EVS32 Symposium
Lyon, France, May 19 - 22, 2019

Quo vadis smart charging? A literature review and expert survey on technical potentials and user acceptance of smart charging systems

Julian Huber[1], Elisabeth Schaule [2], Dominik Jung[2], Christof Weinhardt[2]
[1]*FZI Forschungszentrum Informatik, Germany, julian.huber@fzi.de*
[2]*Karlsruhe Institute of Technology, Germany*

Executive Summary

Uncontrolled charging of plug-in Battery Electric Vehicles (BEV) represents a challenge for the energy system. As a solution, recent studies propose smart charging, or intelligently controlled charging that can avoid grid congestion and integrate renewable energy. While financial benefits for smart charging schemes are currently quite low, there are other reasons for smart charging. However, it is unclear for which objectives smart charging can be used most effectively and which arguments are most likely to convince end users of BEVs to use smart charging schemes. To fill this gap, we conduct a literature review on the objectives of smart charging and how they fit the users motivation to use such smart charging systems. Based on the findings, we present a survey of 16 domain experts who evaluated various statements on smart charging according to their technical correctness and their persuasiveness towards end users. The results show that experts consider those smart charging objectives as most persuasive towards end users which they consider technically correct. Moreover, cost savings and integration of renewable energies are rated highest on both scales. On the contrary, a positive impact of smart charging systems on battery life is rated as rather low and not very convincing.

1 Introduction

Road transportation accounts for 20% of global CO_2 emissions and contributes to the emission of air pollutants within cities. Battery Electric Vehicles (BEV) do not emit any local air pollutants and can be operated CO_2 neutral. Therefore, governments and industry have set ambitious goals for the diffusion of BEVs [1]. However, compared to other electric consumers in households, BEVs have a high peak demand. Moreover, a high degree of simultaneity of the charging demand can be expected. These peaks can challenge the electric grid even at low penetration rates [2].
Smart charging systems use flexibility within the charging process to achieve different optimization objectives. For example, a grid operator can flatten load peaks to avoid grid congestion and thus expensive network expansion, while an electricity supplier can use flexibility to react in price spikes or lower balancing costs. Smart charging systems can further shift the charging process towards times with lower shares of conventional generation within a generation portfolio, which can result in lower prices and CO_2 emissions during charging [3]. A review on algorithms that describe the smart or coordinated charging can be found in [4]. These algorithms require the end users to accept a certain amount of flexibility in their charging process.
In the following, we define smart charging system as an information system that optimizes the charging process towards one or multiple objectives. Typical objectives are technical, financial, and socio-environmental goals [5] as outlined above. The solution space for the optimization of these objectives

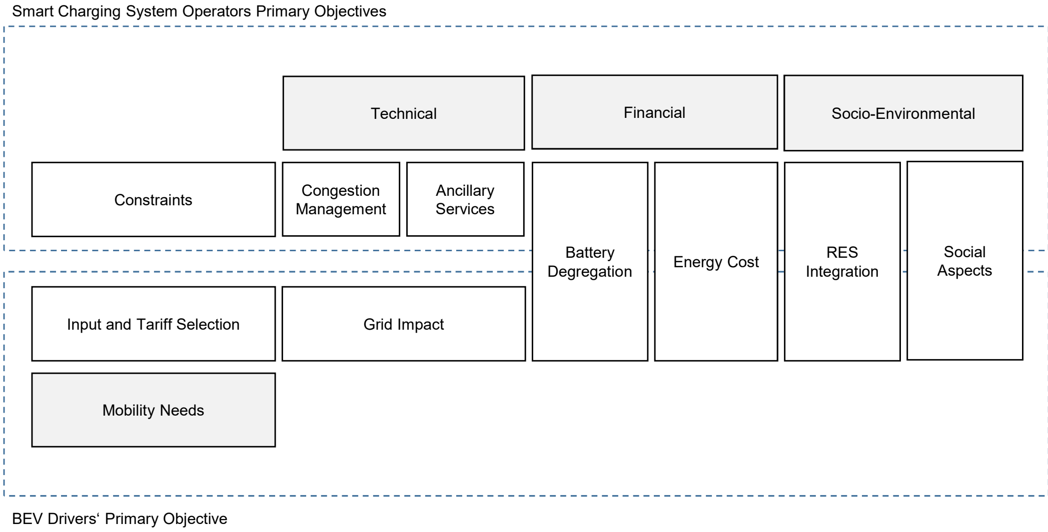

Figure 1: Objectives of Smart Charging System Operators and BEV Drivers

is restrained by the technical properties of the charging system (i. e., the BEV and the charging station) and the willingness of end user to accept a delay in charging or a reduction in the final State of Charge (SoC). The BEV driver can either input this restrictions explicitly in some of the smart charging systems (e. g., via an smart phone application) or accept a certain degree of smart charging by the choice of his charging tariff (e. g., [6]). Figure 1 shows the main objectives of smart charging systems from the perspective of the operator of the smart charging system and the BEV drivers. While the BEV drivers main objective is the fulfillment of their mobility needs, they resemble the constraints for optimizing the objectives of smart charging systems. However, the acceptance for the use of such systems depend on the objective of the smart charging system. For instance, [7] find that smart charging systems are more likely to be accepted if they ensure grid stability and RES integration instead of pure financial benefit. Hence, we argue that the choice of objective function can be an incentive for end users to use smart charging systems. Based on the success of the energy-conservation programs, [8] propose that message framing could nudge people to become more flexible with using a smart charging system.
Therefore, successful business models based on smart charging systems must bring together the end user's motivation to use such systems (lower part of Figure 1) and a financially rewarding objective function for the operator of the smart charging system (upper part of the figure). This opens a large solution space for the design of smart charging systems. To provide guidance and give design recommendations for practitioners and scholars, we investigate the most promising applications for smart charging based on a literature review and a survey of domain experts. For that purpose, this paper answers the following research questions:

RQ 1.1: What are objectives of charging system operators present in academic literature?

