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Societal Acceptability of Large Stationary Battery Storage Systems

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Large stationary battery storage (BS) has experienced rapid growth, but only few studies have examined the social acceptability of these. An online survey is conducted by examining the visual impact (location and design) of BS on acceptability. Analyses indicate that BS is more readily accepted in industrial and rural areas compared to residential areas or the participants' immediate neighborhoods. Adapting the design of BS to its surroundings can help to increase acceptability in residential areas, whereas battery storage design does not significantly influence acceptability in locations further away from homes. Finally, findings concerning public support for diverse mitigation measures with regard to the siting of BS in residential areas show that environmental mitigation measures are most supported. The findings support the notion that the location and design of BS affect technology acceptability. When possible, BS should be built away from residential areas, for which acceptability is rather low. On the other hand, especially industrial areas emerge as a promising location for siting battery storage, with acceptability being very high. If BS is built close to or in residential areas, attention should be paid to minimizing visual intrusion by adapting the exterior of the infrastructure toward its surroundings.

1. Background

Wind and solar power—the expansion of these renewable energies—are key to a sustainable and low-carbon-footprint energy supply. Transitioning away from centralized, any time dispatchable, large fossil-fueled power stations to a decentralized system consisting of many small-scale renewable energy sources poses several challenges to the existing electricity infrastructure.[1,2] Among other things, there is an increased need for energy storage to account for the fluctuating and intermittent energy supply by renewables and to improve electricity grid stability, flexibility, reliability, and resilience.[2–5] Currently, more efforts are required for grid-scale storage capacity growth to meet IEAs Net Zero Emission strategy.[6] However, the International Energy Agency estimates that limiting temperature increase to below 2 °C as set out by the Paris Agreement would require energy storage capacity to triple by 2050.[7]

Worldwide, the total installed capacity of large-scale energy storage is almost based on pumped hydrostorage power, as many other storage technologies are still in their early stages of development.[8] This is also reflected in the storage capacity of Germany, which, as of 2018, was home to 27 pumped hydrostorage power plants with a storage capacity of 38 GWh.[9] Despite the need for increased storage capacity, the construction of several newly planned pumped hydrostorage power plants was abandoned over the recent years due to resistance from the population and lack of profitability.[10–12] In addition, there are hardly any suitable locations left for the construction of pumped hydrostorage power in Germany and no plants are currently under construction or in trial operation.[2,13] Given this, alternative, market-ready storage solutions need to be developed and considered. Several energy storage technologies, such as battery storage, thermal storage, and hydrogen including power to X paths, have experienced rapid growth as well as interest in recent years.[14] In the current article, we will focus on battery storage, whose annual additions of storage capacity of battery storage are expected to overtake additions of storage capacity by pumped hydrostorage by 2023.[15]

As of 2021, the realized capacity of >30 kWh to multi-MWh battery storage in Germany amounted to approximately 703 MW with a capacity of 920 MWh.[16] In general, a high momentum can be seen in the deployment of new battery storage units. For example, BCP the Battery Holding and TransnetBW, one of the German transmission system operators announced projects in a scale of 60–250 MW and capacities up to 250 MWh.[17,18] With the storage technology rising in popularity, many studies are examining the technical, economic,[19] and ecological implications of the technology.[4] However, as the role of citizens in the energy system is changing,[20] there is a call for additional research regarding the social implications of introducing such

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new storage technologies. From an environmental psychology perspective, technological development is understood as a socio-technical system approach[21] in which technological development and people are not seen as independent of each other, but perceived as influencing each other. With consumers being at the heart of the energy transition, citizens nowadays consider themselves not only implicated in the energy system as taxpayers, but voters or members of civil society groups that may support or oppose technologies. In light of this, social acceptability of new storage technologies needs to be considered a key condition for enabling a smooth roll-out of storage technologies. In the current study, we examine acceptability of mid- to large-scale energy stationary battery storage, a topic that has received little attention up to date. More specifically, we consider storage units that are not based inside of buildings, e.g., in basements, but rather larger storage units with a size in the multi-kWh >30 kWh to a multi-MWh scale that are extra stand-alone facilities (containers, buildings, etc.).

Below, we first clarify the concepts acceptance and acceptability. Next, we elaborate on contextual and psychological factors that influence energy technology acceptance. Subsequently, we discuss the visual impact of energy infrastructures, a key factor of the current study, in greater detail.

1.1. Acceptance and Acceptability

In technology acceptance research, several terms such as acceptance, acceptability, attitudes, support, and adoption are used when studying citizen's attitudes and behaviors toward a technology. Some studies define acceptability as attitudes toward a technology before its implementation, whereas acceptance is defined as attitudes toward a technology after its implementation.[22–25] As this definition does not distinguish between attitudes and behavior, we will follow the definition by Huijts, Molin, and Steg[26] in this article. Huijts et al. define technology acceptance as "behavior toward the technology," whereas acceptability is defined as evaluations of or attitudes toward a technology and possible related behaviors, with some degree of favor or disfavor.[27–29] Behaviors toward a technology can be subdivided into four categories according to two dimensions: adoption versus rejection of the technology and active versus passive behavior.[30] People may actively adopt a technology by proclaiming it or purchasing and using it (support), as well more passively adopt it by approving it (approval). Furthermore, people may actively resist the technology by not purchasing and using the technology or protesting against it (resistance), as well as passively resist it by opposing the technology, but not taking action against it (connivance). In the current article, we will focus on acceptability, more specifically attitudes toward approval for battery storage.

