies. Egoistic values reflect a propensity to strive for individual status, power, or monetary gains. These values may therefore hinder the acceptance and adoption of new technologies if they are perceived as costly (Steg, 2016). Conversely, egoistic values can in certain situations promote the adoption of a specific technology if it promises monetary benefits (Steg and de Groot, 2012), or enhances one's status (Steg, 2016). For example, van der Werff and Steg, (2016) found egoistic values to be significantly positively related to participation in smart energy systems. Moreover, Jansson et al. (2011) found that values could successfully explain the early adoption of novel technologies. Due to the importance of egoistic and biospheric values in explaining sustainable energy behavior and adoption, we consider both values as potential antecedents of adoption interest in V2G technology. Previous research has emphasized that values reflect relatively stable overarching goals in life, serving as the underlying motivation for more specific factors. In particular, biospheric values are often assumed to affect sustainable energy behavior via increasing individuals' feeling of moral obligation, commonly referred to as a personal norm (Brandsma and Blasch, 2019; Namazkhan et al., 2019; Sloot et al., 2022; Steg et al., 2005; cf. Stern, 2000). While a large number of studies has provided evidence on the relationships between values, personal norm, and different sustainable energy behaviors (including membership in community energy intitiatives), fewer studies have examined these variables in relation to the adoption of novel energy technologies (Lee et al., 2023; van der Werff and Steg, 2016). To our knowledge, no research has investigated how personal motivational factors are related to individuals' interest in V2G technology, a technology that may lead to personal financial benefits but also introduces constraints on individual flexibility. Drawing upon these findings we state the following hypotheses:

Hypothesis 1a (H1a): Biospheric values are positively related to an individual's personal norm and, in turn, lead to a higher interest in V2G adoption.

Hypothesis 1b (H1b): Egoistic values are negatively related to an individual's personal norm and, in turn, lead to a lower interest in V2G adoption.

D.2.2 Community motives

Despite the important role of personal values, individuals do not act in a vacuum, but their decisions and behaviors are influenced by the social context in which a person resides (Barth et al., 2016). Research has highlighted the importance of social identities for sustainable energy behavior (Fielding and Hornsey, 2016; Fritsche et al., 2018). Local communities and community energy initiatives have received particular attention as potential facilitators of sustainable energy transition practices (Bamberg et al., 2015; Rees and Bamberg, 2014; Sloot et al., 2018). Notably, Walker et al. (2022, p.2) distinguish between the concepts of 'community of interest' and 'community of place'. While the latter puts focus on the geographic aspect and highlights the close distance between members, the previous describes a group of individuals that are bonded by a common interest, but not necessarily by close proximity (Walker et al., 2022). In the context of energy initiatives, the concept of the 'community of place' is particularly relevant and is closely intertwined and interrelated with the local neighborhood, thereby emphasizing the relationship with distinct spatial environments (Ptak et al., 2018). In other words, although community energy initiatives are distinct groups, they are commonly embedded in a wider local neighborhood, which can itself act as an overarching group with relevance for individuals' decision-making (Goedkoop et al., 2022). Moreover, community energy initiatives rely on active participation from the members of the neighborhood, which is easier to attain through direct contact, when neighbors are emotionally attached to their neighborhood (Goedkoop et al., 2022; Kalkbrenner and Roosen, 2016; Oteman et al., 2014), or when there is a general appreciation of place (Hoffman and High-Pippert, 2010; Patrick Devine-Wright and Yuko Howes).

Two community factors seem particularly relevant in this regard. First, the perceived goals and norms of a community can guide individuals' behavior, motivating them to act in accordance with what they believe the community stands for (Fielding et al., 2008; Fielding and Hornsey, 2016). These norms are assumed to affect decision-making not via the mechanism of social pressure but via the internalization of what the relevant social group stands for in terms of their goals and values. From a behavioral economic perspective, this can be understood through the theory of social preferences, which posits that individuals derive utility not only from their own outcomes but also from outcomes that align with group norms or shared values (Fehr and Schmidt, 1999). For instance, community members might participate in shared community projects to demonstrate their commitment to group norms of collective benefit. We refer to this factor as the perceived community sustainable energy motivation (CSEM) and propose that it might not only influence sustainable energy behavior in general, but might also be relevant for technology adoption, particularly in the early adoption phase (Klöckner, 2014; Barth et al., 2016). If individuals perceive other community members to support sustainable energy transition practices, this might in turn affect their own decision through mechanisms like reciprocity (Nowak, 2006; Hilbe et al., 2018). Moreover, previous research indicates that CSEM correlates with higher levels of participation in local sustainable energy projects, including membership in community energy intitiatives (Goedkoop et al., 2022).

A second community factor is an individual's identification with their local community. Community identification is a specific type of group identification and reflects the emotional attachment that a person feels to their community (Postmes et al., 2013). Studies have provided empirical evidence for the idea that a stronger identification with one's local community is positively related to the willingness to participate in energy projects or initiatives with others in the community (e.g., Bomberg and McEwen, 2012; Rees and Bamberg, 2014; Kalkbrenner and Roosen, 2016; Goedkoop et al., 2022). Additionally, bounded rationality may play a role in this process: individuals embedded in a community often use social cues or peer behavior as heuristics for what actions are desirable or normative, reducing cognitive effort in decision-making (Conlisk, 1996). While these studies have tended to examine local communities and initiatives with similar objectives, strategies, and organizational forms, we expect this relationship to generally hold across different types of local communities.

Community energy initiatives can play a vital role in fostering the energy transition (Bauwens et al., 2016; Wierling et al., 2023). By bringing individuals from a local community together, they can go beyond individual change and provide an additional motivation to act as part of a particular group. However, there is little quantitative empirical research on how membership in an energy community can promote sustainable energy behaviors on an individual level and which behaviors are specifically affected. One study tested the relationship between energy initiative membership and different sustainable energy behaviors the initiative aimed to promote, such as energy saving, while accounting for different personal ecological motivations (Sloot et al., 2018). This study found that membership was related to stronger sustainable energy behavior, but the effect differed across different types of behaviors. To our knowledge, no research has examined the relationship between initiative membership and the willingness to adopt novel energy technologies in early adoption phases, in particular when these technologies are not specifically targeted by the initiative. This way, community energy initiatives might foster a sustainable energy transition in a more indirect way by creating involvement in the system transformation beyond their immediate goals. Another reason why membership in community energy initiatives might drive the adoption of new technologies is because these technologies could complement the current goals of the initiatives. This alignment could create additional synergies and benefits, particularly for initiative members. For example, in the changing energy landscape, storage systems are becoming more important to enable a higher integration of renewable energies. V2G is one of those technologies creating synergies between technologies, enabling local communities to become more autonomous (Koirala et al., 2018b) or trade electricity (Hahnel et al., 2020; Hahnel and Fell, 2022). The combination of both, trading and storing, was shown to achieve significant electricity savings for the members of a local community (Lüth et al., 2018). Thus, V2G can bring new opportunities for citizens to actively participate on a local scale and to raise awareness of energy consumption (Parra et al., 2017). Based on the above review of community factors and their relevance in the energy transition as a whole, and regarding energy behavior change more specifically, we expect the following:

Hypothesis 2a (H2a): Community sustainable energy motivation is positively related to an individual's membership in a community energy initiative and, in turn, lead to a higher interest in adopting V2G.

Hypothesis 2b (H2b): Community identity is positively related to an individual's membership in a community energy initiative and, in turn, lead to a higher interest in adopting V2G.

Aside from these two distinctive motivational routes, it is plausible that personal values and the social context are equally relevant in explaining sustainable citizenship behavior, and can be seen as complementary and interdependent. While personal values describe the focus on the self, social values are outward-looking, considering the context within the decision-making process (Bradley et al., 2024). Yet, only a few studies have analyzed the interplay of personal values and community motives on sustainable citizenship practices. Initial research has shown that personal motivations such as non-monetary values can significantly explain energy initiative membership (Sloot et al., 2018, 2019), particularly so for pro-environmental values and motives. While values may increase the likelihood of engaging in collective sustainable initiatives in the first place, initiative membership may itself become internalized as a personal motivation. Specifically, being a member of a community energy initiative might reflect on one's self by strengthening the personal norm to engage in behaviors consistent with the initiative membership. Additionally, to the direct involvement in an energy initiative shaping an individual's personal norm, the perceived goals and values of the initiative might motivate the members to act accordingly. Thus, the perceived goals might strengthen the specific motivation to engage in sustainable energy behavior at the community level as well[1]. In a different context, Sharpe et al., (2022) found that an organization's corporate social responsibility strategy (aking to a group value) increased employees' motivation to behave pro-environmentally at work via increasing the personal norm. Yet, this mechanism of personal norm as a mediator of the relationship between initiative membership and technology adoption has not been tested in the context of community energy initiatives.

Based on these considerations, we suggest that biospheric values positively influence the likelihood to be member of a community energy initiative, which in turn increases adoption interest.

1 We draw a direct link between CSEM and personal norm, because these factors specifically refer to the community members' motivation to engage in sustainable energy behavior at the community level. Community identification, on the other hand, is referring to community members' identification with their local community (i.e., their neighborhood) in general, independent of the energy domain.

In contrast, strong egoistic values may have the opposite effect. Moreover, we propose that community factors likely increase one's personal norm and in turn lead to a higher adoption interest. We propose the following three hypotheses:

Hypothesis 3a (H3a): Biospheric values are positively related to adoption interest via individuals' membership in a community energy initiative.

Hypothesis 3b (H3b): Egoistic values are negatively related to adoption interest via individuals' membership in a community energy initiative.

Hypothesis 4 (H4a): Community sustainable energy motivation is positively related to personal norm, and lead to a higher adoption interest of V2G.

Hypothesis 4 (H4b): Initiative membership is positively related to personal norm, and lead to a higher adoption interest of V2G.

D.2.3 Dual-pathway model of energy technology adoption

Based on our review of the literature, we developed a theoretical model of energy technology adoption that considers both personal motivations and community motivations as determinants of individuals' adoption interest (Figure 1). We denote this model dual-pathway model of energy technology adoption. This model suggests that specific factors on both levels can explain energy transition practices such as the adoption and usage of V2G. The personal-motivation route is based on biospheric and egoistic values, with biospheric values influencing adoption decisions positively (H1a), and egoistic values influencing adoption decisions negatively (H1b), both mainly via personal norm (H1a-H1b). The community-motivation route includes community factors, including community sustainable energy motivation (CSEM) and community identification, predicting adoption decisions mainly via initiative membership (H2a-H2b). Next to these two main routes, we propose that personal and community factors can also influence each other, suggesting an interplay between personal and community-based motivations (personal-community motivation route). More specifically, we suggest that biospheric values are associated with initiative membership and in turn lead to a higher V2G adoption interest (H3a), while we propose the opposite for individuals with strong egoistic values (H3b). Moreover, we hypothesize that community motives (CSEM, initiative membership) have a positive effect on personal norm, and lead to a higher adoption interest of new energy technologies (H4a-H4b, community-personal motivation route). Thus, our hypotheses are related to a decision route as a whole (i.e., an indirect effect) as opposed to a particular relationship between two factors.