RQ 1.2: What incentives motivate BEV drivers to use smart charging systems?

RQ 2: Do the most promising objectives of smart charging system operators fit the BEV drivers motivation to use smart charging systems?

The remainder of the paper is structured as follows: In Section 2, we conduct a structured literature review based on the methodology of [9] to answer RQ 1.1 and 1.2. The findings are based on 1.056 articles from the fields of computer science, economics, and engineering between 1980 [10] and 2019.
In a second step, in Section 3, we conduct an expert survey to answer RQ 2. Based on eight incentive factors for smart charging found in the literature review we derived statements on the benefits of smart charging and ask sixteen domain experts to evaluate this statements on their technical correctness and

their persuasiveness for end users. In a last step, in Section 4, we summarize the results and resulting design principle for smart charging systems to provide design recommendations for information system researchers and designers.

2 Literature Review

Overall, there is a vast amount of literature on *'Smart Charging'*. A Google Scholar yields 823.000 hits as of January 2019. In this chapter, we first describe related works and try to classify literature on smart charging. First, we focus on *RQ1.1* and discuss recent objectives on smart charging systems. Last, we describe the results of the review on motivational factors of smart charging answering *RQ1.2*.

2.1 Reviews on Smart Charging Systems

The authors of [11] outline the technical environment by reviewing battery charger topologies, charging power levels, and charging infrastructure. They distinguish between unidirectional and bidirectional vehicle to grid (V2G) energy and information flows. While unidirectional systems can provide reactive power and provide frequency regulation in one direction by cutting the charging load. Bidirectional systems allow for additional use cases (e. g., can replacement of spinning reserves). On the downside, such applications can age the battery faster due to the frequent circling. Similarly, [12] provide a review of smart charging approaches where they differentiate between V2G and non-V2G concepts. They further analyze the charging systems main objectives, solvers and tools, software, and strategy used. The paper lists frequency regulation, voltage regulation, generation costs, charging cost, provision of ancillary services, minimization of power loss, renewable integration, adaption of load factor and variance, and optimized operation of distribution networks as possible objectives. Meanwhile, [13] focus on the single objective of renewable energy sources integration and provide a review on the potential, impacts, and limitations of V2G technologies. Despite this broad overview, it has not yet been further considered which objectives of smart charging are most strongly addressed and how these objectives are perceived by the users of the systems (i. e., BEV drivers).

2.2 Operators Objectives of Smart Charging Systems

To answer *RQ 1.1* we structure our literature review as follows. First, we select three literature databases covering the fields of computer science, economics, and engineering. As a search term we start with using *'vehicle ∧ charging'*. This search results in several thousand matches spanning topics as charging protocols, route planning, and battery management systems. To narrow down the search space towards the objectives of smart charging systems, we add the terms *'objective ∧ incentive ∧ acceptance'*. This results in the initial 1.056 results of matches noted in Table 1.

	Search Term		
	vehicle ∧ charging ∧		
	objective	*incentive*	*acceptance*
ACM Digital Library	17	6	10
IEEE Explore	422	75	69
ScienceDirect	319	120	98

Table 1: Matches for the search term in different data bases

We focus on a concept-centric approach as proposed in [9]. Using a subset of the initial 1.056 results of papers (the 422 matches from IEEE Explore on smart charging objectives) we analyzed their title and abstracts to identify key concepts. As expected, most paper in the initial 1.056 results describe the design, optimization, and scheduling on charging process of electric vehicles. However the concepts differ in scope and perspective: A fist group of papers focuses on gird or **system operators** who centrally control the charging process of many BEVs to provide system services, optimize power flow, dispatch, or avoid congestion. (e. g., in [14]). This can be either an integrated system operator who manages both energy generation and grid operation or grid operators solely optimizing grip operation. The next group focuses on **charging station operators** or aggregators, who coordinate the charging process of multiple BEVs to optimize their outcome on market level (e. g., matching charging with an product or generation portfolio or using the flexibility of the charging portfolio on reserve markets [15]). Some papers focus on **end users** optimizing the charging of a single BEV, often to match consumption with a local energy resource in their home energy management systems (e. g., [16]).
The smart charging systems pursue different objective functions according to the perspective. The identified concepts match what has been described in the review of [12]. We use the dimensions from [5] for a broader categorization:

Financial

The financial dimension includes all objectives that focus on cost advantages realized by smart charging and the pricing of charging services. Cost advantage is mostly considered by optimizing towards dynamic prices on the energy markets (e. g., [17, 18]). However, some authors also consider using the flexibility in smart charging on frequency reserve markets [19]. One objective not mentioned in [12] but in [5] is the minimization of battery degradation. As battery degradation is influenced by a cyclic term some authors propose to control charging in a battery protecting manner [20]. Others consider battery degradation a constrained to be considered in economic optimization [21]. Like [5] we consider battery degradation to be part of the financial dimension, since the battery lifetime has a direct financial impact on the BEV owner and, unlike the other points of the technical dimension, is not related to the grid.

