ENERGY COMMUNITIES AS ENABLERS FOR INNOVATIVE TECHNOLOGIES?

The Case of Vehicle-to-Grid in Three European Countries

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Abstract

Vehicle-to-grid (V2G) is a particular form of smart charging, allowing a more efficient and sustainable energy system by integrating electric vehicles (EVs) as additional storage capacity into the electricity grid. Techno-economic analyses suggest numerous advantages of this technology, such as a more secure and flexible grid operation, higher potential of integrating renewable energies into the grid, and financial revenues. However, whether and why households are willing to participate in V2G is still being investigated. Therefore, we examined the factors underlying V2G acceptance, focusing on prior EV experience and membership in an energy community. Energy communities were shown to be an essential driver of a bottom-up energy transition in similar contexts. Therefore, we hypothesized that energy communities could facilitate the widespread acceptance and adoption of new technologies such as V2G. Specifically, people who are part of an energy community might actively promote technologies that benefit the energy transition and be more likely to accept potential constraints. We surveyed German, French, and Swiss households (total N = 1,134, some of whom were also energy community members) in June 2023 to investigate the role of energy community membership on the acceptance of V2G. We compared V2G acceptance in the three countries with an extended theory of planned behavior. Hierarchical regression analyses showed that community-related factors, such as community identification, significantly predicted the intention to adopt V2G for energy community members, whereas it did not for non-members.

1 INTRODUCTION

The transport sector significantly contributes to CO_2 emissions in Europe and worldwide. To achieve current climate goals, one strategy is to electrify transport. For example, the German government aims for 15 million electric vehicles (EVs) (SPD, Bündnis 90/Die Grünen and FDP, 2021) and the French government for 7.5 million EVs by 2030 (Ministère de la Transition Écologique et de la Cohésion des Territoires, 2022). This will lead to increased electricity demand, which in turn will add stress to the electricity grid. Utilizing the EV's battery as additional storage could potentially provide additional short-term flexibility, thus enabling the increased integration of renewable energy sources (RES) into the grid and improving grid stability.

In this context, vehicle-to-grid (V2G) is seen as a promising technology. V2G can be defined as a mobile storage with a bidirectional power flow (Kempton & Tomić, 2005; Sovacool & Hirsh, 2009). In other words, EVs that are connected to the grid can both charge and feed electricity back into the grid when necessary. This provides temporal and distributed flexibility (Knezovic et al., 2017), and thus, V2G can be seen as an essential technology to foster the energy transition. However, besides providing flexibility for ancillary services, the EV primarily needs to satisfy users' mobility needs. This tension raises the question of whether and why electric vehicle users and owners would be willing to participate in V2G.

Solutions such as V2G symbolize the changing landscape of the energy system. This transformation is characterized by many but small production units, decentralized and cross-border markets, smaller transmission lines and regional supply, bidirectional distribution, and active prosumers (Friends of the Earth Europe et al., 2019). This broader transformation is also actively shaped by energy communities aiming to increase decentralized renewable energy production, contribute to climate goals, and promote collaborative social transformations (Koirala et al., 2018; Lowitzsch et al., 2020). Energy communities can be defined as "bottom-up energy-related projects driven towards local needs, characterized by strong citizen participation, local ownership, decision-making with a single vote per actor, and sharing of collective benefits" (Reis et al., 2021, 2 f.).

Engaging in energy communities is often motivated by collective long-term benefits (Goedkoop et al., 2022; Sloot et al., 2019). Correspondingly, V2G could contribute to the energy system as a whole by providing ancillary services. However, it could also add a benefit to communities' objectives, for example, by scheduling load operations in off-peak periods or according to local energy generation (Reis et al., 2021; Schram et al., 2021), or by providing flexibility to enable electricity sharing within a community (Huber et al., 2019). Therefore, we hypothesize that the community context can act as a unique enabler for V2G technology. More specifically, we hypothesize that the community context acts as a motivational basis, influencing individuals' intention and behavior to adopt V2G, and that these individuals base their decisions on specific, community-related values.

Moreover, as recent literature suggests, EV experience is another critical factor for informed decision-making and interest in V2G (Chen et al., 2020; Noel et al., 2019; Wong et al., 2023). We therefore elaborate on this factor as well, distinguishing between people with no EV experience, people who already gained experience with EVs during, e.g., test drives or car sharing, and people who own an EV. It is suggested that the intention to adopt V2G is less likely when people have not yet encountered EVs.