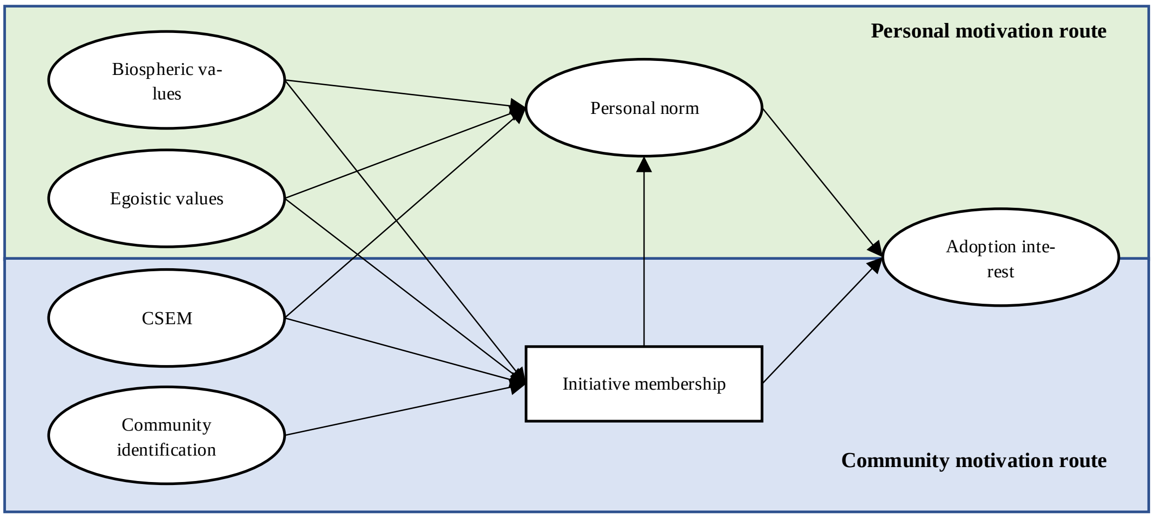

Figure 1 Dual-pathway motivation model of energy technology adoption.

Note: The figure only depicts the paths relevant to our hypotheses. Our hypotheses state that adoption interest can be either motivated by personal values via personal norms (H1a-H1b), by community motivations via initiative membership (H2a-H2b), or jointly, by personal values influencing adoption interest via initiative membership (H3a-H3b), and by community factors (CSEM and initiative membership) influencing personal norms and thus resulting in a higher adoption interest (H4a-H4b). Please note that, while we propose a direct link between initiative membership and personal norm and CSEM and personal norm, we do not draw this link between community identification and personal norm, as this factor is not specifically referring to the energy domain, but captures participants' general attachment to their local community.

D.3 Current study

In 2023, we conducted an online questionnaire study among homeowners in France, Germany, and Switzerland. In addition to sampling participants from the general population, we specifically contacted members of energy communities in the three countries. As V2G technology has yet to be implemented in these three countries, we used a hypothetical adoption decision task to study citizens' adoption interest in the context of V2G. In particular, we created concrete scenarios describing various types of V2G tariffs (see section D.4.2.2) and used the ratings of these scenarios to measure respondents' interest in adopting V2G.

In line with our reasoning above, we hypothesized that an individual's decision is not only guided by personal values and norms (H1a-H1b), but also by the social context in which a person resides and acts (H2a-H2b). The study, therefore, examined the unique role community energy initiatives can play in *novel* energy technology adoption decisions, focusing on V2G technology, a technology that is not yet implemented on a large scale. Specifically, the objective of our study was to analyze adoption interest in an integrated, dual-pathway model that considers both individuals' personal values and their embeddedness within the relevant community context.

We focused on the community energy initiative context, as these initiatives have been playing a significant and influencing role in decentralizing and transforming the energy system over the past decades and will be likely to do so in the near future. As of 2023, more than 10,000 local initiatives existed in Europe, with more than two million people involved in them (Schwanitz et al., 2023). Their story of success lies, among others, in the bottom-up approach, their regional rootedness, allowing individuals to play an active role in this transition, creating acceptance towards energy technologies, and motivating individual and collective sustainable energy behavior. Initiative members are, therefore, likely to have shared goals and to identify with the goals and values of other members (Sloot et al., 2019). To this end, being part of a community energy initiative might influence an individual's technology adoption decision, especially for those technologies that hold benefits for the community energy initiative in addition to the energy transition as a whole. We thus expect community motives to positively influence adoption interest (H2a-H2b).

Apart from these two motivation routes – through personal motivations and community-based motives – we hypothesized that personal values might also influence adoption interest positively via initiative membership. This "personal-community motivation route" emphasizes personal values, i.e., biospheric and egoistic values, as antecedents of initiative membership, while membership might be positively related to adoption interest as well (H3a-H3b). In contrast, community-based motives and community energy initiative membership might also influence adoption through personal norm (H4a-H4b). This "community-personal motivation route" considers that community motives might not only explain membership, but being part of a community energy initiative might in turn be related to increased personal norm, which might impact the adoption decision of a person. Consequently, we suggest that adoption can be driven either solely or jointly by personal motivations and membership in community energy initiatives.

In addition to analyzing the overall model, we examined systematic differences in the assumed adoption processes between Germany, France, and Switzerland. Even within Europe, countries follow different trajectories regarding their energy transition, with likely impacts on the decision-making of individuals in these countries. For example, France relies on nuclear power plants as a core pillar of the energy transition strategy, supporting a system that is (historically) more centralized, with only few main energy actors (Vernay et al., 2023), whereas Germany already phased out nuclear power plants, and Switzerland prohibits the construction of new plants. Moreover, all three countries have differing histories regarding energy communities. While Switzerland has a long history of energy communities (Rivas et al., 2018), this is not the case in France (Vernay et al., 2023). Therefore, it is important to not only study one country, but to investigate the effect of initiative membership in different European countries. To the best of our knowledge this is the first study that systematically examines the joint influence of motivational drivers on energy initiative membership *and* energy technology adoption in early adoption stages.

D.4. Materials and methods

D.4.1 Procedure

We collected data for this online study in 2023 via two ways. First, we collected data through a market research institute to obtain a sample of homeowners in Germany, France, and Switzerland. We targeted only homeowners because the decision to adopt V2G technology is particularly relevant for this group, and aimed for this sample to be representative in terms of gender and age for the total population in each country. Second, as we were interested in the influence of initiative membership on V2G adoption and expected the share of initiative members to be relatively low in this sample, we additionally targeted energy community members directly via contacting several energy community initiatives in the three countries.

With the market research institute, we targeted 400 homeowners per country, using a randomized sampling strategy and leading to a total of $N = 1352$. Furthermore, we followed purposive sampling in several energy communities ($N = 47$). Complete responses included participants who passed at least one of two attention check items, straight-lining checks, and were not identified as speeders. For our analysis, we excluded eight further IDs due to incomplete answers. The final sample included 979 valid responses ($M_{age}= 50.54$, $SD_{age}= 16.50$; 482 male, 494 female, 3 other genders). Due to the fact that we targeted homeowners, the household income within our sample is slightly left-skewed. Moreover, the sample data collected by the market research institute also included a significant share of energy initiative members in all three countries. Together with the sample data based on direct engagement with energy community initiatives this resulted in nearly a quarter (23%) of our final sample being part of a community energy initiative[1] ($M_{age}= 45.43$, $SD_{age}= 17.08$; 147 male, 80 female, 3 other genders). It is likely that this is also an outcome of our sampling strategy to target homeowners only rather than the general population.

The survey was structured into five parts. In the first part, we assessed participants' age, gender, and current home country. Moreover, we asked participants whether they were part of any community energy initiative. Second, we queried the respondents' previous experience with EVs. Unexpectedly, with a total of 433, nearly half of the respondents (44%) already gained experience

[1] As of 2016, there were ~ 300 registered energy communities with ~115 members on average in Switzerland (Rivas et al., 2018). In France, the number of energy community initiatives has significantly increased since 2016, with reaching 54,000 members in 2020, assembled under the umbrella association Enercoop (Château Terrisse et al., 2022). Lastly, in 2022 ~877 registered energy cooperatives with a total of 220.000 members existed in Germany (Deutscher Genossenschafts- und Raiffeisenverband e.V. (DRGV), 2023). This indicates that the share of members compared to non-members in all three countries is rather low. Yet, these numbers have to be read with caution, as nearly no sources reliably indicating the share of energy initiative members compared to the whole population in all three countries. This is due to the fact that the landscape of energy initiatives is very diverse, with different existing definitions and understandings. Moreover, the field of energy initiatives is very dynamic. To this end, based on existing statistics of energy initiatives, we assume the real share of energy initiative members in all three countries to be far lower than in our sample.

with driving an EV or owned an EV. To create a common understanding of V2G, we introduced the concept in a second part. To make sure that people understood the concept, they had to pass a comprehension question. Afterward, participants received eight V2G scenarios sequentially, describing a V2G tariff option (see Figure 2). The scenarios differed on three attributes with two levels each. Participants rated their interest in each tariff option after it was presented. The attributes were varied so that every combination was rated once. The fourth part of the survey assessed individual and community factors. Lastly, we assessed household characteristics, such as owning electricity-generating technologies. The survey was developed in English and translated into French and German by native speakers. Currencies and income groups were adapted for each country.

D.4.2 Measures

D.4.2.1 Predictors

Unless specified otherwise, we used Likert scale-type items to measure our constructs. Values were measured on a scale ranging from -1 (opposed to my values) to 7 (extremely important). All other items were measured on a 7-point Likert scale ranging from strongly disagree to strongly agree. Compound scales were computed based on mean scores across items (Appendix A).

Biospheric values. Biospheric values capture the extent to which the protection of the environment and nature is a guiding principle in a person's life. The scale is based on Schwartz, (1992) and Stern et al., (1998). We used a shortened version, including four items (respecting the earth; unity with nature; protecting the environment; preventing pollution) (Steg et al., 2014).

Egoistic values. Egoistic values capture the importance of power, dominance, and influence as a guiding principle in a person's life. The scale is based on Schwartz, (1992) and Stern et al., (1998). We used a shortened version, including five items (authority, wealth, social power, influence, and ambitious) (Steg et al., 2014).

Personal norm. Schwartz (1973) defines personal norm as 'the extent to which one feels morally obliged to perform a certain action'. We measured this scale using three items (I feel morally obliged to use smart energy systems; I would feel guilty if I would not use smart energy systems; I would feel proud if I would use smart energy systems) according to van der Werff and Steg (2016).

Community identification. Community identification was measured based on Postmes et al.'s (2013) four-item group identification scale. This scale captures the extent, to which a person identifies with a particular group, in this case the local neighborhood[1]. We adopted the scale to: ‘I feel committed to my neighborhood’, ‘I am glad to be part of my neighborhood’, ‘being part of my neighborhood is an important part of how I see myself’, and ‘I identify with my neighborhood’.

Community sustainable energy motivation (CSEM). CSEM measures whether people believe that members from the neighborhood find it important to engage in sustainable energy behavior. This scale was assessed using three items: ‘Members of my community find it important to be conscious about their energy behavior’, ‘Members of my neighborhood find it important to reduce their energy consumption’, and ‘Members of my neighborhood find it important to use sustainable energy’ (Goedkoop et al., 2022).

Initiative membership. This item assesses whether respondents were at the time of responding part of a community energy initiative by asking ‘Are you currently a member of an energy community?’ (cf., Fielding et al., 2008). We provided a definition of energy community when asking this question. This item was answered with yes/no and is, therefore, a binary variable.