Technical

The technical dimension affects the financial dimension, if, as in [22], an integrated system operator manages the generation dispatch and the power grid at the same time. Besides matching the generation, smart charging can also be a tool in congestion management [16] and provide system stability in the form of different ancillary services as frequency regulation, voltage regulation, and minimization of power loss (see [14, 23]).

Socio-Environmental

Flexibility in smart charging systems can also mitigate the uncertainty in wind [24] or Photo Voltaic (PV) [25] generation to integrate a higher share of RES and therefore can help to reduce carbon emission of the energy generation [3]. Other authors consider fairness [17] in scheduling of the chairing loads and discuss of community based charging stations [26].

2.3 Trend Analysis for Smart Charging Objectives

We list the identified objectives in Table 2. As described above, we put cost advantage and battery degradation in the financial dimension, congestion management and ancillary services in the technical dimension, and social aspects and integration of RES in the socio-environmental dimension.
Note that there are other structures and concepts, that can differentiate smart charging systems: The coordination can occur by decentralized or centralized control. Models differ in their assumptions on the flexibility of the charging process and model them either as an interrupting load or as batteries in V2G concepts. The scheduling of loads is based on different methods such as heuristics, genetic algorithms, or optimization. However, those concepts do not help in answering the research question and are not further considered.
Next, we analyze the occurrence of those concepts in the initial 1.056 results of literature matches. Table 2 contains keywords that indicate, whether the paper considers an given objective. E. g., a paper containing the words *'lifetime', 'life time', degradation',* or *'aging'* is likely to consider battery degradation within the smart charging system. We therefore conduct an automated search through the titles and abstracts in the initial 1.056 results. We discard all articles not containing any of the keywords as irrelevant. The 1.056 results are stored in the from of Table 3.

Objectives	Concept Indicators Keywords	Source
Battery degradation	*'lifetime', 'life time', 'degregation', 'aging'*	[20]
Cost advantage	*'market', 'day ahead', 'cost'*	[27]
Social aspects	*'social', 'fairness'*	[28]
Integration of RES (renewable energy sources)	*'PV', 'pv', 'wind', 'RES'*	[7]
Congestion management	*'load curve', 'flattening', 'peak', 'congestion'*	[7]
Ancillary services	*'frequency', 'voltage', 'power quality', 'losses'*	[7]

Table 2: Objectives for smart charging

Table 3 shows the results of the screening of the literature. As an example is holds the three most cited articles fond in the 1.056 results. The first paper [22] proposes a real time coordination mechanism to control multiple BEVs charging to minimize generation costs and grid losses. The keyword indicator also recognize the objectives cost minimization (i. e., the generation costs) and ancillary services (i. e., minimization of grid losses). However, the point is view (the system operator) is not detected. Meanwhile, [29] is classified as ancillary. Indeed, the paper describes the coordination of electric vehicles to minimize distribution system losses. However there is no keyword indication of the perspective of the

	Perspective			Objective					
Source	System Operator	Aggregator	End User	Battery	Cost	Social	RES	Congestion	Ancillary
[22]					●				●
[29]									●
[30]	●		●					●	
...									
Sum	112	76	89	125	634	74	293	225	309

Table 3: Results of the literature review

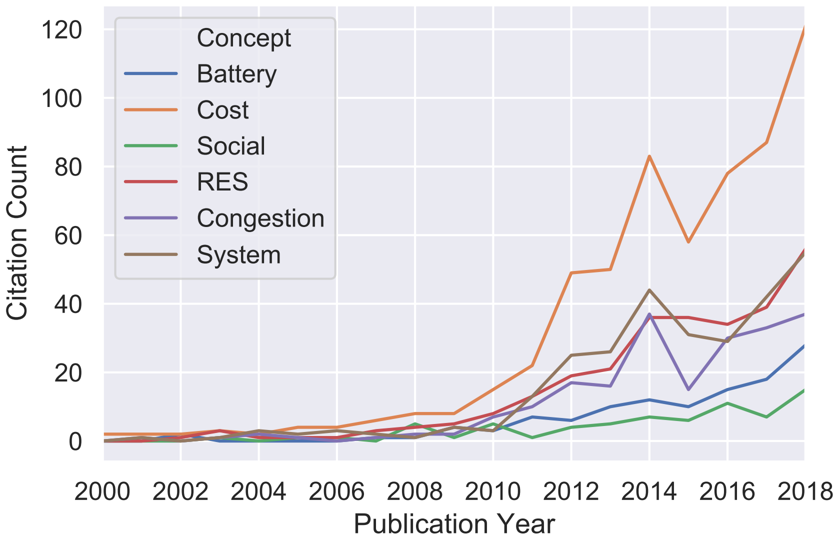

Figure 2: Occurrence of keywords in literature over time

smart charging system operator. [30] uses a decentralized algorithm to coordinate charging between a utility company and car users. This way both, the point of view of the system operator as well as of the end user is considered. The algorithm shifts the charging loads to fill the valleys in order to avoid congestion.