In this paper, we bring these aspects together by asking the question of whether energy communities could be a driver for V2G technology, and what role EV experience has for the intention to adopt V2G. Our paper elaborates on this question for three European countries — Germany, Switzerland, and France. We do so because, even though these countries have direct borders, their energy systems are quite different. To answer our research question, we built a model based on the theory of planned behavior (TPB). We extend this model with community-specific constructs: membership in an energy community, community identification, and community sustainable energy motivation. Furthermore, we analyze the influence of EV experience on the intention to participate in V2G processes.

The paper is structured as follows: First, we provide an overview of the theoretical background of the model. Second, we describe our method, including the study design, participants, measures, and analysis method, before describing and discussing our results. We summarize this paper with a conclusion and policy implications.

2 CONCEPTUAL BACKGROUND

To assess the unique role of community-related values that might underlie the intention to participate in V2G, we started out with a theory of planned behavior model, as this theory has been studied in numerous contexts, including energy behavior and technology acceptance. We extended this model with two further items: community identification, and community sustainable energy motivation. We describe the theoretical basis of our model below.

2.1 Theory of planned behavior

The theory of planned behavior (TPB) is an established model for explaining decision-making processes (Azjen, 1991). Moreover, it allows the inclusion of further variables explaining behavioral intention, which makes it attractive for different contexts. For example, the TPB has been used to explain electric vehicle adoption (Haustein et al., 2021; Lee et al., 2023). In the context of V2G, van Heuveln et al. (2021) used this model to identify potential factors affecting V2G acceptance qualitatively. We adopt the model by Hasan (2021) and Haustein et al. (2021), using attitudes towards bidirectional charging, subjective norms, and perceived behavioral control as predictors of intention, whereby perceived behavioral control is modified to perceived functional barriers, as suggested by Haustein et al. (2021) (see also Section 3.3).

2.2 Social identification and community sustainable energy motivation

As energy community members' intention to engage in V2G might not only be explained by individual attitudes, subjective norms, and perceived functional barriers but also by community factors, we included community-specific variables in our model. Being part of an energy community might shape one's identity and act as a guide for appropriate behavior (Goedkoop et al., 2022; Sloot et al., 2018). For these energy community members in particular, what they perceive their community to value and to what extent they feel attached to it might motivate their interest in V2G. We therefore included community sustainable energy motivation and social identification in the model next to the TPB variables and, in a subsequent step, distinguished between those involved in an energy community and those uninvolved. Previous research combined social identity with the theory of planned behavior to explain involvement in environmental protection (Fielding et al., 2008). However, even though these measures are well established, there has been no research until now combining these measures into one model in the context of V2G.

3 METHODS

To address the research question, we conducted a study to evaluate different values guiding the intention to adopt V2G. Specifically, we compared a sample including energy community members, and a sample including homeowners who are not part of an energy community, which we called "non-members". Furthermore, we analyzed the role of EV experience as another predictor of the intention to adopt V2G.

3.1 Survey design

In June 2023, we conducted an online survey with an interdisciplinary and international research team of students and scientists from Switzerland, France, and Germany. As the survey was distributed among German, French, and Swiss households and energy communities in these countries, the survey was translated into German and French from an English version. To increase the number of participants from energy communities, we combined randomized and purposive data sampling (Maxwell, 2009). Thus, data was collected in two ways: First, data was collected through a commercial marketing panel company. This data is representative of the respective national populations with regard to age and gender, but is restricted to homeowners in these countries. Second, we distributed the survey among German, Swiss, and French energy communities. The energy community members received a monetary incentive to increase the participation rate.

The survey consisted of four parts. In the first part, we assessed participants' age, gender, and current home country. Moreover, we asked them whether they were part of any energy community and to what extent they had experience with electric vehicles. The second part included an introduction to V2G, and a comprehension question to test the technical understanding. In the next part, which is irrelevant to this study, participants had to rate nine scenarios about different V2G options. The fourth part measured individual motivations, beliefs, values, and barriers (such as the TPB and the VBN), as well as community motivations (community identification and community sustainable energy motivation). Lastly, we assessed further household characteristics and further socio-demographic characteristics.