D.4.2.2 Outcome variable

We measured interest in adopting V2G technology with a ratings-based choice experiment. To this end, we developed a V2G charging tariff scenario with three attributes and two attribute levels ($2^3 = 8$ unique charging tariffs). Participants rated their interest in V2G based on the eight tariffs

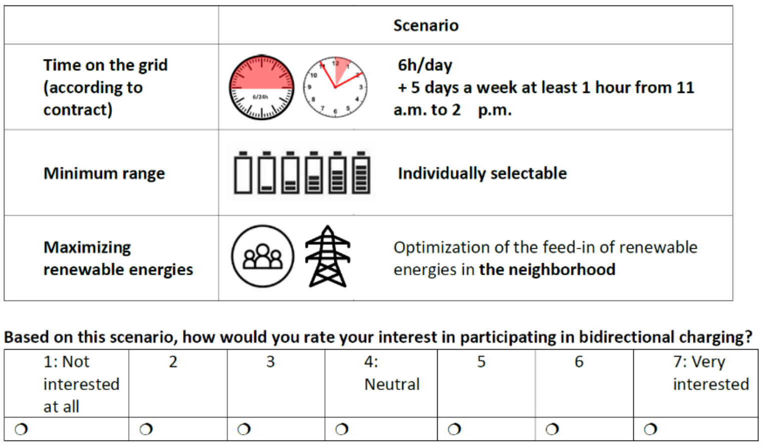

Figure 2 Example of one of the eight V2G tariff options

[1] Please note, that we used both terms ‘neighborhood’ and ‘community’ in our constructs and combined them into ‘community factors’. While the construct ‘initiative membership’ depicts whether a respondent is part of an energy initiative, the other two community constructs (CSEM and community identity) employed the term neighborhood. We chose to use two distinct, but interrelated terms, because we distributed the survey to initiative members and non-members, and therefore had to align the wording so that both parties were able to answer the respective questions.

sequentially on a scale from 1 (not interested at all) to 7 (very interested). For our analysis, we created a compound variable from all ratings based on the mean values.

Based on previous literature (Gschwendtner et al., 2023) the following three attributes and levels were varied between V2G tariff scenarios:

1. Time on the grid: This attribute describes the time that an EV has to be connected to the grid within this charging tariff. Two levels were defined. Level 1: the vehicle has to be connected to the grid for a total of 6h/day, but the time of connection is freely selectable; level 2: the vehicle has to be connected to the grid for a total of 6h/day for five days a week and at least for one hour between 11 a.m. to 2 p.m.

2. Minimum range: The minimum state of charge describes the energy in the battery that is always available for unplanned shorter trips and should, therefore, also be understood as a safety reserve. Two levels were defined. Level 1: the minimum range is individually selectable; level 2: the minimum range is 30% / 100km.

3. Maximization of renewable energies: This attribute measures the optimization of the feed-in of renewable energy sources into the entire energy system vs. the local grid of the neighborhood.

The scenario included an introductory text describing a V2G contract to the respondents. The full scenario text and a table depicting the attributes and levels of the scenarios can be found in Appendix B. The scenarios were presented in a randomized order. Figure 2 displays an example of how the scenario was presented.

Furthermore, half of the participants received a scenario that displayed the minimum range in km, while the other half was randomly assigned to a scenario displaying the minimum range in percent. However, as a t-test revealed no significant difference between these two approaches ($t(967)= 0.983$, $p= .326$), we do not consider them in the following analysis. We assumed that the ratings of the different variations of the V2G tariff reflected an overall propensity to be interested in adopting V2G and thus formed a mean score out of the eight individual items. An analysis of the effects of the tariff attributes on adoption interest is provided in the supplementary material (Table 5, Supplementary material).

D.4.3 Data analysis

We used structural equation modeling to test our overall theoretical model and analyze the relationships between personal and community drivers on V2G adoption decisions. This method is well suited for testing our theoretical model and in particular the indirect decision routes, as it allows the modeling of simultaneous regression equations as well as assessing overall model fit. In the main results, we first present the results of a model for all three countries and subsequently a multigroup model used to examine differences in effects between the three countries. Before testing the structural model part, we performed a confirmatory factor analysis (CFA) to test whether our item measures load appropriately on their underlying constructs. Due to the number of parameters included in the model and given our sample size, we limited the analysis to an observed path model using mean scores and tested the measurement model in a separate CFA,

Table 1 Confirmatory factor analysis (CFA): Factor loadings

Scale items	**Standardized factor loading**
Biospheric values	
Respecting the earth: harmony with other species	.830
Unity with nature: fitting into nature	.828
Protecting the environment: preserving nature	.887
Preventing pollution: protecting natural resources	.821
Egoistic values	
Social power: control over others, dominance	.490
Wealth: material possessions, money	.934
Authority: the right to lead or command	.819
Influential: having an impact on people and events	.789
Ambitious: hardworking, aspiring	.548
Community sustainable energy motivation (CSEM)	
Members of my community find it important to be conscious about their energy behavior.	.850
Members of my neighborhood find it important to reduce their energy consumption.	.854
Members of my neighborhood find it important to use sustainable energy.	.871
Community identification	
I feel committed to my neighborhood.	.737
I am glad to be part of my neighborhood.	.828
Being part of my neighborhood is an important part of how I see myself.	.881
I identify with my neighborhood.	.823
Personal norm	
I feel morally obliged to use smart energy systems	.885
I would feel guilty if I would not use smart energy systems	.852
I would feel proud if I would use smart energy systems	.829
Scenario	
Based on this scenario, how would you rate your interest in participating in bidirectional charging? Scenario rating 1	.856
Scenario rating 2	.864
Scenario rating 3	.857
Scenario rating 4	.861
Scenario rating 5	.881
Scenario rating 6	.858
Scenario rating 7	.866
Scenario rating 8	.867

Note: Model fit indices for the full SEM
$\chi 2= 20094$, $p< .001$
CFI= .928
RMSEA= .069
SRMR= .046

which showed a good overall model fit as well as acceptable item loadings for the variables included (see Table 1).[1] As the structural model contained both continuous and binary endogenous variables (i.e., initiative membership), we estimated the model fit and the coefficients using a diagonally weighted least squares (DWLS) estimator in place of the more common maximum likelihood (ML) estimator, which cannot handle endogenous categorical variables. This is because categorical variables are assumed to violate the normality assumption. Indirect effects (corresponding to the decision routes of the theoretical model) were specified as additional parameters and were calculated as the product of two or more coefficients. Age and gender[2] were included as control variables in the model. The model results with control variables can be found in Appendix C and D. To test for the significance of the indirect effects, we used a bootstrapping procedure for standard errors, with 10,000 bootstrap draws in each model. All continuous variables were mean-centered. The multigroup model was tested by adding country as grouping factor to the model. We lastly compared a constrained model in which all regression parameters were set to be equal across countries to an unconstrained model in which all parameters were allowed to vary freely across the three countries.

[1] Estimating the multigroup model with an integrated measurement and structural part was not possible due to the high number of parameters that need to be estimated (*N*= 300) in relation to the number of observations in the data (*N*= 269, 352, and 358 for the three countries). For the overall model, the integrated model did converge, but the estimation was unstable and most of the bootstrap draws were invalid. Therefore, and to retain consistency between the different model results, we only present results for the observed path model in the main text. The estimated integrated model containing both the measurement and structural model part for all three countries can be found in the Supplementary Materials. For both the integrated and the observed path model, model fit was good and the parameter estimates produced a very similar pattern of results, increasing confidence in our estimation procedure.

[2] Please note that due to the small number of other genders (N=3), we coded gender as 0 for male and 1 for other genders, including females. Recoding this variable such that other genders were included in the male category (instead of the female category) did not change the results.

D.5 Results

D.5.1 Descriptive statistics and correlations

Prior to the analysis of the overall path model, we examined the bivariate correlations (based on Pearson's correlation coefficient) between all variables of the proposed model (Table 2).

Table 2 Descriptive statistics and correlations of the measures used in the model

Variable	*M*	*SD*	1	2	3	4	5	6	7	8
1. Adoption interest	4.05	1.63								
2. Biospheric values	7.84	1.77	.20**							
			[.14, .26]							
3. Egoistic vaues	5.04	1.65	.24**	-.02						
			[.18, .30]	[-.08, .04]						
4. Personal norm	4.17	1.70	.45**	.35**	.25**					
			[.39, .49]	[.29, .40]	[.19, .31]					
5. CSEM	4.07	1.38	.33**	.23**	.27**	.44**				
			[.27, .38]	[.17, .29]	[.22, .33]	[.39, .49]				
6. Community identification	4.25	1.42	.25**	.22**	.23**	.38**	.60**			
			[.19, .31]	[.16, .28]	[.17, .28]	[.33, .43]	[.56, .64]			
7. Initiative membership[a]	0.23	0.42	.27**	.02	.19**	.25**	.17**	.15**		
			[.21, .33]	[-.04, .08]	[.12, .25]	[.19, .31]	[.10, .23]	[.09, .21]		
8. Gender[b]	0.51	0.50	-.19**	.14**	-.15**	-.04	-.07*	-.09**	-.17**	
			[-.25, -.13]	[.08, .20]	[-.21, -.08]	[-.10, .03]	[-.13, -.01]	[-.15, -.03]	[-.23, -.10]	
9. Age	50.58	16.50	-.23**	.21**	-.23**	-.05	-.06	.03	-.17**	.06*
			[-.28, -.17]	[.15, .27]	[-.29, -.17]	[-.11, .01]	[-.12, .00]	[-.04, .09]	[-.23, -.11]	[.00, .13]

Note. *M*= mean. *SD*= standard deviation
*$p<0.05$; **$p<0.01$; ***$p<0.001$
[a] Initiative membership coded as 0= non member , 1= initiative member.
[b] Gender coded as 0= male, 1= other.

Generally, the direction of the correlations was as expected. Specifically, biospheric values and personal norm were significantly correlated. Interestingly, egoistic values were positively correlated with personal norm. Moreover, CSEM and community identification were correlated to all latent variables of the model. The relationships were especially strong between CSEM and personal norm and community identification and personal norm.

D.5.2 Dual-paathway model of energy technology adoption: Overall results

We first tested the overall model (Figure 3) without accounting for country differences. The final path model showed a good model fit, with model fit indices being within acceptable range, χ^2= 12.266, *p*= .015, CFI= .947, RMSEA= .046, SRMR= .006.

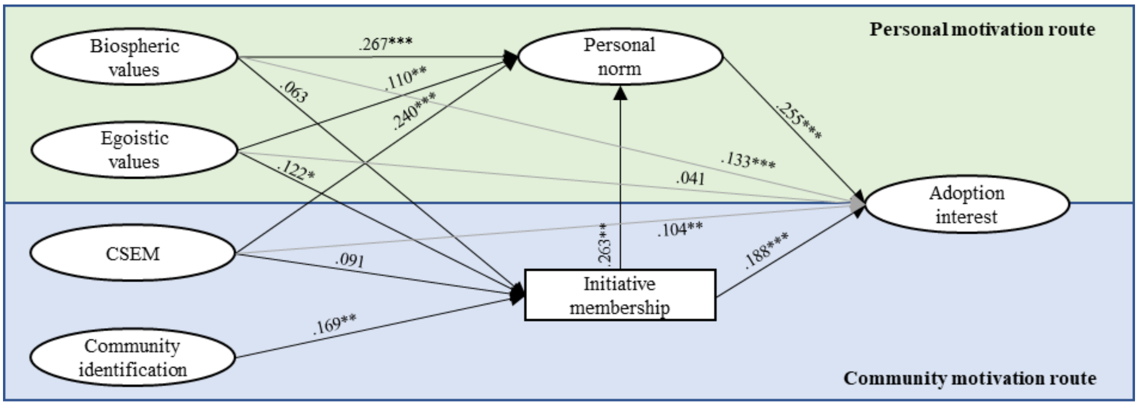

Figure 3 Dual-pathwaymodel of energy technology adoption showing direct standardized effects; * *p*< .05; ***p*< .01; ****p*< .001. *Note:* Paths that are part of our hypotheses are depicted in black. For better readability, the paths representing direct effects that are not part of the hypotheses are greyed out.