As seen in Table 3 scientific literature often (in 112 cases) assumes the existence of an integrated system operator that manages both energy procurement and the distribution system. As a consequence, they often consider more than one objective in smart charging (i. e., cost reduction and congestion management). In doing so, financial optimization is often the main objective (e. g., if loading flexibility is used to minimize generation costs and line losses that also can be expressed as costs). An aggregator that only focuses on the market and an end user that optimizes his consumption locally is much less in focus. Furthermore, we find evidence that cost minimization is the main objective of optimization (mentioned 634 times). As cost minimization can often be achieved by aligning consumption with the generation from RES, RES also emerge quite frequently. Congestion management and other auxiliary services are are mentioned at a similar frequency. Just under 10% of the work address social aspects and battery degradation in their abstracts. As pictured in Figure 2 there is a rising interest in all topics over time.

2.4 BEV Drivers Motivation to use Smart Charging Systems

In [7] the authors provide a review on twelve studies that research the acceptance factors of smart charging. Most of the study consider the financial (monetary incentives) and socio-environmental (RES integration) dimension as positive factors. Three out of twelve studies postulate technical aspects (contribution to grid stability) as an motivation factor. For instance, the same authors [7] conduct a survey with 237 BEV users and find an positive influence of RES integration and grid stability on the acceptance of smart charging systems. However, no positive influence of monetary incentives is reported. In contrary, in a interview survey with BEV drivers that used smart charging systems in a field trial, [31] find that financial benefits are an important motivational driver for the usage of such systems. They further name RES integration, contribution to grid stability, awareness of energy consumption, and satisfaction from gamification. In order to gain more recent insights, we perform a forward search for papers citing these two sources [31, 7].

While financial reward might not be sufficient to convince BEV drivers to use smart charging [7] it is yet an open challenge to win them over to use such systems. Especially, since they usually have only limited knowledge about the energy system [32].

This finding is in line with the review of [5] that presents a socio-technical approach for smart charging. They distinguish three types of user intervention in smart charging: Time-of-use pricing where the user receives price signals and actively decides when to charge his BEV. Revenue sharing, whereby users enter their flexibility in for the charging process and receive financial compensation in return. Last, a voluntary shift in charging based on education and non-material motives. The socio-technical dimensions for smart charging objectives, as already explained, are technical, financial, and socio-ecological. They also consider a behavioural dimension which is the BEV users perception of all the above factors.

A review provided by [33] analyzes the user interaction with BEVs and their charging behaviour in particular. They find that users have individual time-stable differences in the way they charge their cars. They further analyze that interaction with smart charging systems is costly for the user (with reduced mobility flexibility and increased planning effort). They suggest that smart charging systems are user-centered. This can be achieved by minimizing effort for the user and considering their objectives.

One of the few a surveys on the end-users perspective is a discreet-choice experiment by [34] among 611 (conventional) vehicle users, including 14 BEV drivers. The acceptance of uncontrolled and smart charging is higher (5.5 and 5.4 out of 7) than for V2G concepts. Financial and socio-ecological aspects are the main motivating factors. Technical aspects (avoidance of grid congestion and reserve power plants are less important). In addition, they find systematic differences in acceptance between different types of users (e. g., drivers with high mileage having different acceptance levels).

Insights from smart charging initiatives in the Netherlands are described in [35]. They describe eleven smart charging projects focusing on smart charging in households. The objectives in these projects are mainly financial and socio-economical. Five out them focus on two objectives at the same time (e. g., lowering energy cost while using more local renewables). Two of the project explicitly focus in the community aspect in the socio-economical dimension and almost all of the project try to benefit more than one stakeholder (e. g., end user, DSO, municipality,or aggregator) at the same time. Considering the objectives of BEV fleet operators [6] propose a new tariff design for smart charging. They conduct a survey with fleet operators and BEV drivers to optimize the tariff design. Both BEV drivers and fleet operators want a minimum level for state of charge of 100 km for emergencies. This states the importance of mobility needs for BEV drivers. In an earlier study [36] the same authors focus on fleet owners willingness-to-pay for smart charging services. Both, the guarantee of a minimum level for state of charge an the use of higher shares of renewable to minimize CO_2 emissions has an positive effect on their willingness-to-pay for smart charging services.

2.5 Fit between Operator and User Objectives

The reviews and surveys found in literature indicate that the smart charging system operators financial, socio-economic, and technical objectives are also promising motivation factors for BEV users to use such systems. Therefore, it is important to communicate the objectives and benefits of smart charging systems to BEV drivers in a way that is understandable and attractive to them.

Table 4 maps the identified objective functions from *RQ1.1* with arguments that could convince users to use smart charging systems from *RQ1.2*. The arguments base on the results of the studies collected in the previous section (mainly *'vehicle $\wedge$ charging $\wedge$ incentives'*) or from related research areas like energy conservation in households. They are explained in more detail below.