1.2. Contextual and Psychological Factors Influencing Energy Technology Acceptance

Generally, the energy transition and renewable energy technologies are well perceived by the public.[31,32] Nevertheless, while most people approve of new energy technologies in general, protests and acceptability problems can arise when energy projects are to be implemented, oftentimes eliciting resistance from the local population.[33–36] While this discrepancy between general and local acceptance has often been called "NIMBY" phenomenon ("not in my backyard") in the past, NIMBY explanations have since been declared as being too simplistic to accurately represent and explain the causes of opposition to energy projects.[36,37] Rather, acceptability of energy technology is influenced by different factors, and the importance of both psychological and contextual factors has been highlighted in numerous studies.[31,38–40] For example, factors such as perceived risks and benefits, perceived fairness, affect, and personal norms have been shown to influence attitudes and behaviors toward a technology.[26] Furthermore, there is some evidence that a greater awareness of the link between new energy infrastructure and the energy transition can lead to increased acceptability of energy projects.[34,41]

In the current study, we examine acceptability of stationary battery storage, a topic that has received little attention up to date. Research in the UK, Canada, Germany, and Italy has examined factors such as perceived benefits and risks, trust in project developers, evoked affect, and awareness of energy storage in general.[42–47] Overall, the results indicate that respondents had positive attitudes toward energy storage in general as well as toward battery storage in specific. Trust in actors responsible for the technology (municipalities and industry) has been found to increase acceptance by influencing perceived benefits as well as affective responses to the technology, which, in turn, influence acceptance.[43,47] Furthermore, self-claimed awareness of energy storage, affect, and environmental values significantly predict acceptance.[45,46] Additionally, qualitative research results indicate that the visual impact of battery storage may influence acceptability,[44] a finding which we aim to extend in the current study.

1.3. Effect of Visual Impact and Location on Energy Technology Acceptance

Landscape changes and the visual impact of energy infrastructures have been shown to influence the acceptance of energy technologies such as wind farms,[48–50] transmission lines,[34,51–53] and solar farms.[54] Research from the field of urban planning suggests that the perceived visual quality of landscapes is often positively related with the landscape's degree of naturalness, while a disturbance of this state, e.g., in the form of human-made elements and "negative" interventions in the landscape, such as roads, factories, or power lines, is negatively related with perceived visual quality.[53,55,56] That is, a lack of contextual fit between interventions in the landscape and the landscape is associated with lower perceived visual quality.[57] These findings are also reflected in research on energy technology acceptance. For instance, it has been found that surroundings featuring transmission lines evoke more negative affect than the same surroundings without transmission lines.[34] Furthermore, this effect is even stronger for natural landscapes (e.g., rural areas) than for urban surroundings (e.g., highways, cities). For wind power farms, there is high variety in acceptability of wind turbines in different locations, but generally, research points to a preference for locations away from housing areas,[49] which is attributed to the high spatial impact of wind farms. For on-ground solar systems, people seem to prefer already constructed areas like roofs over natural areas.[21] With regard to mid-to-large battery scale (as defined in Section 1) energy storage, qualitative findings indicate citizen concerns about the potential industrial appearance and size of battery containers, which in line with this were not perceived as appropriate in certain residential areas.[44] However, the results also indicate that battery storage, which is perceived unaesthetic, may be considered more acceptable if its appearance blends in with the local environment and the technology can be disguised or situated out of the way. The results suggest that such negative visual impacts can be reduced by adapting the design of battery storage or by situating the technologies in new buildings that can accommodate the technology. Furthermore, grid-scale battery storage technologies were evaluated in light of how distant they were from populated areas.

1.4. Current Study

Following these findings, the current study explores, via a mixed factorial design, how the location and design of mid-to-large stationary battery storage (>30 kWh, external installation) influences acceptability. First, we investigate whether being presented with images of battery storage in different designs influences evaluations of battery storage. Second, we assess whether distinguishing between different locations for siting battery storage as well as battery storage design influences acceptability of battery storage. With regard to the location, we expect battery storage to be more readily accepted in negatively perceived landscapes, such as industrial areas, and in locations further away from residential areas, such as rural areas. On the other hand, we expect acceptability to be the lowest in positively perceived areas and in locations close to the homes of people, such as in residential areas. In line with this, we expect acceptability in rural areas to be higher than in residential areas due to the further distance from homes, but somewhat lower than in industrial areas, as rural areas are more positively perceived landscapes. With regard to visual battery storage design, we expect battery storage in an urban design to be perceived as more positively and aesthetic than battery storage in an industrial design. Furthermore, we hypothesize to see an effect of design on acceptability in positively perceived landscapes and locations close to people's homes. In line with this, we expect acceptability of battery storage in an urban design to be higher in residential areas and the participant`s own neighborhood compared to battery storage in an industrial design. With regard to industrial areas, the design of battery storage units is not expected to influence acceptability because aesthetics are of minor concern to participants in these areas. In rural areas, we do not expect battery storage design to have an effect on acceptability as we are asking about rural areas in general. If we were to include a rural area of personal relevance to the participants in the study, one could probably expect an effect of battery storage design. The third goal of the study was to explore whether the predictors of acceptability would differ between the locations studied. Finally, as we expected acceptability in residential areas to be the lowest overall, we additionally explored how participants evaluated potential mitigation measures that could help to increase acceptability in residential areas.