Figure 3 shows the standardized coefficients for the direct effects in the overall model. A table with path coefficients, standard errors, and exact p-values can be found in Appendix C. Both personal norm (ß= .255, *p*< .001) and initiative membership (ß= .188, *p*< .001) were positively related to the main outcome adoption interest. That is, participants with a stronger personal norm and who were part of a community energy initiative were more likely to report higher interest in V2G adoption. Moreover, biospheric values and CSEM significantly predicted adoption interest whereas egoistic values and community identification showed no direct effect on adoption interest. Initiative membership also had a significant effect on personal norm (ß= .263, *p*< .001), indicating that those who were part of a community energy initiative held a stronger personal norm than those who were not. As expected, biospheric values and CSEM were also related to a stronger personal norm. Somewhat surprisingly, there was also a small positive effect of egoistic values on personal norm (ß= .110, *p*= .001). In line with our expectations, stronger community identification increased the likelihood of initiative membership (ß= .169, *p*= .004), but there was no significant effect of CSEM or biospheric values on membership. However, stronger egoistic values increased the likelihood that people were initiative members (ß= .122, *p*= .012).

D.5.3 Indirect effects on adoption interest

We first tested indirect effects that would indicate adoption interest via a personal motivation route (H1a-H1b). In support of this, there was an indirect effect of biospheric values via personal norm on adoption interest (ß= .068, p< .001) (Table 3). Contrary to our expectations, egoistic values predicted adoption interest positively via personal norm as well (ß= .28, p= .004). Next, we examined indirect effects indicating a path to adoption interest via community factors. In line with H2b, community identification predicted adoption interest indirectly via an increased likelihood of initiative membership (ß= .032, p= .026). Moreover, we explored a joint personal-community path, which would mean that personal motivations are related to adoption interest via community factors. As there was no direct effect of biospheric values on initiative membership, the indirect effect was also non-significant (ß= .012, p= .224). However, egoistic values were indirectly related to adoption interest via an increased likelihood of initiative membership (ß= .023, p= .038). We also found support for the reverse route, namely a community-personal motivation path. Specifically, initiative membership predicted adoption interest indirectly via personal norm (ß= .067, p< .001). Additionally, there was an indirect effect of CSEM on adoption interest via personal norm (ß= .061, p< .001).

Table 3 Dual-pathway model of energy technology adoption – indirect effects

Predictor	→ personal norm → adoption interest	→ initiative membership[a] → adoption interest
Biospheric values	.068***	.012
Egoistic values	.028**	.023*
CSEM	.061***	.017
Community identification		.032*
Initiative membership[a]	.067***	

*p< .05; **p< .01; ***p< .001; coefficients are standardized.
[a] Initiative membership coded as 0= non member , 1= initiative member.

D.5.4 Dual-pathway model of energy technology adoption: Multigroup results

In a second step we conducted a multigroup analysis to explore country differences in the paths to adoption interest. The final model in which all parameters could freely vary between countries showed a good overall model fit, and model fit indices were within acceptable range, χ^2= 16.648, p= .163, CFI= .970, RMSEA= .035, SRMR= .009. This model had a slightly better model fit than a constrained model in which the regression parameters were fixed to be equal across all countries, χ^2= 55.026, p= 0.170, CFI= .941, RMSEA= .025, SRMR= .043. Yet, a Chi-square test comparing both models was not significant, suggesting that accounting for differences between countries neither improves nor worsens the explanation of adoption interest. Nevertheless, as we expected to find differences between countries due to different approaches to community energy initiatives and energy transition strategies, we explored the different motivational routes between the three countries.

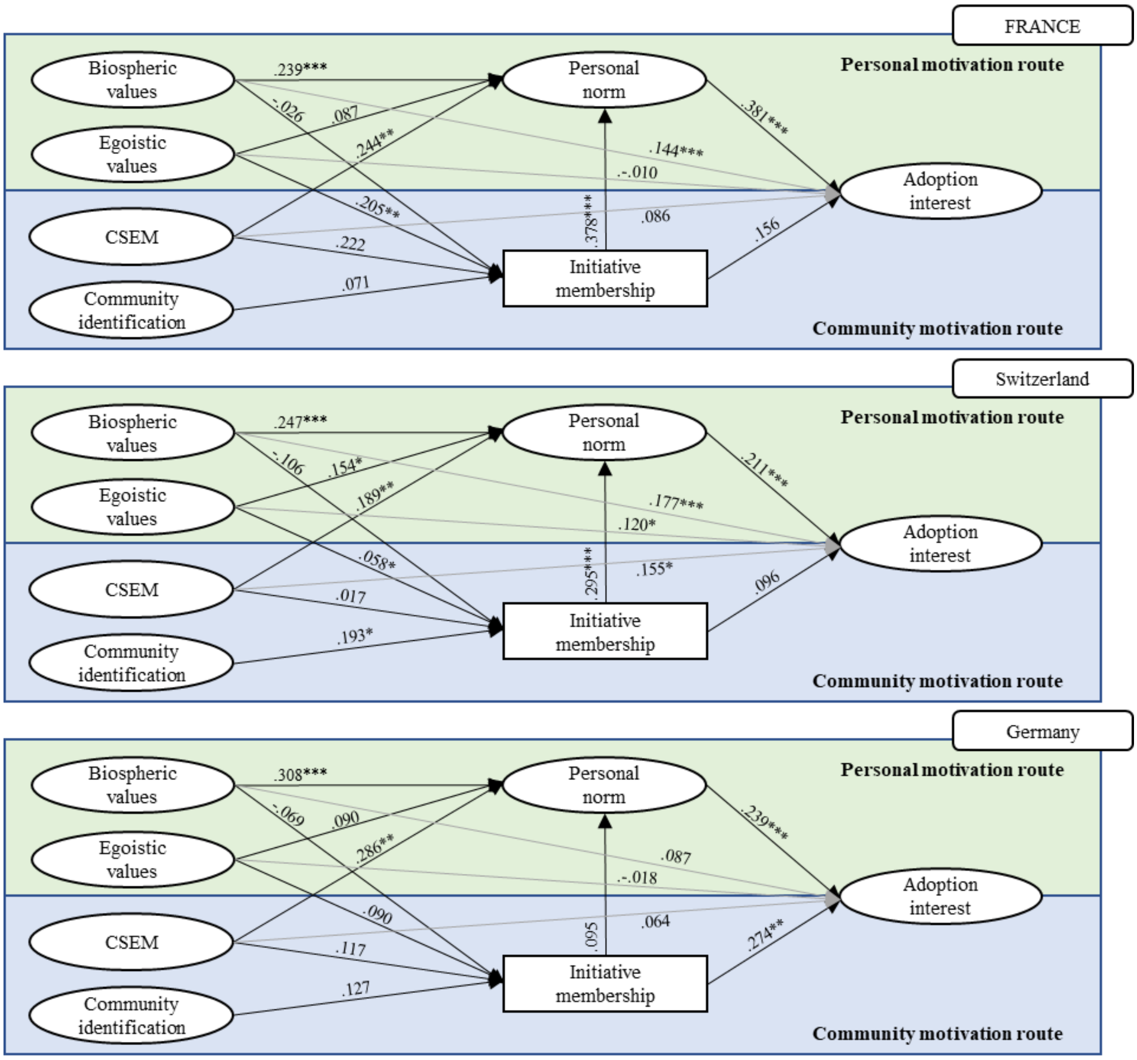

Figure 4 Dual-pathway model of energy technology adoption showing direct standardized effects; * p< .05; ** p< .01; *** p< .001. Note: As our focus is on indirect effects, some paths representing direct effects are greyed out for better readability. Read paths highlight significant direct effects.

Figure 4 shows the standardized coefficients for the direct effects in the multigroup model. A Table with path coefficeints, standard erros and p-values can be found in Appendix D. For the personal route, biospheric values significantly predicted adoption interest in France (ß= .144, *p*= .009), whereas, in Switzerland, both biospheric and egoistic values played direct predictive roles. Personal norm were consistently influenced by biospheric values and by CSEM across all three countries. Additionally, stronger egoistic values increased personal norm for the Swiss sample (ß= .154, *p*= .012), but not in France and Germany. Initiative membership only predicted personal norm in France (ß= .378, *p*< .001) and in Switzerland (ß= .295, *p*< .001), but not in Germany. On the community route, we found differences in the predictors of initiative membership and the relation between membership and adoption interest. In France, initiative membership was influenced by egoistic values, whereas in Switzerland, it was solely predicted by community identification (ß= .193, *p*= .022). Strikingly, no significant predictors for initiative membership were found in Germany. However, only in Germany, initiative membership (ß= .274, *p*< .002) significantly predicted adoption interest directly.

D.5.5 Country differences in indirect effects on adoption interest

As we had no specific hypothesis on country differences, we pursued an explorative analysis of the indirect effects of the multigroup model. Table 4 shows the indirect effects across countries. Results show that personal norm was the only relevant mediator for all three countries. Contrary to our expectations, initiative membership did not play a significant role when examining the countries separately.

Table 4 Dual-pathway model of energy technology adoption - indirect effects

Predictor	→ personal norm → adoption intention	→ initiative membership[a] → adoption intention
France		
Biospheric values	.091**	-.004
Egoistic values	.033	.032
CSEM	.093*	.011
Community identification		.035
Initiative membership[a]	.144**	
Switzerland		
Biospheric values	.052**	.010
Egoistic values	.032	.006
CSEM	.040	.002
Community identification		.019
Initiative membership[a]	.062*	
Germany		
Biospheric values	.074**	.019
Egoistic values	.021	.025
CSEM	.069**	.032
Community identification		.035
Initiative membership[a]	.023	

*p<.05; **p<.01; ***p<.001, coefficients are standardized.
[a] Initiative membership coded as 0= non member, 1= initiative member.

Analysis of the personal motivation route showed that only biospheric values significantly predicted adoption interest via personal norm. This indirect effect was consistent in all three countries. Yet, we found no support for a solely community-based route. Instead, results suggested a community-personal route. Specifically, we found that CSEM predicted adoption interest indirectly via increased personal norm, but only for France and Germany. As already expected from the direct effects, initiative membership solely predicted adoption interest indirectly via personal norm for France and Switzerland. The results highlight that values – both, personal and community sustainable energy motivation – influence adoption interest through personal norm for all three countries.

D.6 Discussion

In this study, we investigate different non-monetary motivational factors that underpin the adoption of new technologies by individuals, with a special focus on community factors as potential drivers of adoption. By doing so, we transcend mere rationally-based motivations that are often assumed by classic ecological economics (Schlüter et al., 2019; Verburg et al., 2016). Specifically, we focus on the adoption of novel energy technologies, which is a precondition to a successful energy transition. This is important, as the energy transition brings about new technologies, such as EVs that are able to feed electricity back to the grid. Thus, the individual is given a new and active role in this transition and, consequently, needs not only to accept these technologies but also to engage with them. Our objectives were twofold. First, we proposed and empirically tested a new theoretical model that considers the community context as a motivational route to technology adoption, next to the more commonly studied personal (e.g., ecological) motivation route. In particular, we focused on the role of membership in community energy initiatives, which has received relatively little attention next to the role of personal motivations. Second, as the effects of community factors could be heterogeneous between countries, we analyzed a sample from three European countries and tested for differences in effects between them.