3.2 Participants

Table 1: EV experience levels and energy community membership according to country

	Germany (N=359)		France (N=271)		Switzerland (N=352)	
	Amount	%	Amount	%	Amount	%
EV experience levels						
No EV experience	215	59.9	163	60.1	170	48.3
EV experience	92	25.6	47	17.3	103	29.3
EV owner	52	14.5	61	22.5	79	22.4
Energy community membership						
Member	52	14.5	79	29.2	101	23.6
No member	307	85.5	192	70.8	251	71.3

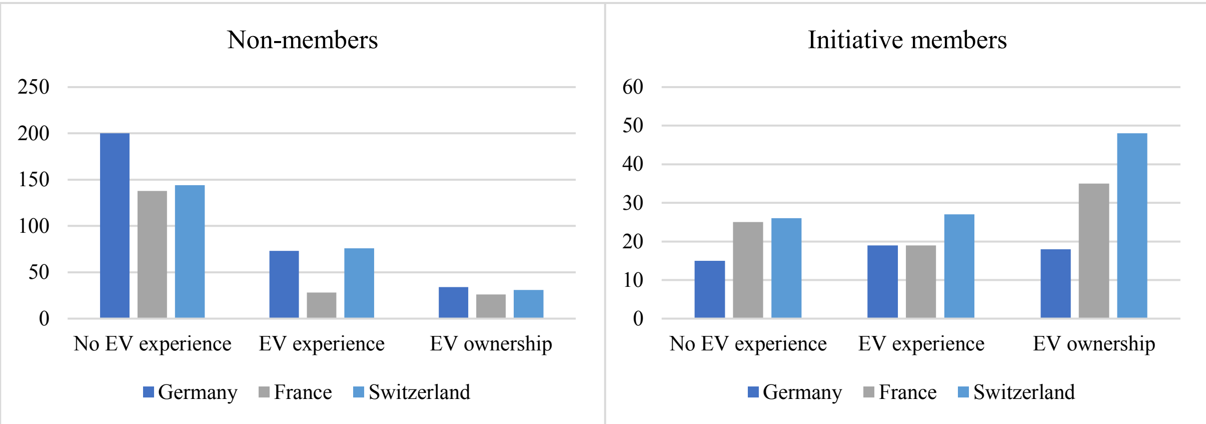

Figure 1: EV experience levels by community membership and country

Our sample is comprised of two sources. The majority of answers were collected with the help of a panel company (*N*=1,351). Furthermore, in order to increase the number of persons who are part of an energy community, we distributed the survey among several energy communities in Germany, France, and Switzerland (*N*=47). After data cleaning, we retained a final sample of *N*=982. As we are especially interested in analyzing the effect that energy community membership and EV experience have on V2G adoption, we show the distribution of energy community members and EV experience among the three countries in Table 1. As can be seen, we have nearly the same number of responses from Switzerland and Germany, while there are fewer responses from French people in our sample. Astonishingly, the share of energy community members in the German sample is far smaller than in the other two countries. Finally, as can be seen in Figure 1, there seems to be a strong correlation between energy community membership and the level of EV experience, independent of the country. For all three countries, EV experience is lower when people are not part of an energy community, while EV experience increases for energy community members.

3.3 Measures

Table 2: Measures and their respective sources

Scales	Source
Theory of planned behavior	
Subjective norms	Hasan, 2021
Perceived behavioral control / perceived functional barriers	Haustein et al., 2021
Attitude	Hasan, 2021
Intention	Haustein et al., 2021
Social Identification	Postmes et al., 2013; Goedkoop et al., 2022
Community sustainable energy motivation	Goedkoop et al., 2022

In this manuscript, we focus on concepts from different theories: TPB variables as well as the social identity concepts community identification and community sustainable energy motivation. The constructs were measured based on the sources provided in Table 2. We adapted the TPB constructs to the case of V2G, including the term "bidirectional electric vehicle" in the four constructs: attitudes, subjective norms, perceived behavioral control, and intention. Finally, as suggested by Haustein et al. (2021), we changed the construct of perceived behavioral control to perceived functional barriers, referring to functional barriers regarding the use of an EV, which is able to charge bidirectionally.

To measure community-related factors, we used two measures: For community identification, we used the three-item scale suggested by Postmes et al. (2013), which was adapted to the community context by Goedkoop et al. (2022). As a second community-related measure, we chose the community sustainable energy motivation scale, as suggested by Goedkoop et al. (2022).

To measure energy community membership, we asked the participants of the survey in the beginning whether they were part of an energy community. We provided a definition of "energy community" in German, English, and French.