2. Experimental Section

2.1. Design and Sample

We carried out an online questionnaire study regarding the public opinions on battery storage in Germany in June 2020. First, participants filled in a value questionnaire. Afterward, we briefly introduced the broad context of the study and asked the participants to indicate their support for the energy transition and renewables as well as their knowledge of energy storage in general and battery storage specifically. Next, we introduced the energy storage technology in question, mid- to large-scale battery storage, in more detail. Alongside this introduction, participants were shown different images of battery storage: no images were shown in the control condition, a container infrastructure was shown in the industrial design condition (see **Figure 1**), and a building resembling an office was shown in the urban design condition (see **Figure 2**). It has to be mentioned that the image used in the survey has been changed in frame of the publication. To ensure that sufficient attention was paid to the image, we asked participants to indicate the first word, image, or thought

Figure 1. Image provided in industrial design condition. Reproduced with permission. Copyright 2019, KIT/Amadeus Bramsiepe.

Figure 2. Image provided in urban design condition. Reproduced with permission. Copyright 2022, eins energie in Sachsen GmbH & Co. KG.

they had when looking at the image. Next, participants evaluated battery storage on bipolar attitude scales, judged acceptability of battery storage in four different locations, and indicated how they perceived different mitigation measures.

The study was conducted via the online panel SoSci Panel (www.soscipanel.de). In total, the questionnaire was completed by 259 participants. Data quality was controlled for with a control question, which asked participants to click on a specific value in a scale. After excluding cases from the dataset based on the aforementioned reason ($N = 31$), our final sample consisted of $N = 228$ cases (109 females, 119 males), with the participants being about equally distributed across all conditions: control ($N = 75$), industrial design ($N = 76$), and urban design ($N = 77$). Below, the measures reported in this study will be introduced.

2.2. Measures

2.2.1. Knowledge of Energy Storage and Battery Storage

The knowledge about battery storage was measured with two items [I am familiar with battery storage; I am well informed about battery storage] on a 7-point Likert scale [1 = strongly disagree, 7 = strongly agree]. The scale showed good reliability ($\alpha = 0.89$) and was combined for further analysis. Participants were not very familiar with stationary battery storage ($M = 3.91$, $SD = 1.68$), which was in line with our expectations.

2.2.2. Affect Elicited by Battery Storage

Affect elicited by the energy storage was measured with a single item [Imagine a battery storage plant was built in the vicinity of your home, which emotions does that elicit in you?] that was answered on a 7-point Likert scale [1 = very negative emotions, 7 = very positive emotions].

2.2.3. Attitudes toward Battery Storage

After having read the introductory text on battery storage, respondents were asked to evaluate battery storage on bipolar attitude scales, which were adapted from the risks and benefits scale in Huijts, Molin, and van Wee[58] and semantic differential scale in Zaunbrecher, Bexten, Wirsum, and Ziefle.[59] For this purpose, participants indicated on a 5-point scale how useful [1 = useless, 5 = useful], innovative [1 = traditional, 5 = innovative], beautiful [1 = ugly, 5 = beautiful], positive [1 = negative, 5 = positive], safe [1 = dangerous, 5 = safe], and environmentally friendly [1 = bad for the environment, 5 = environmentally-friendly] they found battery storage. After assessing whether being presented with different images of battery storage influenced evaluations of battery storage, the scale was combined for further analysis ($\alpha = 0.81$).

2.2.4. Acceptability of Battery Storage in Different Landscapes

We briefly introduced how battery storage can be implemented in the following four locations: rural areas, residential areas, and industrial areas. Additionally, we once more showed the respective picture (industrial design vs urban design vs control) alongside this text. Then, we asked respondents whether they were in favor or against battery storage being built in industrial, rural, and residential areas, as well as their own neighborhood [1 = totally opposed to, 7 = totally in favor].

2.2.5. Perception of Mitigation Measures

To capture opinions of different mitigation measures, respondents were asked: "If the construction of a new battery storage facility was proposed in your place of residence, what measures do you think could increase acceptability of such a construction project?". Following this, eight mitigation measures based on insight from previous studies[43,47,60] were presented, including "building the battery storage away from homes and schools," "providing financial compensation to those living in sight," "including residents in the planning process," "adapting the design of the battery storage to its surroundings," "ensuring the proper recycling of batteries," "observing strict environmental and social standards," "storing electricity generated from renewable sources," and "using second life batteries from electric cars." Answers to these statements were given on a 7-point Likert scale [1 = strongly disagree, 7 = strongly agree].

3. Results

3.1. Attitudes toward Battery Storage

Across all groups, battery storage was perceived as quite useful, innovative, and positive. Ratings for perceptions of safety were just above the midrange of the scale, whereas ratings for aesthetics were just above the midrange of the scale for the building and control groups and in the lower half of the scale for the industrial design group. Analyses of variance showed that perceptions of usefulness and safety were not affected by the manipulation, $F(2, 225) = 1.24$, $p > 0.05$ for usefulness and $F(2, 225) = 2.61$, $p > 0.05$ for safety. All other perceptions were affected based on the images, $F(2, 225) = 6.10$, $p < 0.05$ for positiveness, $F(2, 225) = 5.50$, $p < 0.05$ for environmentally friendliness, Welch's $F(2, 144.075) = 9.10$, $p < 0.001$ for innovativeness, and Welch's $F(2, 143.356) = 30.88$, $p < 0.001$ for aesthetics.