D.6.1 Summary and theoretical implications

Our analysis provides new insights with valuable theoretical implications. Our study is unique in that we aim to understand novel technology adoption interest by interlinking personal factors, such as values, with the community context in which a person resides and acts. We do so by developing a new theoretical model and testing it with an empirical study considering energy initiative members and non-members in three neighboring European countries. We thereby focused on V2G, a technology that could provide benefits on a system, community, and household level. In line with our central predictions, we find that not only personal factors but also community factors can act as drivers of adoption interest in novel energy technologies. First, our results corroborate previous findings by showing that personal motivational factors (e.g., ecological values) can explain different types of sustainable energy behavior, including energy technology acceptance. In line with a large body of literature, we find support for a personal motivation path to adoption interest (Huijts et al., 2012). Specifically, adoption interest is driven by biospheric values via increased personal norm (cf., van der Werff et al., 2013; van der Werff and Steg, 2016). Unexpectedly, we also find a positive effect of egoistic values on personal norm. As theorized by de Groot and Steg (2008) and Steg (2016), one explanation might be that people with strong egoistic values either pursue an environmentally-friendly behavior because this behavior is perceived to increase a person's social status or due to expected benefits or perceived savings. The latter argument in particular applies to the case of V2G. Abundant literature shows that individuals can expect to receive monetary benefits from V2G (Sovacool et al., 2017). However, as EVs are a visible expression of a certain status (Axsen et al., 2018; McBain et al., 2023), V2G might also indirectly enhance a person's status, as this technology adds significant costs on top of the investment of an EV (Heilmann and Friedl, 2021; Lanz et al., 2022).

Notably, we show that community factors are also uniquely related to adoption interest, even when accounting for the role of personal motivational factors. Accounting for the role of personal motivations is important for ruling out the possibility that any effects of initiative membership are merely due to a self-selection of individuals with strong ecological values into these initiatives (cf. Sloot et al., 2018). Specifically, we found support for a community-based route, which is driven by community identification and initiative membership. This finding corroborates and extends previous research that found initiative membership to be positively related to sustainable energy behavior (Middlemiss, 2011; Sloot et al., 2018) but did not specifically study adoption interest in new energy technologies. Unexpectedly, we found no support for a community route by CSEM via initiative membership. This finding is in contrast to previous research on social identity and collective action (Fritsche et al., 2018). It suggests, however, that the degree of identification with one's community is more important in explaining adoption interest via inititiave membership than what a person beliefs other members to find important. In line with this, Goedkoop et al., (2022) suggested that community identification in general might be more important than specific beliefs of other initiative members. Yet, the non-significant relationship between CSEM and initiative membership might also be explained by the strong correlation between CSEM and community identification. Interestingly, while we find no indirect effect of CSEM via intitiative membership on adoption interest, we find CSEM to be a significant direct predictor of both personal norm and adoption interest. Thus, while initiative membership is not motivated by what people from the neighborhood believe to be important, CSEM is important with regard to personal norm and the adoption interest of new technologies. Especially with regard to the latter, the perceived motivations of others in the local community seem to matter and influence a person's interest in V2G technology directly. This is particularly interesting in the early adoption phase when a technology is not yet that known, during which these perceived community motivations seem to have an influence on an individual's interest in this technology (cf., Barth et al., 2016; Klöckner, 2014), and thus might influence, among others, the uptake of new energy technologies. More generally, the role of CSEM as a predictor of adoption interest underscores the role of group motivations. Other research has shown this influence to work via social norms (e.g., Cialdini et al., 1990) or group values (e.g., Bouman et al., 2020). Our findings on CSEM thus extend this literature by showing intrinsic group motivations as an additional social influence mechanism.

Additionally, our results underline the interdependencies between the two distinct routes – the personal motivation route and the community motivation route. In other words, both, personal and community factors jointly play a role for an individual's decision to adopt novel energy technologies. More specifically, our results reveal that adoption interest is indirectly predicted by initiative membership via personal norm. When looking at the direct effects, initiative membership was found to be a strong predictor of personal norm. This suggests that, next to being linked to adoption interest directly, initiative membership might strengthen the members' personal norm, implying that identities such as one's initiative membership can become internalized. Sharpe et al., (2022) found evidence for this phenomenon in the context of corporations, showing that employees' motivation to act pro-environmentally within their working environment is increased when the company is perceived to follow an environmentally responsible strategy. We further find evidence for a reverse, personal motivation-community route, suggesting that adoption interest is increased indirectly by egoistic values via an increased likelihood of being an initiative member. This finding is interesting, as we expected this motivation path to be primarily driven by non-monetary values, and the motivation to collectively foster a just and participatory energy transition (Koirala et al., 2018a; Sloot et al., 2019). Yet, even though joining an energy initiative is seemingly not egoistic, it is important to recognize that the outcomes of such initiatives may directly benefit the individual in monetary terms, e.g., in the sense of lower electricity prices. By pooling resources and collectively investing in renewable energy sources, energy initiatives often achieve cost savings that translate into reduced electricity bills for members. In this light, joining a community energy initiative could become a choice informed by egoistic considerations.

With regard to country differences, our findings are mixed and somewhat ambiguous. As energy systems differ between the European countries in our study and they pursue different energy transition strategies, we expected that an individual's interest to adopt a novel energy technology might be influenced by these variations and thus be linked to different underlying factors in these countries. While we find some differences in the strength of the direct effects, our results show that indirect effects are similar for all three countries. This could suggest that the process by which individuals form an adoption interest in novel energy technologies is more universal than it is distinct across the countries we studied. Indeed, the most consistent result is that all statistically significant motivation routes are indirectly affecting adoption interest via personal norm, which is true for all three countries. In contrast, personal and community factors do not consistently explain adoption interest via initiative membership.

To summarize, in this study, we emphasized that adoption interest of novel energy technologies can be explained either by a personal or a community motivation route, or jointly by both routes, pointing to interdependencies between individual community factors. Importantly, we find evidence that community factors such as initiative membership can become internalized as personal norm. These processes seem to hold across nations.

D.6.2 Limitations and future research

Our study is, of course, not without shortcomings and opens up new avenues for future research. First and foremost, we primarily targeted homeowners as they are the stakeholders who would most likely be the first ones to adopt V2G. This is due to the fact that homeowners are more independent in their energy-related decisions compared to tenants, especially when they are associated with an investment decision, such as the installation of a wall box. As we did not expect the sample to include many energy initiative members, we addressed energy initiatives in all three countries directly to distribute the survey among their members. In sum, we achieved an unexpectedly high share of energy initiative members and the analysis of the overall model revealed interesting insights. Yet, for the multigroup model, the low number of initiative members per country might be a reason why we couldn't detect more pronounced differences between countries. Moreover, especially the imbalanced and low numbers of initiative members might be one reason why we, for example, could not explain initiative membership in Germany, where, comparably, we had the smallest sample of initiative members. Another reason might be that the adoption processes are universal across the countries we studied. Future research could, therefore, explore country differences in more detail. In our study, we focused on three neighboring, European countries. It would be particularly interesting to study countries that are more diverse in their political ambitions, their culture, and political structures.

Furthermore, we used a very specific, not yet established energy technology as a use case, which confronted us with two major challenges. First of all, we were not able to assess the respondents' behavior, but only their V2G adoption intention. Future research could examine to what extent such intentions translate into actual adoption. Additionally, constructs that refer to actual behavior, such as the willingness to receive further information, could be an interesting avenue for future research to measure acceptance of innovative technologies more directly. Secondly, understanding the technology in focus required some basic understanding of EV technology and the functioning of the energy system in order to anticipate and understand the challenges that come along with higher shares of EVs and the potential benefits that could arise from V2G for the individual. To measure the respondents' intention to adopt V2G, we created a scenario with three attributes, putting much emphasis on providing sufficient and intuitive information to the respondents in order to create a common knowledge base, and to provide a balanced description of the associated advantages and disadvantages. Yet, providing sufficient information to rate the choices adequately, while at the same time influencing the participant as little as possible is a challenging task. As the energy transition holds many other relevant energy technologies it would be interesting to test whether our model is transferrable to other, more widely established energy technologies, such as household or community battery storage technologies. Moreover, it would be interesting to test technologies, that are societally contested, such as heat pumps.

Furthermore, various social contexts exist that directly or indirectly influence a person's decision to adopt innovative technologies and that are noteworthy to investigate. In this study, we focus on energy initiatives as one particular context, uniting individuals who wish to actively participate in the energy transition. We do so by drawing from literature based on social identity, thus, emphasizing that norms and values of the group become internalized and affect decision-making. Future research could consider other contexts that socially influence an individual's decision-making and, furthermore, operationalize it with constructs capturing social influence in terms of perceived social norms or expectations. One example would be subjective norms from the TPB. This would be particularly interesting in a time, where energy technologies are strongly contested and individuals perceive policies to intrude on their private lives and sovereignty in energy-related decision-making (Spence et al., 2015).

D.6.3 Practical implications and conclusion

Our results emphasize that the adoption interest in novel energy technologies can be explained based on personal and community factors, as well as on their interplay. To summarize, an individual's interest to adopt novel energy technologies, such as V2G, is guided not only by the personal values and norms a person holds, but also by the community context in which a person resides and acts. This points to the opportunity that community energy initiatives can also play a leading role when it comes to creating interest in and acceptance towards novel energy technologies among intitiative members. Adoption of key energy transition technologies is thus not only a question of how environmentally-friendly a person is or how much value the technology is perceived to bring about, but also a question of whether people identify with their initiative and local neighborhood. This underlines the important and unique role energy initiatives hold in the energy transition, suggesting that they can foster sustainable energy transition practices.

CRediT author statement:

Nora Baumgartner: Conceptualization; Data curation; Formal analysis; Funding Acquisition; Investigation; Methodology; Project administration; Resources; Software; Validation; Visualization; Writing - original draft; **Daniel Sloot**: Conceptualization; Data curation; Formal analysis; Funding Acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Visualization; Writing - original draft; **Ulf Hahnel**: Conceptualization; Funding acquisition; Methodology; Project administration; Supervision; Validation; Writing – review & editing; **Anne Günther**: Conceptualization; Investigation; Methodology; Validation; Writing – review & editing.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process:

During the preparation of this work the authors used Grammarly and ChatGPT in order to avoid grammatical and spelling errors. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

APPENDIX

Appendix A

Table 1 Descriptive statistics and reliabilities: Mean scores latent variables

	N	Mean	Std error	Std deviation	Variance
bios latent	981	7.84	0.06	1.77	3.13
ego latent	981	5.05	0.05	1.66	2.74
norm latent	980	4.17	0.05	1.70	2.89
SI latent	979	4.25	0.05	1.42	2.00
CSEM latent	979	4.07	0.04	1.38	1.92

Table 2 Descriptive statistics and reliabilities: Mean scores latent variables per country

Country		N	Mean	Std error	Std deviation	Variance
Germany	bios latent	358	7.67	0.10	1.85	3.41
	ego latent	358	4.93	0.08	1.60	2.55
	norm latent	358	3.95	0.09	1.79	3.19
	SI latent	358	4.19	0.08	1.45	2.10
	CSEM latent	358	3.92	0.08	1.42	2.02
France	bios latent	271	8.05	0.10	1.66	2.76
	ego latent	271	5.10	0.10	1.70	2.90
	norm latent	270	4.36	0.10	1.65	2.72
	SI latent	269	4.44	0.08	1.34	1.79
	CSEM latent	269	4.24	0.08	1.35	1.81
Switzerland	bios latent	352	7.84	0.09	1.76	3.09
	ego latent	352	5.13	0.09	1.68	2.81
	norm latent	352	4.26	0.09	1.62	2.63
	SI latent	352	4.17	0.08	1.43	2.05
	CSEM latent	352	4.09	0.07	1.36	1.85

Table 3 Descriptive statistics and reliabilities: Mean scores of aggregated variables for initiative membership

Community membership		N	Mean	Std error	Std deviation	Variance
Members	bios latent	229	7.75	0.12	1.77	3.12
	ego latent	229	4.99	0.10	1.55	2.41
	norm latent	228	4.23	0.11	1.68	2.82
	SI latent	228	4.31	0.09	1.37	1.89
	CSEM latent	228	4.11	0.09	1.32	1.75
Non-members	bios latent	752	7.87	0.06	1.77	3.14

ego latent	752	5.06	0.06	1.69	2.84
norm latent	752	4.16	0.06	1.71	2.91
SI latent	751	4.23	0.05	1.43	2.04
CSEM latent	751	4.06	0.05	1.40	1.97

Appendix B

Scenario introduction

{constantly shown above every scenario; use CHF for Swiss version}

Imagine you own a bidirectional electric car with a range of 350 km. To be able to charge your electric car bidirectionally, you sign a contract with a service provider. The contract allows you to charge your electric car bidirectionally at home, at your workplace and at public charging stations. Assume, the charging infrastructure is available. Additionally, you have the possibility to flexibly pause the contract.