Battery degradation is a big concern of many BEV users [31]. Therefore, we assume that users would use smart charging systems capable of reducing battery degradation as proposed in [20] Although [37] find no significant influence, other studies show that cost benefits are one of the main drivers of smart charging. This is why cost benefits, which are passed on to the customer in revenue sharing concepts (see [5]), are expected make the user more flexible in charging. Socio-economic aspects as fairness and community aspects are not focused in most smart charging systems. However, they play a role in implementation and design of such systems. Research on energy consumption in households has shown that normative information and feedback on neighbours' electricity consumption can reduce electricity consumption by households. Similarly, aspects and the idea of sharing the power grid within a community could also provide an incentive to charge more flexibly [8]. The integration of a higher percentage

Objective	Incentive	Source
Battery degradation	Battery degradation	[20, 31]
Cost advantage	Cost advantage	[27, 31, 39]
Social aspects	Social aspects	[28]
Integration of RES	Integration of RES	[7]
	Environmental protection	[28]
	Health impact	[38]
	Climate impact	[40, 3]
Congestion management and ancillary services	Grid impact	[7]

Table 4: Mapping of smart charging objectives with possible incentives

of renewable energies has several advantages and can be framed towards the user from different angles. First, the information about the share of renewable energies in the energy supply mix can motivate and influence users. Therefore, Germany specifies electricity suppliers to print their generation mix on the customers electricity bill. Second, the displacement of conventional power plants reduces emissions of air pollutants. Studies on energy savings show that households consume less energy if they are informed that this results in fewer air pollutants being emitted, thereby preventing respiratory diseases [38]. In addition to air pollutants, carbon dioxide emissions can be avoided by load shifting, what could motivate users to use less energy or be more flexible in consumption. Finally, congestion management and provision of auxiliary services are summarized under grid impact. According to [37], concerns about grid stability has a positive influence on the acceptance of smart charging. We assume that the end user does not differentiate between voltage quality, frequency, thermal overload, and other grid stability problems. In summary, the objectives of smart charging studied in the literature overlap well with the incentives that could convince BEV drivers to use smart charging systems. We illustrate this, in Table 4, which presents the mapping of promising incentives and smart charging objectives.

3 Expert Survey

The literature review shows that from the point of view of charging system operators, energy costs, integration of renewable, and auxiliary services are the main objectives of smart charging. At the same time, there are only a few studies that research which factors will convince BEV users to use smart charging systems. Although the motivational factors for the BEV users seem to agree with the objective functions of the operators, there is no clear picture on what are the most convincing motivation factors. Studies even contradict each other, for example [31] find a positive effect of financial incentives while [7] do not. Therefore, we conduct a survey with experts to examine their assessment of the potentials of motivational factors.

3.1 Research Design

To identify the most promising motivational factors and objectives, we first grouped the different arguments for smart charging into eight groups based on the results of the literature review (see Table 4). For each group we derive three to five one-sentence statements proclaiming the benefits of smart charging. After a revision round discussing the statements in a round of three scientists convened with with behavioural economics and electric mobility we resulted in 31 statements. Getting the agreement of the experts to assess statements is a standard procedure, which is also used in the Delphi method to reach consensus between expert opinions [41].
We then design an online survey for the evaluation of each statement regarding the arguments technical accuracy as well as their expected persuasiveness towards end users and allowed the participants to rate each statement independently in a five-level Likert scale from strong disagreement to strong agreement (compare [42]).
The survey was conducted in German in Germany. In the following we report the English translations of the responses. The evaluation of the statements are rated on a five-level Likert scale from disagreement *strongly disagree (stimmt nicht)* to *strongly agree (stimmt völlig)* to this statement being technically correct or persuasive. Technical accuracy was measured by agreement on *In my opinion, this statement is technically correct. (Diese Aussage scheint mir fachlich korrekt)*. The persuasiveness towards end users by agreement on *In my opinion this statement is able to convince users (Diese Aussage scheint mir Nutzer überzeugen zu können)*.

Incentive	Example Statement
Battery degradation	*Flexible charging can help protect the battery.*
Cost advantage	*Flexible charging allows the user to benefit from lower electricity prices.*
Social aspects	*The power grid is shared with other users and benefits from the fact that they are flexible when charging BEVs.*
Integration of RES	*If users provide charging flexibility, the BEV can be charged with more solar and wind power.*
Environmental protection	*Flexible charging allows more electricity from renewable energy sources to be used, thus protecting the environment.*
Health impact	*Charging flexibility can avoid conventional generation and thus save harmful emissions.*
Climate impact	*Additional temporal flexibility can make a positive contribution towards mitigating climate change.*
Grid impact	*Flexible charging contributes positively to grid stability.*

Table 5: Translation of examples for motivational statements used in the survey

Example statements for the distinct motivational factors a provided in Table 5. In addition, the participants were asked to rate their own ability to correctly evaluate the statements on their accuracy as well as there domain background.

We distributed the survey within a German state-founded research project[1] and other channels to professionals in the domain of electric mobility. The 16 completed survey included researchers in electric mobility (10), OEMs (1), grid operators (3), consultants for electric mobility providers, and cross-sector experts (2). As in incentive for each complete survey a donation of 5 Euros was made to an non-governmental organization concerned with sustainable mobility in Wrocaw, Poland.

3.2 Results

In Table 6 the motivational factors are listed based on the highest ranking in the two categories. It becomes evident that the two categories are ranked similarly - that is what is viewed as correct is also viewed as persuasive with only minor differences. The motivational factors 'Integration of RES', 'Cost advantage' and 'Environmental protection' are rated with the highest persuasiveness (ranging from 4.4 to 3.9 out of the maximum 5). These groups, along with 'Grid impact' are also the top rated in accuracy (ranging from 4.4 to 4.2).