Multiple comparisons revealed that for perceptions of positivity, there was a significant mean difference of 0.48 scale points [95% confidence interval (CI), 0.15; 0.81] between the urban design and the industrial design groups ($p < 0.01$). For perception of environmental friendliness, there was a significant mean difference of 0.53 scale points [95% CI, 0.14; 0.92] between the urban design and the industrial design groups ($p < 0.01$) and a significant difference of 0.41 scale points [95% CI, 0.01; 0.80] between the urban design and the control groups ($p < 0.05$). For perceptions of innovativeness, we found a significant difference of 0.55 scale points [95% CI, 0.20; 0.90] between the urban design and the industrial design groups ($p < 0.01$) and a significant difference of 0.50 scale points [95% CI, 0.13; 0.87] between the urban design and the control groups ($p < 0.01$). Finally, for perceptions of aesthetics, there was a significant difference of 1.13 scale points [95% CI, 0.78; 1.47] between the urban design and the industrial design groups ($p < 0.001$) and a significant difference of 0.43 scale points [95% CI, 0.14; 0.73] between the urban design and the control groups ($p < 0.01$). All the other group differences were not statistically significant.

3.2. Effect of Location and Design on Acceptability of Battery Storage

We conducted a 3×4 ANOVA with the between-subjects factor "group" (industrial design vs urban design vs control) and the within-subjects factor "location" (rural vs residential area vs neighborhood vs industrial area) to examine the effect of design and location on the acceptability of battery storage. The analysis of variance yielded a significant interaction effect of location and group on acceptability, $F(4.652, 523.384) = 2.51$, $p < 0.05$, partial $\eta^2 = 0.022$ (see **Figure 3**). Next, we analyzed the simple main effects for group and location. We found a statistically significant main effect of group on acceptability for the locations "residential area," $F(2, 225) = 4.53$, $p < 0.05$, partial $\eta^2 = 0.039$ and "neighborhood," $F(2, 225) = 4.97$, $p < 0.01$, partial $\eta^2 = 0.042$. For the location "residential area," acceptability was statistically significantly greater in the control group compared to the industrial design group ($p < 0.01$), whereas for the location "immediate neighborhood," acceptability was statistically significantly greater in both the control group ($p < 0.01$) and the urban design group ($p < 0.05$) compared to the industrial design group. Analyzing the simple main effect of the variable "location," we found a statistically significant effect of location on acceptability for the industrial design group $F(2.46, 184.68) = 94.90$, $p < 0.001$, partial $\eta^2 = 0.559$, the urban design group, $F(2.09, 159.03) = 63.29$, $p < 0.001$, partial $\eta^2 = 0.454$, and the control group, $F(2.06, 152.69) = 56.71$, $p < 0.001$, partial $\eta^2 = 0.434$. For all groups (industrial design, urban design, control), acceptability was not statistically significant different between "residential area" and "neighborhood" ($p > 0.05$), but for all other locations ($p < 0.001$). Acceptability was highest for the location "industrial area," second highest in the location "rural area," and about equally low in the locations "residential area" and "neighborhood."

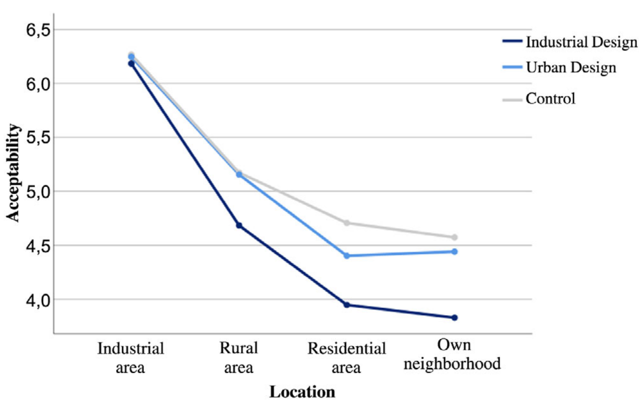

Figure 3. Impact of location (industrial area vs rural area vs residential area vs participant's own neighborhood) and design (industrial vs urban vs control) on battery storage acceptability.

3.3. Predictors of Acceptability in Different Landscapes

To gain a better understanding of which factors are associated with acceptability, we performed multiple regression analyses for each location to see whether predictors differed between the locations examined. **Table 1** provides the correlations between the predictors and acceptability in the four locations. Affect, attitudes, and knowledge about battery storage were included as predictors. Furthermore, we examined whether support for the energy transition and renewables would increase acceptability, as we depicted energy storage as a means for the successful implementation of the energy transition. Additionally, gender was included as a predictor as well as house ownership for the locations "residential areas" and "immediate neighborhood" because we suspected that it might influence acceptability in these locations.

The results indicate that the models explained 27–39% of variance in acceptability of battery storage in the different landscapes examined (see **Table 2–4**). Evoked affect emerged as a consistent significant predictor of acceptability across all locations. The more positive affect was evoked, the higher acceptability was. Whereas affect was the strongest predictor in rural areas, residential areas,

Table 1. Bivariate correlations between outcome variables and predictor variables (N).