As soon as you plug in your electric car, it is initially charged to a minimum range without interruption. The minimum range corresponds to the range that is always available for unplanned shorter trips and should therefore also be understood as a safety reserve. Once the minimum range is reached, the bidirectional charging phase begins. In an app, you can set your planned departure times and the desired destination range at departure. In addition, your system has an opt-out function that allows you to cancel the bidirectional charging mode and charge your vehicle directly. You will receive a monthly compensation of 50€ for providing your battery. Below we present eight different contract conditions. The introductory text remains the same. We ask you to read the contract conditions carefully and then evaluate them. There is no right or wrong answer. Your opinion alone counts.

Table 4 Scenario attributes and levels

Attributes	Level 1	Level 2
Time on the grid	The vehicle has to be connected to the grid for a total of 6h/day, but the time of connection is freely selectable	The vehicle has to be connected to the grid for a total of 6h/day for five days a week and at least for one hour between 11 a.m. to 2 p.m.
Minimum range	The minimum range is individually selectable	The minimum range is 30% / 100km
Maximization of renewable energies	Optimization of the feed-in of renewable energy sources into the entire energy system	Optimization of the feed-in of renewable energy sources into the local grid of the neighborhood

Appendix C

Table 5 Path analysis to predict adoption interest in energy technologies - direct effects

	Dependent variables		
	Membership	Personal norm	Adoption interest
Personal norm			.255*** [SE= .038, *p* < .001]
Biospheric values	.063 [SE= .030, *p*= .182]	.267*** [SE= .032, *p* < .001]	.133*** [SE= .030, *p* < .001]
Egoistic values	.122* [SE= .032, *p*= .012]	.110** [SE= .034, *p* < .001]	.041 [SE= .101, *p* = .202]
Initiative membership[a]		.263*** [SE= .062, *p* < .001]	.188*** [SE= .069, *p* < .001]
CSEM	.091 [SE= .044, *p* = .096]	.240*** [SE= .045, *p* < .001]	.104** [SE= .044, *p* = .006]
Community identification	.169** [SE= .047, *p* = .004]		
Gender[b]	-.173*** [SE= .095, *p* < .001]		-.130*** [SE= .101, *p* < .001]
Age	-.200*** [SE= .003, *p* < .001]		-.177*** [SE= .003, *p* < .001]
R^2	.188	.309	.320

CSEM= Community sustainable energy motivation
*p< .05; **p< .01; ***p< .001; coefficients are standardized.
[a] Initiative membership coded as 0= non member , 1= initiative member.
[b] Gender coded as 0= male, 1= other.

Appendix D

Table 6 Path analysis of the multigroup model to predict adoption interest in energy technologies – direct effects

	Dependent variables		
	Membership	Personal norm	Adoption interest
France			
Personal norm			.381*** [SE= .066, *p* < .001]
Biospheric values	-.026 [SE= .054, *p* = .732]	.239*** [SE= .064, *p* < .001]	.144** [SE= .056, *p* = .009]
Egoistic values	.205** [SE= .055, *p* = .010]	.087 [SE= .065, *p* = .201]	-.010 [SE= .058, *p* = .865]
Initiative membership[a]		.378*** [SE= .125, *p* < .001]	.156 [SE= .138, *p* = .106]
CSEM	.222 [SE= .081, *p* = .062]	.244** [SE= .093, *p* = .002]	.086 [SE= .083, *p* = .191]
Community identification	.071 [SE= .080, *p* = 196]		
Gender[b]	-.135 [SE= .167, *p* = .056]		-.086 [SE= .006, *p* = .131]
Age	-.253***		-.211***

	[SE= .005, *p* < .001]		[SE= .064, *p* < .001]
R^2	.287	.377	.419
Switzerland			
Personal norm			.211*** [SE= .061, *p* =.001]
Biospheric values	.106 [SE= .045, *p* = .138]	.247*** [SE= .052, *p* < .001]	.168*** [SE= .045, *p* =.001]
Egoistic values	.058 [SE= .048, *p* = .424]	.154* [SE= .057, *p* = .012]	.120* [SE= .049, *p* = .025]
Initiative membership[a]		.295*** [SE= .108, *p* < .001]	.096 [SE= .116, *p* = .253]
CSEM	.017 [SE= .071, *p* = .844]	.189** [SE= .084, *p* = .010]	.155* [SE= .072, *p* = .015]
Community identification	.193* [SE= .066, *p* = .022]		
Gender[b]	-.270*** [SE= .147, *p* < .001]		-.181*** [SE= .156, *p* < .001]
Age	-.162* [SE= .005, p= .017]		-.179*** [SE= .005, p= .001]
R^2	.189	.302	.336
Germany			
Personal norm			.239*** [SE= .061, *p* < 001]
Biospheric values	.069 [SE= .057, *p* = .483]	.308*** [SE= .054, *p* < .000]	.087 [SE= .053, *p* = .160]
Egoistic values	.090 [SE= .063, *p* = .061]	.090 [SE= .060, *p* = .105]	-.018 [SE= .053, *p* = .736]
Initiative membership[a]		.095 [SE= .131, *p* = .246]	.274** [SE= .132, *p* = .002]
CSEM	.117 [SE= .086, *p* = .089]	.286*** [SE= .075, *p* < .001]	.064 [SE= .086, *p* = .404]
Community identification	.127 [SE= .084, *p* = .095]		
Gender[b]	-.091 [SE= .184, *p* = .284]		-.147** [SE= .170, *p* = .006]
Age	-.243** [SE= .006, *p* =.007]		-.131* [SE= 006, *p* = .036]
R^2	.144	268	.265

CSEM= Community sustainable energy motivation
*p< .05; **p< .01; ***p< .001; coefficients are standardized.
[a] Initiative membership coded as 0= non member , 1= initiative member.
[b] Gender coded as 0= male, 1= other.

SUPPLEMENTARY MATERIALS

Complete structural equation model (SEM)

Table 1 Model fit indices for complete SEM predicting adoption interest

Model fit	Model fit indices
Chi-square (df; p-value)	595.212 (df=332; *p* =0.000)
CFI	.990
TLI	.988
RMSEA	.028
SRMR	.043

Table 2 Scale items and factor loading for complete SEM predicting adoption interest

Scale items	Factor loading
Biospheric values 01	.769
Biospheric values 02	.809
Biospheric values 03	.866
Biospheric values 04	.909
Egoistic values 01	.530
Egoistic values 02	.516
Egoistic values 03	.745
Egoistic values 04	.874
Egoistic values 05	.566
CSEM 01	.875
CSEM 02	.807
CSEM 03	.867
Community identification 01	.877
Community identification 02	.777
Community identification 03	.800
Community identification 04	.783
Personal norm 01	.849
Personal norm 02	.837
Personal norm 03	.875
Scenario 01	.830
Scenario 02	.873
Scenario 03	.854
Scenario 04	.869
Scenario 05	.869
Scenario 06	.844
Scenario 07	.888
Scenario 08	.869

Table 3 Path analysis predicting adoption interest - direct effects

	Dependent variable		
	Membership	**Personal norm**	**Adoption interest**
Personal norm			.294***
Biospheric values	-.022	.231***	.070*
Egoistic values	.191***	.102**	.102**
Initiative membership[a]		.250***	.232***
CSEM	.108	.352***	.092*
Community identification	109		
R^2	.099	.417	.308

CSEM= Community sustainable energy motivation
*p< .05; **p< .01; ***p< .001; coefficients are standardized.
[a] Initiative membership coded as 0= non member , 1= initiative member.

Table 4 Path analysis predicting adoption interest - indirect effects

Predictor	**-> personal norm -> adoption intention**	**-> membership -> adoption intention**	**-> membership -> personal norm -> adoption intention**
Biospheric values	.086***	-.005	
Egoistic values		.044**	
CSEM	.104***		
Community identification		.025	.008
Initiative membership[a]	.074***		

CSEM= Community sustainable energy motivation
*p< .05; **p< .01; ***p< .001; coefficients are standardized.
[a] Initiative membership coded as 0= non member , 1= initiative member.

V2G tariff attributes as predictors of adoption interest

Table 5 Linear mixed model with V2G tariff attributes as predictors of adoption interest

	Adoption interest				
Predictors	*Estimates*	*std. Beta*	*CI*	*standardized CI*	*p*
(Intercept)	3.75	-0.16	3.48 – 4.02	-0.31 – -0.02	**<0.001**
Time on grid [6h]	0.24	0.13	0.20 – 0.28	0.11 – 0.15	**<0.001**
Minimum range [selectable]	0.39	0.21	0.35 – 0.43	0.19 – 0.23	**<0.001**
Renewable energies [local]	-0.00	-0.00	-0.05 – 0.04	-0.02 – 0.02	0.837
Random Effects					
σ^2	0.87				
$\tau_{00\ subject}$	2.51				
$\tau_{00\ country}$	0.05				
ICC	0.75				
$N_{subject}$	981				
$N_{country}$	3				
Observations	7848				

Table 6 Linear Mixed Model with all Dual Path Model Components as Direct Predictors of Adoption Interest

	Adoption Interest				
Predictors	*Estimates*	*std. Beta*	*CI*	*standardized CI*	*p*
(Intercept)	3.61	-0.17	3.44 – 3.77	-0.25 – -0.09	**<0.001**
Time on Grid [6h]	0.24	0.13	0.20 – 0.28	0.11 – 0.15	**<0.001**
Minimum Range [Selectable]	0.39	0.21	0.35 – 0.43	0.19 – 0.23	**<0.001**
Renewable Energies [Local]	-0.01	-0.00	-0.05 – 0.04	-0.03 – 0.02	0.790
Biospheric Values[a]	0.10	0.05	0.01 – 0.20	0.00 – 0.11	**0.038**
Egoistic Values[a]	0.16	0.09	0.07 – 0.26	0.04 – 0.14	**0.001**
Personal Norm[a]	0.50	0.27	0.39 – 0.60	0.21 – 0.32	**<0.001**
CSEM[a]	0.20	0.11	0.10 – 0.30	0.05 – 0.16	**0.001**
Initiative Membership	0.57	0.13	0.35 – 0.79	0.08 – 0.18	**<0.001**
Random Effects					
σ^2	0.87				
$\tau_{00\ subject}$	1.87				
$\tau_{00\ country}$	0.01				
ICC	0.68				
$N_{subject}$	979				
$N_{country}$	3				
Observations	7832				

Note. a Predictors are standardized using z-transformation.

References

Axsen, J., Cairns, J., Dusyk, N., Goldberg, S., 2018. What drives the Pioneers? Applying lifestyle theory to early electric vehicle buyers in Canada. Energy Research & Social Science 44, 17–30. 10.1016/j.erss.2018.04.015.

Azjen, I., 1991. The Theory of Planned Behavior. Organizational Behavior and Human Decision Processes (50), 179–211.