Group ranking	Avg accuracy	Group ranking	Avg persuasiveness
Grid impact	4.4	Cost advantage	4.4
Integration of RES	4.4	Integration of RES	4.1
Cost advantage	4.3	Environmental protection	3.9
Environmental protection	4.2	Climate impact	3.6
Climate impact	3.8	Grid impact	3.5
Health impact	3.6	Social aspects	3.3
Social aspects	3.4	Health impact	3.1
Battery conservation	2.9	Battery conservation	2.9

Table 6: Ranking of groups based on accuracy and persuasiveness rating

The domain experts were very confident in their evaluation: 13 out of 16 agreed or agreed strongly to the statement that they could correctly assess the technical accuracy of the statements, only 3 out of 16 said they partly agreed.

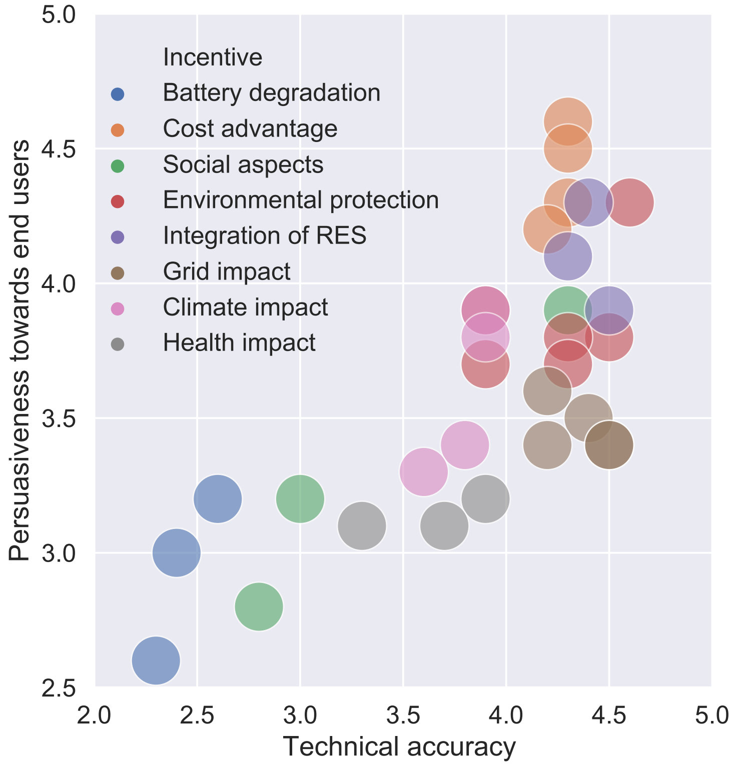

Figure 3: Statements evaluated on their technical accuracy (x-axis) and persuasiveness towards end users (y-axis)

3.3 Discussion

In Figure 3 all statements are depicted in a scatter plot in the two dimensions. The plot shows that the statements of a motivational clusters always come close together. This indicates that valid pre-selection and allocation of the statements to the clusters.
However, there is one exception visible in Figure 3: One statement regarding the social aspects of smart charging rates much higher than the other two. The statement rated higher reads: *The power grid is shared with other users and benefits from the fact that they are flexible when charging BEVs*. It combines social aspects (i. e., use of a common good) with grid impact. On the contrary, the other statements are normative messages without any mentioning of other objectives (*BEV users agree that charging should be flexible.* and *Others of the charging station usually allow smart charging.*).
The results show that experts consider those smart charging schemes as most persuasive which they consider technically correct. Moreover, cost savings and integration of renewable energies are rated highest on both scales. On the contrary, a positive impact of smart charging on battery degradation is rated as rather low and not very convincing.

4 Conclusion and Outlook

In this paper, we conduct a literature review to identify objectives of and incentives to use smart charging systems. From the point of view of the charging system operator cost advantage is the single most important objective. Minimizing the charging costs often also considers RES integration and the optimal operation the the energy system (by means of auxiliary services). These objectives are also important incentives for BEV users to use intelligent charging systems.
According to the experts' assessment, smart charging can contribute primarily to cost savings and the integration of RES and thus protect the environment. Meanwhile cost savings and the integration of RES have also been rated most convincingly. However, this assessment contradicts the findings of [7], where BEV users stated that financial incentives were not relevant for early adopters of BEVs. Although the avoidance of grid congestion is a relevant area of application, experts doubt that this field of application can convince users to use smart charging. To verify this findings, the experts' assessments could be reviewed in an experiment or survey with BEV users.

[1]https://www.csells.net/

The results indicate that the objectives of the system operators are well compatible with the objectives of the BEV users (see Figure 1). However, the objectives of the charging system operators can be framed towards the BEV users in different ways (e. g., the integration of RES can be framed as having a health or climate impact). The design of the user-friendly smart charging systems should therefore not only consider the operator's optimization objectives, but also how these targets are communicated to the BEV drivers.

Acknowledgments

The authors want to thank the Germany Federal Ministry for Economic Affairs and Energy for the funding and support. This research was partly financed by the Smart Energy Showcases - Digital Agenda for the Energy Transition (SINTEG) program.

References

[1] Georgina Santos. Road transport and co2 emissions: What are the challenges? *Transport Policy*, 59:71–74, 2017.

[2] K. Clement-Nyns, E. Haesen, and J. Driesen. The impact of charging plug-in hybrid electric vehicles on a residential distribution grid. *IEEE Transactions on Power Systems*, 25(1):371–380, 2010.