	Industrial areas	Rural areas	Residential areas	Own neighborhood
Affect	0.461**	0.589**	0.524**	0.531**
Mean evaluation perceptions	0.454**	0.468**	0.393**	0.420**
Knowledge battery storage	0.182**	0.228**	0.336**	0.326**
Support energy transition and renewables	0.286**	0.178**	0.138*	0.170*
Industrial design	−0.036	−0.155*	−0.180**	−0.203**
Urban design	0.011	0.074	0.023	0.073
Gender	−0.077	−0.267**	−0.246**	−0.215**
House ownership	0.082	−0.027	0.014	−0.051

*$p < 0.05$; **$p < 0.01$.

Table 2. Predictors of acceptability in industrial areas.

	B	SE	ß
Constant	2.808	0.422	
Affect	0.186	0.072	0.213*
Mean attitudes	0.424	0.121	0.294**
Knowledge battery storage	0.040	0.038	0.070
Support energy transition and renewables	0.146	0.051	0.170
Industrial design	0.033	0.136	0.016
Urban design	−0.204	0.135	−0.101
Gender	−0.030	0.126	−0.016
	Adjusted $R^2 = 0.270$		
	$F(7, 220) = 13.00$; $p < 0.001$		

*$p < 0.05$; **$p < 0.01$.

Table 3. Predictors of acceptability in rural areas.

	B	SE	ß
Constant	1.163	0.593	
Affect	0.620	0.102	0.461**
Mean attitudes	0.304	0.170	0.137
Knowledge battery storage	−0.013	0.054	−0.015
Support energy transition and renewables	0.053	0.071	0.040
Industrial design	−0.396	0.191	−0.127*
Urban design	−0.236	0.190	−0.076
Gender	−0.614	0.177	−0.209**
	Adjusted $R^2 = 0.391$		
	$F(7.\ 220) = 21\,786$; $p < 0.001$		

*$p < 0.05$; **$p < 0.01$.

Table 4. Predictors of acceptability in residential areas.

	B	SE	ß
Constant	0.714	0.666	
Affect	0.597	0.114	0.411**
Mean attitudes	0.194	0.192	0.081
Knowledge battery storage	0.167	0.060	0.178*
Support energy transition and renewables	0.011	0.080	0.007
Industrial design	−0.733	0.215	−0.219**
Urban design	−0.499	0.213	−0.149*
Gender	−0.318	0.198	−0.100
House ownership	−0.158	0.175	−0.050
	Adjusted $R^2 = 0.345$		
	$F(8,\ 219) = 15\,917$; $p < 0.001$		

*$p < 0.05$; **$p < 0.01$.

and the participants' own neighborhoods, it was only the second strongest predictor in industrial areas. Instead, the mean evaluation of the perceptions emerged as the strongest predictor for acceptability in industrial areas. For the other locations on the other hand, the mean evaluation was not a significant predictor. In rural areas, gender was a strong predictor of acceptability, with women rating acceptability lower than men. In residential areas and the participants' own neighborhood, knowledge of battery storage emerged as a predictor of acceptability. The more the respondents knew about battery storage, the more acceptable the technology was being regarded. In the participant's own neighborhoods, house ownership was another significant predictor, with house ownership decreasing acceptability.

3.4. The Impacts of Different Mitigation Measures on Local Battery Storage Acceptability

Evaluations of mitigation measures referring to issues of participation, design, compensation, recycling of batteries, and

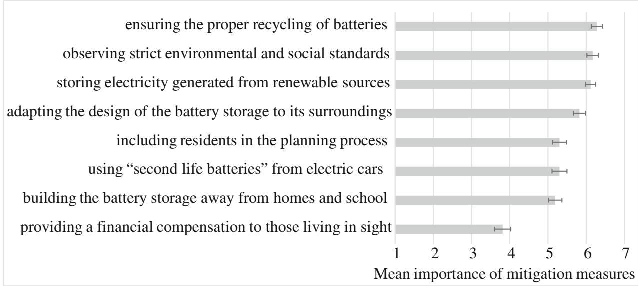

Figure 4. Mean importance of mitigation measures.

standards for responsible raw material mining did not differ significantly between groups, so we combined the data of the groups for the further analysis. All measures except for one were above the midpoint of the scale and thus rated as rather important (see **Figure 4**). Analysis of variance indicated that the importance ratings of mitigation measures differed significantly from each other, $F(7,\ 221) = 65\,880$, $p < 0.001$; Wilks' $\Lambda = 0.324$; partial $\eta^2 = 0.676$. Environmental measures, such as ensuring proper recycling of the batteries ($M = 6.28$, $\mathrm{SE} = 1.13$), storing electricity generated from renewable sources ($M = 6.12$, $\mathrm{SE} = 1.02$), and observing strict environmental and social standards in the extraction of raw materials ($M = 6.12$, $\mathrm{SE} = 1.16$), were rated as most important. This underpins the relevance of regulatory developments such as the European battery directive, which explicitly handle these aspects.[61] That means that these three environmental measures did not differ significantly from each other ($p > 0.05$), but were significantly higher compared to all other mitigation measures included ($p < 0.001$). The mitigation measure adapting the design of the battery storage to its surroundings ($M = 5.82$, $\mathrm{SE} = 1.22$) was rated as fairly important and differed significantly from all other mitigation measures ($p > 0.05$), providing further support for the claim that visual impacts of energy infrastructure may influence acceptance. The least supported mitigation measure, providing a financial compensation to those living in sight ($M = 3.82$, $\mathrm{SE} = 1.63$) was rated significantly lower compared to all other mitigation measures ($p < 0.001$). The three mitigation measures building the battery storage away from homes and school ($M = 5.19$, $\mathrm{SE} = 1.36$), including residents in the planning process ($M = 5.30$, $\mathrm{SE} = 1.39$) and using "second life batteries" from electric cars for the battery storage ($M = 5.30$, $\mathrm{SE} = 1.50$), were rated similarly high. While the means of these three measures did not differ significantly from each other ($p > 0.05$), they did diverge significantly from the rest of the mitigation measures ($p < 0.001$).