Bamberg, S., Rees, J., Seebauer, S., 2015. Collective climate action: Determinants of participation intention in community-based pro-environmental initiatives. Journal of Environmental Psychology 43, 155–165. 10.1016/j.jenvp.2015.06.006.

Barth, M., Jugert, P., Fritsche, I., 2016. Still underdetected – Social norms and collective efficacy predict the acceptance of electric vehicles in Germany. Transportation Research Part F: Traffic Psychology and Behaviour 37, 64–77. 10.1016/j.trf.2015.11.011.

Bauwens, T., Gotchev, B., Holstenkamp, L., 2016. What drives the development of community energy in Europe? The case of wind power cooperatives. Energy Research & Social Science 13, 136–147. 10.1016/j.erss.2015.12.016.

Bomberg, E., McEwen, N., 2012. Mobilizing community energy. Energy Policy 51, 435–444. 10.1016/j.enpol.2012.08.045.

Bouman, T., Verschoor, M., Albers, C.J., Böhm, G., Fisher, S.D., Poortinga, W., Whitmarsh, L., Steg, L., 2020. When worry about climate change leads to climate action: How values, worry and personal responsibility relate to various climate actions. Global Environmental Change 62. 10.1016/j.gloenvcha.2020.102061.

Bradley, G.L., Deshpande, S., Paas, K.H., 2024. The personal and the social: Twin contributors to climate action. Journal of Environmental Psychology 93, 102194. 10.1016/j.jenvp.2023.102194.

Brandsma, J.S., Blasch, J.E., 2019. One for all? – The impact of different types of energy feedback and goal setting on individuals' motivation to conserve electricity. Energy Policy 135, 110992. 10.1016/j.enpol.2019.110992.

Château Terrisse, P., Karmouni, H.E., Maignan, M., 2022. The construction of a citizen-centered ecosystem for renewable energies in France, in: , Energy Communities. Elsevier, pp. 183–193.

Cialdini, R.B., Reno, R.R., Kallgren, C.A., 1990. A focus theory of normative conduct: Recycling the concept of norms to reduce littering in public places. Journal of personality and social psychology 58 (6), 1015–1026. 10.1037/0022-3514.58.6.1015.

Conlisk, J., 1996. Why Bounded Rationality? Journal of Economic Literature 34 (2).

Conner, M., Armitage, C.J., 1998. Extending the Theory of Planned Behavior: A Review and Avenues for Further Research. J Applied Social Pyschol 28 (15), 1429–1464. 10.1111/j.1559-1816.1998.tb01685.x.

Devine-Wright, P., Howes, Y., 2010. Disruption to place attachment and the protection of restorative environments: A wind energy case study. Journal of Environmental Psychology 30 (3), 271–280. 10.1016/j.jenvp.2010.01.008.

Dietz, T., 2015. Environmental value. Oxford University Press, 329–350. 10.1093/acprof:oso/9780198716600.003.0016, 329-350.

Dreyer, H., Sonnenberg, N., van der Merwe, D., 2022. Transcending Linearity in Understanding Green Consumer Behaviour: A Social–Cognitive Framework for Behaviour Changes in an Emerging Economy Context. Sustainability 14 (22), 14855. 10.3390/su142214855.

Energy Cooperatives in Germany: State of the Sector 2023 Report, 10 pp. https://www.dgrv.de/news/energiegenossenschaften-2023/. Accessed 6 July 2024.

Evans, J.S.B.T., 2008. Dual-processing accounts of reasoning, judgment, and social cognition. Annual review of psychology 59, 255–278. 10.1146/annurev.psych.59.103006.093629.

Fehr, E., Schmidt, K.M., 1999. A Theory of Fairness, Competition, and Cooperation. The Quarterly Journal of Economics 114 (3), 817–868.

Fielding, K.S., Hornsey, M.J., 2016. A Social Identity Analysis of Climate Change and Environmental Attitudes and Behaviors: Insights and Opportunities. Frontiers in psychology 7, 121. 10.3389/fpsyg.2016.00121.

Fielding, K.S., McDonald, R., Louis, W.R., 2008. Theory of planned behaviour, identity and intentions to engage in environmental activism. Journal of Environmental Psychology 28 (4), 318–326. 10.1016/j.jenvp.2008.03.003.

Franke, T., Krems, J.F., 2013. Understanding charging behaviour of electric vehicle users. Transportation Research Part F: Traffic Psychology and Behaviour 21, 75–89. 10.1016/j.trf.2013.09.002.

Franke, T., Schmalfuß, F., Rauh, N., 2018. Human Factors and Ergonomics in the Individual Adoption and Use of Electric Vehicles, in: Thatcher, A., Yeow, P.H. (Eds.), Ergonomics and Human Factors for a Sustainable Future. Springer Singapore, Singapore, pp. 135–160.

Fritsche, I., Barth, M., Jugert, P., Masson, T., Reese, G., 2018. A social identity model of pro-environmental action (SIMPEA). Psychological review 125 (2), 245–269. 10.1037/rev0000090.

Gigerenzer, G., Gaissmaier, W., 2011. Heuristic decision making. Annual review of psychology 62, 451–482. 10.1146/annurev-psych-120709-145346.

Goedkoop, F., Sloot, D., Jans, L., Dijkstra, J., Flache, A., Steg, L., 2022. The Role of Community in Understanding Involvement in Community Energy Initiatives. Frontiers in psychology 12, 775752. 10.3389/fpsyg.2021.775752.

Groot, J.I.M. de, Steg, L., 2008. Value Orientations to Explain Beliefs Related to Environmental Significant Behavior. Environment and Behavior 40 (3), 330–354. 10.1177/0013916506297831.

Gschwendtner, C., Knoeri, C., Stephan, A., 2023. The impact of plug-in behavior on the spatial–temporal flexibility of electric vehicle charging load. Sustainable Cities and Society 88, 104263. 10.1016/j.scs.2022.104263.

Hahnel, U.J., Fell, M.J., 2022. Pricing decisions in peer-to-peer and prosumer-centred electricity markets: Experimental analysis in Germany and the United Kingdom. Renewable and Sustainable Energy Reviews 162, 112419. 10.1016/j.rser.2022.112419.

Hahnel, U.J., Herberz, M., Pena-Bello, A., Parra, D., Brosch, T., 2020. Becoming prosumer: Revealing trading preferences and decision-making strategies in peer-to-peer energy communities. Energy Policy 137. 10.1016/j.enpol.2019.111098.

Hamann, K.R., Bertel, M.P., Ryszawska, B., Lurger, B., Szymański, P., Rozwadowska, M., Goedkoop, F., Jans, L., Perlaviciute, G., Masson, T., Fritsche, I., Favaro, T., Hofer, A., Eisenberger, I., Gutschi, C., Grosche, C., Held, J., Athenstaedt, U., Corcoran, K., 2023. An interdisciplinary understanding of energy citizenship: Integrating psychological, legal, and economic perspectives on a citizen-centred sustainable energy transition. Energy Research & Social Science 97, 102959. 10.1016/j.erss.2023.102959.

Hargreaves, T., Hielscher, S., Seyfang, G., Smith, A., 2013. Grassroots innovations in community energy: The role of intermediaries in niche development. Global Environmental Change 23 (5), 868–880. 10.1016/j.gloenvcha.2013.02.008.

Haustein, S., Jensen, A.F., Cherchi, E., 2021. Battery electric vehicle adoption in Denmark and Sweden: Recent changes, related factors and policy implications. Energy Policy 149. 10.1016/j.enpol.2020.112096.

Heilmann, C., Friedl, G., 2021. Factors influencing the economic success of grid-to-vehicle and vehicle-to-grid applications—A review and meta-analysis. Renewable and Sustainable Energy Reviews 145, 111115. 10.1016/j.rser.2021.111115.

Hilbe, C., Chatterjee, K., Nowak, M.A., 2018. Partners and rivals in direct reciprocity. Nature human behaviour 2 (7), 469–477. 10.1038/s41562-018-0320-9.

Hoffman, S.M., High-Pippert, A., 2010. From private lives to collective action: Recruitment and participation incentives for a community energy program. Energy Policy 38 (12), 7567–7574. 10.1016/j.enpol.2009.06.054.

Hossain, M., 2016. Grassroots innovation: A systematic review of two decades of research. Journal of Cleaner Production 137, 973–981. 10.1016/j.jclepro.2016.07.140.

Huber, J., Schaule, E., Jung, D., Weinhardt, C., 2019. Quo Vadis Smart Charging? A Literature Review and Expert Survey on Technical Potentials and User Acceptance of Smart Charging Systems. WEVJ 10 (4). 10.3390/wevj10040085.

Huijts, N., Molin, E., Steg, L., 2012. Psychological factors influencing sustainable energy technology acceptance: A review-based comprehensive framework. Renewable and Sustainable Energy Reviews 16 (1), 525–531. 10.1016/j.rser.2011.08.018.

Jackson, T., 2005. Motivating Sustainable Consumption: a review of evidence on consumer behaviour and behavioural change. a report to the Sustainable Development Research Network. Sustain Dev Res Netw 29.

Jansson, J., Marell, A., Nordlund, A., 2011. Exploring consumer adoption of a high involvement eco-innovation using value-belief-norm theory. Journal of Consumer Behaviour 10 (1), 51–60. 10.1002/cb.346.

Kahneman, D., 2003a. Maps of Bounded Rationality: Psychology for Behavioral Economics. American Economic Review 93 (5), 1449–1475. 10.1257/000282803322655392.

Kahneman, D., 2003b. Maps of Bounded Rationality: Psychology for Behavioral Economics. The American Economic Review 93 (5), 1449–1475.

Kalkbrenner, B.J., Roosen, J., 2016. Citizens' willingness to participate in local renewable energy projects: The role of community and trust in Germany. Energy Research & Social Science 13, 60–70. 10.1016/j.erss.2015.12.006.

Kempton, W., Tomić, J., 2005. Vehicle-to-grid power fundamentals: Calculating capacity and net revenue. Journal of Power Sources 144 (1), 268–279. 10.1016/j.jpowsour.2004.12.025.

Klöckner, C.A., 2014. The dynamics of purchasing an electric vehicle – A prospective longitudinal study of the decision-making process. Transportation Research Part F: Traffic Psychology and Behaviour 24, 103–116. 10.1016/j.trf.2014.04.015.

Knezovic, K., Martinenas, S., Andersen, P.B., Zecchino, A., Marinelli, M., 2017. Enhancing the Role of Electric Vehicles in the Power Grid: Field Validation of Multiple Ancillary Services. IEEE Trans. Transp. Electrific. 3 (1), 201–209. 10.1109/TTE.2016.2616864.

Koirala, B.P., Araghi, Y., Kroesen, M., Ghorbani, A., Hakvoort, R.A., Herder, P.M., 2018a. Trust, awareness, and independence: Insights from a socio-psychological factor analysis of citizen knowledge and participation in community energy systems. Energy Research & Social Science 38, 33–40. 10.1016/j.erss.2018.01.009.

Koirala, B.P., van Oost, E., van der Windt, H., 2018b. Community energy storage: A responsible innovation towards a sustainable energy system? Applied Energy 231, 570–585. 10.1016/j.apenergy.2018.09.163.

Krueger, H., Cruden, A., 2020. Integration of electric vehicle user charging preferences into Vehicle-to-Grid aggregator controls. Energy Reports 6, 86–95. 10.1016/j.egyr.2020.02.031.

Lanz, L., Noll, B., Schmidt, T.S., Steffen, B., 2022. Comparing the levelized cost of electric vehicle charging options in Europe. Nature communications 13 (1), 5277. 10.1038/s41467-022-32835-7.

Lee, S.S., Kim, Y., Roh, T., 2023. Pro-environmental behavior on electric vehicle use intention: Integrating value-belief-norm theory and theory of planned behavior. Journal of Cleaner Production 418, 138211. 10.1016/j.jclepro.2023.138211.