To identify the level of EV experience, respondents were first asked whether they had already gained experience in driving an EV, followed by the question of whether they owned an EV. Based on these two questions, we grouped participants into three groups – people who did not have any experience with EVs, people who have had experience with EVs but did not own one, and people who owned an EV. This approach was based on Baumgartner et al. (2022).

3.4 Method of analysis

All statistical analyses were conducted using IBM SPSS 29. First, we conducted a correlation analysis to test for the strength of the relationships between variables. Second, we conducted a hierarchical multiple regression analysis testing the extended TPB. In the first step, we included two dummy variables to control for the fact that participants were from three different countries. In the second step, we included the dummy variables for EV experience, and EV owner, before entering the psychological variables, starting with the basic model of the TPB. In the last step, we entered the community-specific variables, namely community identification and community sustainable energy motivation. We first tested the model for the whole sample. Second, we split the file to compare the model for the energy community members and non-members.

4 FINDINGS

As outlined in Section 3.4, we performed three hierarchical regression analyses for the whole sample and the two subsamples of non-members and members, respectively. The four steps of the hierarchical regression were identical for each of the three models. Table 3 displays the results for the whole sample. As can be seen, participants' country was not a significant predictor of the intention to participate in V2G. The opposite is true for EV experience and EV ownership, which are both highly significant and remain significant even when further variables are entered. As expected, the TPB model is highly significant, F_{change}=347.378, p<.001. All three predictors have a strong effect size, with attitudes having the highest standardized coefficient with ß=.413, p<.001 in Step three and ß=.404, p<.001 in Step four. As expected, perceived functional barriers had a negative effect on intention (ß=-.208, p<.001). Step four did not add any variation to model three, and community sustainable energy motivation and community identification were not significant predictors of intention. Overall, the model explained 59% of the variation.

The results for non-members (Table 4) were similar to the results of the total sample. The country was not a significant predictor of intention, while EV experience and EV ownership were. However, the effect of EV experience decreases in Step three and four, while EV ownership remains highly significant. The TPB predictors are highly significant, again with attitudes having the strongest effect on intention and with perceived functional barriers having a negative sign. Including community sustainable energy motivation and community identification in the model did not change the effect of the TPB predictors significantly. These last two predictors were, again, not significant and did not explain any additional variation compared to Model 3.

Table 3: Hierarchical multiple regression analysis predicting intention – Total sample

Step	Predictor	R^2	R^2 change	F change	df	p	Step 1ß	Step 2ß	Step 3ß	Step 4ß
1	Germany vs. France	0.003	0.003	1.537	979	0.251	0.032	0.014	-0.026	-0.029
	Germany vs. Switzerland						0.063	0.022	-0.032	-0.029
2	No EV experience vs. EV experience	0.121	0.118	65.477	977	<0.001		0.163***	0.074****	0.074***
	No EV experience vs. EV owner							0.354***	0.094***	0.087***
3	Attitudes	0.594	0.471	347.378	974	<0.001			0.413***	0.404***
	Subjective norm								0.331***	0.316***
	Perceived functional barriers								-0.208***	-0.209***
4	Community sustainable energy motivation	0.594	0.002	2.575	972	0.077				0.018
	Community identification									0.039

*p<0.05; **p<0.01; ***p<0.001.

Table 5 shows the results of the hierarchical regression analysis for individuals who were part of an energy community (i.e., members). Again, the participant's country of origin did not predict intention. However, the picture changes for EV experience and EV ownership. While

Table 4: Hierarchical multiple regression analysis predicting intention – Non-members

Step	Predictor	R^2	R^2 change	F change	df	p	Step 1ß	Step 2ß	Step 3ß	Step 4ß
1	Germany vs. France	0.002	0.002	0.776	747	0.461	-0.026	-0.025	-0.038	-00.041
	Germany vs. Switzerland						0.028	0.014	-0.040	-0.039
2	No EV experience vs. EV experience	0.101	0.099	41.115	745	<0.001		0.115***	0.053*	0.053*
	No EV experience vs. EV owner							0.318***	0.101***	0.097***
3	Attitudes	0.599	0.498	307.580	742	<0.001			0.413***	0.406***
	Subjective norm								0.328***	0.315***
	Perceived functional barriers								-0.203***	-0.203***
4	Community sustainable energy motivation	0.601	0.01	1.358	740	0.258				0.063
	Community identification									0.011

*p<0.05; **p<0.01; ***p<0.001.