4. Discussion

Research on energy technologies suggests that specific local contexts and the visual impact of energy technologies can significantly influence acceptability.[34,50,54] As there are first indications that the visual impact of battery storage might influence acceptability as well,[44] the present article aimed to extend these findings by providing insights into whether the design and location of battery storage influences acceptability. Furthermore, we examine public perceptions of the technology and how these affect acceptability of battery storage in different landscapes. Taken together, the results can inform decision-making processes regarding the siting and design of battery storage. Furthermore, they reveal the perceived impacts of different mitigation measures for battery storage siting in residential areas, which generally show the lowest acceptability.

4.1. Impact of Battery Design on Battery Storage Evaluations

The first goal of our study was to investigate whether being presented with images of battery storage in different designs influences evaluations of battery storage. Our findings indicate that participants who were presented with an image of battery storage in an urban design overall evaluated the technology as significantly more positive, environmentally friendly, innovative, and aesthetic compared to people in the industrial design and control group (with one exception, battery storage was only perceived as more positive in comparison to the industrial design group, not the control group). This illustrates how situational cues can influence evaluations and attitudes, as posited by dual-process models of information processing.[62] Furthermore, the fact that participants perceived battery storage more positive, environmentally friendly, and innovative in the urban design compared to the control group suggests that the participants had no image of the technology in mind, which is in line with the fact that participants had little knowledge about the technology.

4.2. Impact of Location and Design on the Acceptability of Battery Storage

The second goal of the study was to highlight the importance of distinguishing between different locations for siting battery storage as well as battery storage design when assessing the acceptability of battery storage. In line with our expectations, acceptability of battery storage was dependent on the location (industrial areas, rural areas, residential areas, own neighborhood) and design of the battery storage. Our data show a clear preference for industrial areas over the other locations, with acceptability being the lowest in residential areas and the participant's own neighborhood. Acceptability in rural areas was significantly lower compared to industrial areas, but significantly higher compared to residential areas and the participant's own neighborhood. Whereas in industrial and rural areas, acceptability was rated similarly independent of battery storage design, acceptability was significantly affected by battery storage design for residential areas and the participant's own neighborhood. For the location residential areas, acceptability was significantly higher in the control group compared to the industrial design group, whereas for the participant's own neighborhood, acceptability was significantly higher in the both the control and urban design group compared to the industrial design group. The different effects of design could be attributed to the stronger personal relevance when being asked about a battery storage project in one's own neighborhood rather than residential areas in general. Given these findings, certain conclusions can be drawn. First, our results indicate that there is an added value of not only studying whether acceptability differs on a general and local level as stipulated by the NIMBY phenomenon. Rather, a careful consideration of possible locations for siting the energy technology is necessary in order to gain a comprehensive insight into acceptability and to assess whether resistance toward construction processes might develop in general or only for certain locations. Second, in terms of practical relevance, our findings indicate a clear preference for siting battery storage "out of sight" and further away from residential areas. This goes in line with qualitative results by Thomas et al.,[44] who reported that participants indicated that they might accept battery storage more readily if it was located out of sight or if it fit in with the local environment. Additionally, when planning to implement battery storage in residential areas, communicating a clear picture of the visual changes that accompany the energy storage project could be a starting point to prevent or counteract opposition to construction processes.

While our findings illustrate the importance of considering both location and design when assessing acceptability, there are several limitations to our study that need to be kept in mind. Battery storage comes in different sizes, which is an aspect that exceeded the scope of this study. It is possible that battery storage would be more readily accepted in residential areas or the participant's own neighborhood if it was only of small size. Furthermore, a potential limitation of our study is that we did not adapt the background of the images according to the respective locations studied, but simply showed the pictures of battery storage and asked about acceptability by adapting the items only. This way, we were able to include the participant's own neighborhood as a location, which we could not depict visually. However, while the backgrounds of the images were relatively neutral and similar, simply naming a location such as "rural areas" might have called forth different mental images of the locations within the participants, which could have influenced their acceptability ratings. Future studies that assess acceptability of energy technologies in different settings could employ visual methods such as images or laboratory studies with virtual reality simulations that systematically vary landscapes and technology design. Furthermore, the visual quality of landscapes and perceived fit of technology and landscape could be assessed based on key visual quality concepts identified in the literature, such as naturalness, coherence, and disturbance.[57]