López-Mosquera, N., Sánchez, M., 2012. Theory of Planned Behavior and the Value-Belief-Norm Theory explaining willingness to pay for a suburban park. Journal of environmental management 113, 251–262. 10.1016/j.jenvman.2012.08.029.

Lüth, A., Zepter, J.M., Del Crespo Granado, P., Egging, R., 2018. Local electricity market designs for peer-to-peer trading: The role of battery flexibility. Applied Energy 229, 1233–1243. 10.1016/j.apenergy.2018.08.004.

McBain, S.M., Axsen, J., Wilson, C., 2023. Function, symbolism or society? Exploring consumer interest in electric and shared mobility. Transportation Research Part D: Transport and Environment 118, 103675. 10.1016/j.trd.2023.103675.

Middlemiss, L., 2011. The effects of community-based action for sustainability on participants' lifestyles. Local Environment 16 (3), 265–280. 10.1080/13549839.2011.566850.

Namazkhan, M., Albers, C., Steg, L., 2019. The role of environmental values, socio-demographics and building characteristics in setting room temperatures in winter. Energy 171, 1183–1192. 10.1016/j.energy.2019.01.113.

Nielsen, K.S., Cologna, V., Bauer, J.M., Berger, S., Brick, C., Dietz, T., Hahnel, U.J.J., Henn, L., Lange, F., Stern, P.C., Wolske, K.S., 2024. Realizing the full potential of behavioural science for climate change mitigation. Nature Clim Change 14 (4), 322–330. 10.1038/s41558-024-01951-1.

Nilsson, A., Lazarevic, D., Brandt, N., Kordas, O., 2018. Household responsiveness to residential demand response strategies: Results and policy implications from a Swedish field study. Energy Policy 122, 273–286. 10.1016/j.enpol.2018.07.044.

Nowak, M.A., 2006. Five rules for the evolution of cooperation. Science (New York, N.Y.) 314 (5805), 1560–1563. 10.1126/science.1133755.

Oteman, M., Wiering, M., Helderman, J.-K., 2014. The institutional space of community initiatives for renewable energy: a comparative case study of the Netherlands, Germany and Denmark. Energ Sustain Soc 4 (1). 10.1186/2192-0567-4-11.

Parra, D., Swierczynski, M., Stroe, D.I., Norman, S., Abdon, A., Worlitschek, J., O'Doherty, T., Rodrigues, L., Gillott, M., Zhang, X., Bauer, C., Patel, M.K., 2017. An interdisciplinary review of energy storage for communities: Challenges and perspectives. Renewable and Sustainable Energy Reviews 79, 730–749. 10.1016/j.rser.2017.05.003.

Postmes, T., Haslam, S.A., Jans, L., 2013. A single-item measure of social identification: reliability, validity, and utility. The British journal of social psychology 52 (4), 597–617. 10.1111/bjso.12006.

Proka, A., Hisschemöller, M., Loorbach, D., 2020. When top-down meets bottom-up: Is there a collaborative business model for local energy storage? Energy Research & Social Science 69. 10.1016/j.erss.2020.101606.

Ptak, T., Nagel, A., Radil, S.M., Phayre, D., 2018. Rethinking community: Analyzing the landscape of community solar through the community-place nexus. The Electricity Journal 31 (10), 46–51. 10.1016/j.tej.2018.11.006.

Rees, J.H., Bamberg, S., 2014. Climate protection needs societal change: Determinants of intention to participate in collective climate action. Euro J Social Psych 44 (5), 466–473. 10.1002/ejsp.2032.

Reis, I.F., Gonçalves, I., Lopes, M.A., Henggeler Antunes, C., 2021. Business models for energy communities: A review of key issues and trends. Renewable and Sustainable Energy Reviews 144. 10.1016/j.rser.2021.111013.

Rivas, J., Schmid, B., Seidl, I., 2018. Energiegenossenschaften in der Schweiz: Ergebnisse einer Befragung. WSL Berichte 71, Birmensdorf, 108 pp. www.wsl.ch/berichte. Accessed 16 February 2023.

Schlüter, M., Müller, B., Frank, K., 2019. The potential of models and modeling for social-ecological systems research: the reference frame ModSES. E&S 24 (1). 10.5751/ES-10716-240131.

Schram, W.L., Aghaie, H., Lampropoulos, I., van Sark, W.G., 2021. Insights on the capacity value of photovoltaics, community batteries and electric vehicles. Sustainable Energy, Grids and Networks 26, 100421. 10.1016/j.segan.2020.100421.

Schwanitz, V.J., Wierling, A., Arghandeh Paudler, H., Beck, C. von, Dufner, S., Koren, I.K., Kraudzun, T., Marcroft, T., Mueller, L., Zeiss, J.P., 2023. Statistical evidence for the contribution of citizen-led initiatives and projects to the energy transition in Europe. Scientific reports 13 (1). 10.1038/s41598-023-28504-4.

Schwartz, S.H., 1973. Normative explanations of helping behavior: A critique, proposal, and empirical test. Journal of Experimental Social Psychology 9 (4), 349–364. 10.1016/0022-1031(73)90071-1.

Schwartz, S.H., 1992. Universals in the Content and Structure of Values: Theoretical Advances and Empirical Tests in 20 Countries, in: Zanna, M.P. (Ed.), Advances in Experimental Social Psychology, vol. 25. Academic Press, I. N.C., pp. 1–65.

Seyfang, G., Smith, A., 2007. Grassroots innovations for sustainable development: Towards a new research and policy agenda. Environmental Politics 16 (4), 584–603. 10.1080/09644010701419121.

Sharpe, E., Ruepert, A., van der Werff, E., Steg, L., 2022. Corporate environmental responsibility leads to more pro-environmental behavior at work by strengthening intrinsic pro-environmental motivation. One Earth 5 (7), 825–835. 10.1016/j.oneear.2022.06.006.

Simon, H.A., 1955. A behavioral model of rational choice. Q. J. Econ 69, 99–118.

Simon, H.A., 1982. Models of Bounded Rationality. MIT Press.
Sintov, N.D., Schultz, P.W., 2015. Unlocking the potential of smart grid technologies with behavioral science. Frontiers in psychology 6, 410. 10.3389/fpsyg.2015.00410.
Sloot, D., Jans, L., Steg, L., 2018. Can community energy initiatives motivate sustainable energy behaviours? The role of initiative involvement and personal pro-environmental motivation. Journal of Environmental Psychology 57, 99–106. 10.1016/j.jenvp.2018.06.007.
Sloot, D., Jans, L., Steg, L., 2019. In it for the money, the environment, or the community? Motives for being involved in community energy initiatives. Global Environmental Change 57, 2–10. 10.1016/j.gloenvcha.2019.101936.
Sloot, D., Lehmann, N., Ardone, A., 2022. Explaining and promoting participation in demand response programs: The role of rational and moral motivations among German energy consumers. Energy Research & Social Science 84, 1–15. 10.1016/j.erss.2021.102431.
Sovacool, B.K., Axsen, J., Kempton, W., 2017. The Future Promise of Vehicle-to-Grid (V2G) Integration: A Sociotechnical Review and Research Agenda. Annu. Rev. Environ. Resour. 42 (1), 377–406. 10.1146/annurev-environ-030117-020220.
Sovacool, B.K., Hirsh, R.F., 2009. Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition. Energy Policy 37 (3), 1095–1103. 10.1016/j.enpol.2008.10.005.
Spence, A., Demski, C., Butler, C., Parkhill, K., Pidgeon, N., 2015. Public perceptions of demand-side management and a smarter energy future. Nature Clim Change 5 (6), 550–554. 10.1038/nclimate2610.
Steg, L., 2016. Values, Norms, and Intrinsic Motivation to Act Proenvironmentally. Annu. Rev. Environ. Resour. 41 (1), 277–292. 10.1146/annurev-environ-110615-085947.
Steg, L., Dreijerink, L., Abrahamse, W., 2005. Factors influencing the acceptability of energy policies: A test of VBN theory. Journal of Environmental Psychology 25 (4), 415–425. 10.1016/j.jenvp.2005.08.003.
Steg, L., Groot, J.I.M. de (Eds.), 2012. Environmental Values. Oxford University Press.
Steg, L., Perlaviciute, G., van der Werff, E., 2015. Understanding the human dimensions of a sustainable energy transition. Frontiers in Psychology (Front. Psychol.).
Steg, L., Perlaviciute, G., van der Werff, E., Lurvink, J., 2014. The Significance of Hedonic Values for Environmentally Relevant Attitudes, Preferences, and Actions. Environment and Behavior 46 (2), 163–192. 10.1177/0013916512454730.
Steg, L., Shwom, R., Dietz, T., 2018. What Drives Energy Consumers?: Engaging People in a Sustainable Energy Transition. IEEE Power and Energy Mag. 16 (1), 20–28. 10.1109/MPE.2017.2762379.
Stern, P.C., Dietz, T., Abel, T., Guagnano, G.A., Kalof, L., 1999. A Value-Belief-Norm Theory of Support for Social Movements: The Case of Environmentalism. Human Ecology Reviews (6), 81–97.
Stern, P.C., Dietz, T., Guagnano, G.A., 1998. A Brief Inventory of Values. Educational and Psychological Measurment (58), 984–1001.
van der Werff, E., Steg, L., 2016. The psychology of participation and interest in smart energy systems: Comparing the value-belief-norm theory and the value-identity-personal norm model. Energy Research & Social Science 22, 107–114. 10.1016/j.erss.2016.08.022.

van der Werff, E., Steg, L., Keizer, K., 2013. It is a moral issue: The relationship between environmental self-identity, obligation-based intrinsic motivation and pro-environmental behaviour. Global Environmental Change 23 (5), 1258–1265. 10.1016/j.gloenvcha.2013.07.018.

van Heuveln, K., Ghotge, R., Annema, J.A., van Bergen, E., van Wee, B., Pesch, U., 2021. Factors influencing consumer acceptance of vehicle-to-grid by electric vehicle drivers in the Netherlands. Travel Behaviour and Society 24, 34–45. 10.1016/j.tbs.2020.12.008.

Verburg, P.H., Dearing, J.A., Dyke, J.G., van der Leeuw, S., Seitzinger, S., Steffen, W., Syvitski, J., 2016. Methods and approaches to modelling the Anthropocene. Global Environmental Change 39, 328–340. 10.1016/j.gloenvcha.2015.08.007.

Vernay, A.-L., Sebi, C., Arroyo, F., 2023. Energy community business models and their impact on the energy transition: Lessons learnt from France. Energy Policy 175, 113473. 10.1016/j.enpol.2023.113473.

Walker, C., Poelzer, G., Leonhardt, R., Noble, B., Hoicka, C., 2022. COPs and 'robbers?' Better understanding community energy and toward a Communities of Place then Interest approach. Energy Research & Social Science 92. 10.1016/j.erss.2022.102797.

Wierling, A., Schwanitz, V.J., Zeiss, J.P., Beck, C. von, Paudler, H.A., Koren, I.K., Kraudzun, T., Marcroft, T., Müller, L., Andreadakis, Z., Candelise, C., Dufner, S., Getabecha, M., Glaase, G., Hubert, W., Lupi, V., Majidi, S., Mohammadi, S., Nosar, N.S., Du Pont, Y.R., Roots, P., Rudek, T.J., Sciullo, A., Sehdev, G., Ziaabadi, M., Zoubin, N., 2023. A Europe-wide inventory of citizen-led energy action with data from 29 countries and over 10000 initiatives. Scientific data 10 (1), 9. 10.1038/s41597-022-01902-5.