[3] Julian Huber and Christof Weinhardt. Waiting for the sun - can temporal flexibility in bev charging avoid carbon emissions? *Energy Informatics*, 1(1):49, Oct 2018.

[4] J. A. Peças Lopes, F. J. Soares, P. M. Almeida, and M. Moreira da Silva. Smart charging strategies for electric vehicles: Enhancing grid performance and maximizing the use of variable renewable energy resources. *EVS 24 Proceedings*, 2009.

[5] Benjamin K Sovacool, Jonn Axsen, and Willett Kempton. The future promise of vehicle-to-grid (v2g) integration: a sociotechnical review and research agenda. *Annual Review of Environment and Resources*, 42:377–406, 2017.

[6] Axel Ensslen, Philipp Ringler, Lasse Dörr, Patrick Jochem, Florian Zimmermann, and Wolf Fichtner. Incentivizing smart charging: Modeling charging tariffs for electric vehicles in german and french electricity markets. *Energy Research and Social Science*, 42:112–126, 2018.

[7] Christian Will and Alexander Schuller. Understanding user acceptance factors of electric vehicle smart charging. *Transportation Research Part C: Emerging Technologies*, 71:198–214, oct 2016.

[8] Julian Huber, E. Schaule, and Dominik Jung. How to increase charging flexibility? developing and testing framing nudges for bev drivers. In *31st Conference on Environmental Informatics (EnviroInfo 2018), Garching, 5.-7. September 2018*. LRZ, Garching, 2018.

[9] Jane Webster and Richard T Watson. Analyzing the past to prepare for the future: Writing a literature review. *MIS quarterly*, pages xiii–xxiii, 2002.

[10] Richard H Schallenberg. Prospects for the electric vehicle: a historical perspective. *IEEE Transactions on Education*, 23(3):137–143, 1980.

[11] Murat Yilmaz and Philip T Krein. Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles. *IEEE Transactions on Power Electronics*, 28(5):2151–2169, 2013.

[12] J García-Villalobos, I Zamora, JI San Martín, FJ Asensio, and V Aperribay. Plug-in electric vehicles in electric distribution networks: A review of smart charging approaches. *Renewable and Sustainable Energy Reviews*, 38:717–731, 2014.

[13] Francis Mwasilu, Jackson John Justo, Eun-Kyung Kim, Ton Duc Do, and Jin-Woo Jung. Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration. *Renewable and sustainable energy reviews*, 34:501–516, 2014.

[14] Mohammad Nikkhah Mojdehi and Prasanta Ghosh. An on-demand compensation function for an ev as a reactive power service provider. *IEEE Transactions on Vehicular Technology*, 65(6):4572–4583, 2016.

[15] Chao Luo, Yih-Fang Huang, and Vijay Gupta. Stochastic dynamic pricing for ev charging stations with renewable integration and energy storage. *IEEE Transactions on Smart Grid*, 9(2):1494–1505, 2018.

[16] Yuting Mou, Hao Xing, Zhiyun Lin, and Minyue Fu. Decentralized optimal demand-side management for phev charging in a smart grid. *IEEE Transactions on Smart Grid*, 6(2):726–736, 2015.

[17] Steffen Limmer and Manuel Dietrich. Optimization of dynamic prices for electric vehicle charging considering fairness. In *2018 IEEE Symposium Series on Computational Intelligence (SSCI)*, pages 2304–2311. IEEE, 2018.

[18] Taoyong Li, Jing Zhang, Yuanxing Zhang, Linru Jiang, Bin Li, Dongxiang Yan, and Chengbin Ma. An optimal design and analysis of a hybrid power charging station for electric vehicles considering uncertainties. In *IECON 2018-44th Annual Conference of the IEEE Industrial Electronics Society*, pages 5147–5152. IEEE, 2018.

[19] Tobias Brandt, Sebastian Wagner, and Dirk Neumann. Evaluating a business model for vehicle-grid integration: Evidence from germany. *Transportation Research Part D: Transport and Environment*, 50:488–504, 2017.

[20] Jennifer Schoch. Modeling of battery life optimal charging strategies based on empirical mobility data. *it-Information Technology*, 58(1):22–28, 2016.

[21] Miguel A Ortega-Vazquez. Optimal scheduling of electric vehicle charging and vehicle-to-grid services at household level including battery degradation and price uncertainty. *IET Generation, Transmission & Distribution*, 8(6):1007–1016, 2014.

[22] Sara Deilami, Amir S Masoum, Paul S Moses, and Mohammad AS Masoum. Real-time coordination of plug-in electric vehicle charging in smart grids to minimize power losses and improve voltage profile. *IEEE Transactions on Smart Grid*, 2(3):456–467, 2011.

[23] Anil Kumar Mathur, Pradeep Kumar Yemula, et al. Optimal charging schedule for electric vehicles in parking lot with solar power generation. In *2018 IEEE Innovative Smart Grid Technologies-Asia (ISGT Asia)*, pages 611–615. IEEE, 2018.

[24] Qilong Huang, Qing-Shan Jia, Zhifeng Qiu, Xiaohong Guan, and Geert Deconinck. Matching ev charging load with uncertain wind: A simulation-based policy improvement approach. *IEEE Transactions on Smart Grid*, 6(3):1425–1433, 2015.