4.3. Predictors of Acceptability in Different Locations

The third goal of the study was to explore whether predictors of acceptability would differ between the locations studied. Affect emerged as a consistent and strong predictor across all the locations studied, which is in line with previous studies on technology acceptance.[43,58,63] The more positive affect is evoked with regard to a technology, the higher acceptability is. According to dual-process models of cognition, which posit that we have a deliberate, rational, and an intuitive, affective system of reasoning, affective response plays a prominent role in decision-making when complex decisions have to be made or mental resources are limited.[64] Given that many participants indicated to have little knowledge of battery storage, the consistent role of affect can be explained in light of this. While affect was the strongest predictor of acceptability in the location's rural areas, residential areas, and the participant's own neighborhood, it was not the strongest predictor for the location industrial area. Likely, this can be attributed to the low personal relevance industrial areas have for most people. For the location industrial area, the attitude scale was the strongest predictor, whereas it was not a significant predictor for the other locations included in the study. Future studies could explore whether some of the specific qualities included in the attitude scale, such as perceived usefulness predict acceptability. As each attitudinal quality was only measured with a single item in the current study, we were unable to test whether some of the specific qualities such as perceived usefulness would emerge as significant predictors of acceptability. Several studies report technology acceptance to be dependent on perceived usefulness,[65,66] with some studies even indicating that people who see a technology as useful are not negatively affected by having it in their view in rural areas.[67,68] Future studies could include multiple-item scales on perceived usefulness in order to study in more detail how it affects acceptability in different areas. In rural areas, gender was a significant predictor of acceptability, with women rating acceptability as lower than men. Studies have shown that women display greater concern for the environment,[69] which could explain why women rate acceptability of battery storage significantly lower in natural, rural areas. However, more research is needed to clarify this relationship. For residential areas and the participant's own neighborhood, higher knowledge of battery storage was associated with higher acceptability of the technology. Previous research has mainly found positive effects of knowledge on technology acceptance, with examples including hydrogen technology acceptance[70] and acceptance of carbon capture and storage.[71] However, most studies, including our own study, were of correlational nature, making it impossible to establish the causal direction between knowledge and acceptance empirically. Hence, while knowledge does possibly influence acceptance, it could also be the case that acceptance influences information uptake and knowledge indirectly.[26] For instance, some research indicates that knowledge about a specific technology influences perceptions of risks and benefits.[72]

4.4. Measures to Increase Acceptability of Stationary Battery Storage in Residential Areas

The last goal of the study was to examine whether certain mitigation measures could help to increase acceptability of battery storage in residential areas, as we expected acceptability to be fairly low for this location. We included both environmental measures and measures relating to participation, compensation, and design. All except for one of the mitigation measures (providing a financial compensation) were rated above the midpoint of the scale, pointing to important implications for the implementation of battery storage projects. Three of the environmental mitigation measures (ensuring proper recycling of batteries, observing strict environmental and social standards in the extraction of raw material, and storing electricity generated from renewable sources) were rated as significantly more important compared to all other measures included. This indicates that reducing environmental concerns may present an opportunity for increasing acceptability of the technology. With regard to this, it will be important to transparently communicate the (dis) advantages of the technology and how potential environmental risks are mitigated. This type of communication could be enabled in the frame of the battery directive, which aims to reduce environmental and social impact of batteries.[73] Additionally, the fact that participants indicated acceptability to be higher if battery storage was used to store electricity generated from renewable sources (something that in reality can actually not be ensured) indicates that making the link between the expansion of renewables and the use of energy storage technologies might help to increase acceptability. This is in line with findings by Lienert et al.,[34] who have found that people who link the necessary grid expansion in Switzerland with the energy transition more readily accept new power lines. Future studies could explore whether discussing battery storage against the background of renewables and the energy transition changes perceptions of risks and benefits and whether this increases acceptability compared to providing no information on the link with renewables and the energy transition. Further, participants indicated to more readily accept battery storage if its design was adapted to its surroundings and if it was built away from homes and schools, which reflect our own results regarding battery design and preference of siting the technology in industrial and rural areas. Furthermore, these results are in line with findings by Thomas et al.,[44] who found that battery storage might be more acceptable if it fits with the local environment, be disguised (e.g., as garden shed), or if it was situated out of the way. Contrary to the popular belief of economic compensation being a tool to increase acceptability of energy technologies, providing a financial compensation to those living in sight was not rated as important by the participants of the current study. Previous studies on other energy technologies indicate that offering financial compensations may backfire as it could signal negative impacts for residents, create perceptions of bribery or a lack of adequate local benefits.[74–76] In line with this, these findings suggest that financial compensations should not in general be considered as an adequate mitigation measure. However, it is worth mentioning that how a battery storage unit is operated might also influence acceptability. This was highlighted in the work of Ambrosio-Albalá[77] on community batteries, which indicated that participants were skeptical regarding battery sharing business models.

4.5. Future Research Demands

Taken together, these results can serve as a starting point for mitigating opposition to battery storage projects. However, given our small sample size and the fact that the sample of the current study was not representative of the German population, generalizability of the results concerning the mitigation measures cannot be ensured. In line with this, future research could examine potential mitigation measures in more detail. Once battery storage is rolled out on a wider scale, additional first-hand experience with potential barriers to implementing the technology should feed into future studies. This could include an investigation that analyzes in which way the assessment of the acceptance object, battery storage, changes with the better understanding and direct interaction by the acceptance subject before and after a battery project installation.