Table 5: Hierarchical multiple regression analysis predicting intention – Energy community members

Step	Predictor	R^2	R^2 change	F change	df	p	Step 1ß	Step 2ß	Step 3ß	Step 4ß
1	Germany vs. France	0.002	0.002	0.284	229	0.753	0.061	0.063	0.037	0.034
	Germany vs. Switzerland						0.024	0.011	0.020	0.025
2	No EV experience vs. EV experience	0.058	0.055	6.645	227	0.002		0.209**	0.164**	0.164**
	No EV experience vs. EV owner							0.272***	0.124	0.103
3	Attitudes	0.437	0.380	50.401	224	<0.001			0.415***	0.388***
	Subjective norm								0.301***	0.287***
	Perceived functional barriers								-0.217***	-0.232***
4	Community sustainable energy motivation	0.453	0.015	3.118	222	0.046				-0.043
	Social identity									0.153*

*p<0.05; **p<0.01; ***p<0.001.

EV experience remained significant overall, EV ownership turned from highly significant (ß=.272, p<.001) to non-significant in Steps three (ß=.124, p=.063) and four (ß=.103, p=.130). Model 2, however, was significant, with F_{change}=6.645, p=.002. Also, in this case, the TPB variables significantly predicted intention. However, the R^2-value was smaller than in the previous models, explaining less variation. Finally, Step 4 was significant as well, with F_{change}=3.118, p=.046. This is due to the fact that community identification was a significant predictor of intention, with ß=.153, p=.016. Community sustainable energy motivation was, again, not significant. One explanation for the non-significant effect of community sustainable energy motivation on intention might be the strong correlation between this predictor and subjective norm, undermining the effect on intention.

The results support our hypothesis that individuals' decision is guided not only by individual motivations but also by their identification with their community if they belong to a specific energy community. People who are part of an energy community thus consider their community in their decision-making process regarding future V2G charging.

5 CONCLUSION

The current study drew on a well-established socio-psychological model to explain the intention to adopt V2G. As we had a special focus on energy community members, we extended the model with community-specific constructs, namely community identification and community sustainable energy motivation. Furthermore, as we collected data in three countries – Germany, Switzerland, and France – and asked participants about their experience with EVs, we included these measures as well in our model. Overall, the revised model accounted for the intention to participate in V2G, explaining 59% of the variance in the total sample, 60% of the variance in the sample, including non-members, and 45% of the variance in the sample, including energy community members. The results support our hypothesis that the decision of an individual who is part of an energy community is guided by their social identity, specifically the way in which they define themselves as part of a local community and, therefore, consider the communities' objectives.

Energy communities unite individuals pursuing similar goals. Besides aims to foster bottom-up energy transitions, protect the environment, and achieve climate goals, communities enable individuals to connect and act collectively. Our study showed that apart from individual motives, identification with the community or the neighborhood is another important factor guiding individuals' behavior. We exemplified this based on the intention to adopt V2G.

Finally, we included a country comparison in our model as well as the level of EV experience. We defined three levels of EV experience – no EV experience, EV experience, and EV ownership. As expected, the country did not predict the intention to adopt V2G, whereas EV experience and EV ownership did. This is true for the total sample and the sample comprised of non-members. For energy community members, the effect of EV experience on intention was smaller than in the other two models, whereas the effect of EV ownership diminished.

Our research is, however, not without limitations. For example, in our research, we talked about the energy community as it was one entity. Yet, even though we provided a definition of an energy community, energy communities can be very different in their form and size. Moreover, energy communities might differ between countries and might, due to the different energy systems, pursue different goals. Moreover, V2G is very abstract to most people. Although we provided a definition and explanation of V2G and people had to answer a comprehension question, they might not foresee the benefits and consequences of such a technology. Thus, evaluating such a novel technology is necessarily hypothetical and might not reflect peoples' actual decisions. Finally, our sample is not representative for homeowners in the three countries, as we supplemented the main sample with additional energy community members. Yet, combining purposive and randomized sampling methods facilitates our objective to assess the role of energy community membership in shaping individual's decision to engage with V2G technology.

In spite of these limitations, we can summarize that our results show the importance of energy communities and local neighborhoods for stimulating V2G charging, even when considering individuals with different levels of EV experience and from different countries. Our results have important policy implications, as they suggest that energy communities can act as enablers of novel energy technologies. Being a member of an energy community seems to strengthen the link between community identification and V2G intentions. Practitioners could thus emphasize the value of V2G for local communities and link it to existing energy communities currently focusing on other aspects of the sustainable energy transition.

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