[25] R Le Goff Latimier, B Multon, H Ben Ahmed, Franck Baraer, and Mickael Acquitter. Stochastic optimization of an electric vehicle fleet charging with uncertain photovoltaic production. In *Renewable Energy Research and Applications (ICRERA), 2015 International Conference on*, pages 721–726. IEEE, 2015.

[26] George Koutitas. Scheduling of community based charging stations with genetic algorithms. In *Green Technologies Conference (GreenTech), 2018*, pages 75–80. IEEE, 2018.

[27] US Energy Department. Residential charging behavior in response to utility experimental rates in san diego, april 2015.

[28] Judith IM De Groot, Wokje Abrahamse, and Kayleigh Jones. Persuasive normative messages: The influence of injunctive and personal norms on using free plastic bags. *Sustainability*, 5(5):1829–1844, 2013.

[29] Eric Sortomme, Mohammad M Hindi, SD James MacPherson, and SS Venkata. Coordinated charging of plug-in hybrid electric vehicles to minimize distribution system losses. *IEEE transactions on smart grid*, 2(1):198–205, 2011.

[30] L. Gan, U. Topcu, and S. H. Low. Optimal decentralized protocol for electric vehicle charging. *IEEE Transactions on Power Systems*, 28(2):940–951, May 2013.

[31] Franziska Schmalfu, Claudia Mair, Susen Dbelt, Bettina Kmpfe, Ramona Wstemann, Josef F. Krems, and Andreas Keinath. User responses to a smart charging system in germany: Battery electric vehicle driver motivation, attitudes and acceptance. *Energy Research and Social Science*, 9:60 – 71, 2015. Special Issue on Smart Grids and the Social Sciences.

[32] Mehmet Efe Biresselioglu, Melike Demirbag Kaplan, and Barbara Katharina Yilmaz. Electric mobility in europe: A comprehensive review of motivators and barriers in decision making processes. *Transportation Research Part A: Policy and Practice*, 109:1–13, 2018.

[33] Thomas Franke, Franziska Schmalfuß, and Nadine Rauh. Human factors and ergonomics in the individual adoption and use of electric vehicles. In *Ergonomics and Human Factors for a Sustainable Future*, pages 135–160. Springer, 2018.

[34] Joachim Geske and Diana Schumann. Willing to participate in vehicle-to-grid (v2g)? why not! *Energy policy*, 120:392–401, 2018.

[35] M Tamis, R van den Hoed, and RH Thorsdottir. Smart charging in the netherlands. In *In Proceedings of the European Battery, Hybrid & Electric Fuel Cell Electric Vehicle Congress*, 2017.

[36] Axel Ensslen, Till Gnann, Joachim Globisch, Patrick Plötz, Patrick Jochem, and Wolf Fichtner. Willingness to pay for e-mobility services: a case study from germany. In *Proceedings of the Karlsruhe Service Summit Workshop*, 2016.

[37] Christian Will and Alexander Schuller. Understanding user acceptance factors of electric vehicle smart charging. *Transportation Research Part C: Emerging Technologies*, 71:198 – 214, 2016.

[38] Omar Isaac Asensio and Magali A. Delmas. The dynamics of behavior change: Evidence from energy conservation. *Journal of Economic Behavior & Organization*, 126:196–212, 2016.

[39] Axel Ensslen, Philipp Ringler, Lasse Dörr, Patrick Jochem, Florian Zimmermann, and Wolf Fichtner. Incentivizing smart charging: Modeling charging tariffs for electric vehicles in german and french electricity markets. *Energy Research and Social Science*, 42:112 – 126, 2018.

[40] Stewart Barr, Andrew Gilg, and Gareth Shaw. helping people make better choices: exploring the behaviour change agenda for environmental sustainability. *Applied Geography*, 31(2):712–720, 2011.

[41] Harold A Linstone, Murray Turoff, et al. *The delphi method*. Addison-Wesley Reading, MA, 1975.

[42] Nicola Döring and Jürgen Bortz. *Forschungsmethoden und Evaluation*. Springer, 2016.

Authors



Julian Huber studied industrial engineering at Technical University of Berlin and Karlsruhe Institute of Technology (KIT), Germany. During a research scholarship at University of North Carolina at Charlotte he focused on energy economics and analytics. He is currently working at Forschungszentrum Informatik (FZI) in Karlsruhe and is engaged in research concerning demand side management, demand response, and end users flexibility in the Smart Grid.

Elisabeth Schaule studies industrial engineering at the Karlsruhe Institute of Technology. In her bachelor thesis she investigated the use of framing nudges to encourage BEV smart charging.

Dominik Jung is a researcher in the group Electronic Markets and User Behaviour at the Karlsruhe Institute of Technology (KIT), and the Karlsruhe Decision & Design Lab (KD2Lab), Germany. He earned multiple bachelor and master degrees in the area of economics and computer science. Last year he finished his doctorate in information systems about robo-advisors. His research focuses on decision support systems, and behavioral decision-making, and has been published in top international outlets such as Economic Psychology, Electronic Markets, or Business & Information Systems Engineering.

Christof Weinhardt is a professor at the Karlsruhe Institute of Technology at the Institutes of Information Systems and Marketing (IISM) and Karlsruhe Service Research Institute (KSRI). In addition, he is a director at Forschungszentrum Informatik (FZI).