4.6. Discussion on Specific Implications of Battery Storage Systems

In line with the survey, the factors of recyclability and environmental impacts (proper recycling, strict environmental and social standards in the extraction of raw material, storing renewable generated electricity) have been named as the most crucial aspects for mitigation of acceptance problems by the participants. In the public debate, the discussion on the topic of stationary batteries is often linked to the use of critical raw materials (such as lithium, nickel, and cobalt), potential safety issues (e.g., fire and explosion hazard), low recycling rates (in case of lithium), potential high environmental impacts (e.g., global warming potential), and human rights abuses (e.g., child labor in cobalt mines).[47] The raw materials of public concern are used in one certain type of lithium-ion battery, NMC, the most prominent chemistry used in electric vehicles. It is thus important to highlight that there are different battery technologies available, with very different technical and economic properties and different potential environmental impacts. There are, e.g., at present lithium-based battery types available, such as lithium iron phosphate (LFP), which are mostly used in stationary applications, and do not contain Co or Ni. In addition, LFP is considered to be very safe during operation. On the other hand, LFP has a lower energy density than NMC, but due to the higher costs, NMC plays a minor role for stationary applications.[4] There are also other energy storage systems, such as redox flow batteries, which are based on very different technical principles (electrolyte is stored in tanks and pumped through a reaction stack) with different technical and environmental implications.[78] New emerging technologies, such as sodium-ion batteries (SIBs), are considered as a sustainable alternative drop-in technology for lithium-ion batteries. Here, sodium (Na) is used instead of lithium for the electrode and the electrolyte. An overview of the difference of Li- and Na-based systems on a raw materials level is provided in Baumann et al.[79] and clearly shows how chemistry dependent the performance and resulting impacts are. Considering the entire life cycle (extraction of resources, manufacturing, use, and recycling) of the batteries is crucial. For example, Peters et al.[80] calculated that the overall environmental impact of a NMC battery with advanced hydrometallurgical recycling could be even lower than for LFP or different SIBs that use abundant materials. In total, the discussion on the topic is quite complex and there is often not enough data available to quantify in a reliable manner (with low uncertainties) sustainability and risks related to batteries. Also, it requires a robust base and harmonization of battery assessment methods, the data used, and the way of how results are communicated. The battery directive aims to establish a common playground by defining sustainability, performance, and labeling requirements for all types of batteries. Additionally, common recycling collection and recovery rate as well as due diligence policies to address risks are defined. Having such a common base for transparent battery labeling is considered as an important step to inform the public and to potentially increase in this way acceptance, if batteries are environmentally and socially benign. This might also be beneficial for newer and unknown systems, such as SIB, where the public might be more skeptical, which could result in lower acceptance.

5. Conclusions and Policy Implications

Using a mixed factorial design, we have sought to gain insights into how the design and siting of battery storage influences acceptability. In order to do so, participants were divided into three groups and were either shown an image of battery storage in an industrial design, an urban design, or no image at all. We then examined how participants evaluated battery storage according to a number of criteria, such as usefulness, innovativeness, and environmental friendliness. Afterward, we assessed acceptability in four different locations: industrial areas, rural areas, residential areas, and the participant's own neighborhoods. Additionally, we examined whether predictors of acceptability differed between locations. Finally, as we expected acceptability to be the lowest in residential areas and the participant's own neighborhoods, we studied whether different mitigation measures could help to increase acceptability in such a location.

In conclusion, our findings support the notion that the location and design of battery storage affect acceptability of the technology. As large-scale battery storage is not a widespread technology yet, our results can serve as guidance for future battery storage projects, in order to hinder or counteract resistance toward and increase acceptability of the planning and construction processes. Taken together, our results emphasize the importance of siting decisions in the context of battery storage projects. When possible, battery storage should be built away from residential areas, for which acceptability was rather low. On the other hand, especially industrial areas emerged as a promising location for siting battery storage in our study, with acceptability being very high (independent of battery storage design).

In situations where it is inevitable for battery storage to be built close to or in residential areas (e.g., as a community electricity storage), attention should be paid to minimizing visual intrusion by adapting the exterior of the infrastructure toward its surroundings. While this strategy might come with higher costs, it might mitigate additional costs that may arise in case of project delays due to resistance and protest form the local population. Furthermore, our results indicate that a higher knowledge about battery storage is associated with increased acceptability of the technology. On the other hand, the more innovative the technology is seen, the lower acceptability is. Additionally, our analysis of potential mitigation measures indicates that linking the use of the technology to the energy transition and the use of renewables as well as eliminating environmental concerns may help to increase acceptability. In line with this, we suggest to provide people with more information about the technology while keeping the aforementioned aspects in mind. Additionally, the business case could influence acceptance (e.g., community energy storage, shared storage, integration of renewables). As the technology is still relatively unknown and not very widespread, people are likely not to have too many negative connotations toward battery storage yet, which might otherwise impede susceptibility to cognitive arguments, as it seems to the case for power lines. Taken together, siting decisions and well-developed communication strategies present necessary considerations for utility companies seeking to anticipate and mitigate opposition to battery storage projects. In line with this, corresponding information campaigns with experts and active involvement of residents could be of help. In addition, we believe that a clear product declaration in frame of the European Battery Directive toward, e.g., a carbon footprint and recyclability and a corresponding labeling of batteries could influence the acceptance of named systems in a positive manner. In any case, more research is required focusing specifically on energy storage in residential areas.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

Research data are not shared.

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