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Shaping stable support: Leveraging digital feedback interventions to elicit socio-Political acceptance of renewable energy

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ABSTRACT

In democratic countries, the success of energy policies hinges on citizens' support and their acceptance of policy outcomes. In this study, we develop a digital feedback intervention to prompt citizens with information that visualizes the geographical distribution of wind turbines and to evaluate the effects on socio-political acceptance. In an online experiment, we exposed 430 German citizens to a personalized digital feedback intervention and elicited their acceptance of renewable wind energy. The results are threefold: First, citizens' acceptance of renewable wind energy that results from digital feedback is lower than initially claimed. Second, citizens who meaningfully engage with the digital feedback intervention are more likely to revise their acceptance of wind energy. Third, and surprisingly, citizens' ecological attitude and place attachment to their current residence had no significant effect on the extent to which they revised their acceptance of renewable wind energy. Our results demonstrate that digital feedback interventions can act as a "sensor" for socio-political acceptance. This contributes to informing citizens about energy policy outcomes and provides valuable insights for policymakers promoting a participatory democracy paradigm.

1. Introduction

The impact of climate change is global in scope and unprecedented in scale (United Nations, 2020). Without drastic action today, the preservation of our planet's ability to sustain human life is at considerable risk (Gasparrini et al., 2017; Pecl et al.; Voosen, 2019). To effectively mitigate global greenhouse gas emissions, a drastic decarbonization of energy systems is imperative, as they are the primary source of greenhouse gas emissions (International Energy Agency, 2023). Renewable electricity generation offers valuable alternatives to electricity generation based on fossil fuels and allows the mitigation of greenhouse gas emissions effectively (Sims et al., 2003). Although most people agree with the scientific consensus on the need for global decarbonization efforts (Fairbrother, 2016; Oreskes, 2018), expanding renewable electricity generation and implementing associated energy policies has proven to be an uphill battle. One reason for this is the absence of socio-political acceptance (Drews and van den Bergh, 2016; McGrath and Bernauer, 2017; Weber et al., 2017). For example, Germany has been among the first countries to initiate the transition to a low-carbon energy system and aspires to be the first major economy to phase out coal and nuclear energy. The expansion of Germany's wind energy capacity is a central pledge in the election manifestos of the country's main political parties and has been a contentious issue in several electoral campaigns. Recent surveys suggest high public support for renewable energies (Agora Energiewende, 2020; Onshore Wind Energy Agency, 2020). Nevertheless, plans for the expansion of Germany's wind energy capacity have faced strong opposition at a local level (Arifi and Winkel, 2020; Kamlage et al., 2020; Weber et al., 2017) as socio-political acceptance tends to drop as soon as policy outcomes affect citizens individually. For example, the acceptance of wind energy development drops once associated aesthetic and geographic implications become apparent (Weber et al., 2017).

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To successfully navigate renewable energy expansion, it is critical to take socio-political acceptance into account (Dermont et al., 2017; Ellis et al., 2023). Political engagement among citizens - whether through elections, referenda, petitions, protests, or involvement in political parties and organizations - is a substantial driver of policy change in democratic countries and can, therefore, significantly affect renewable energy expansion (Drews and van den Bergh, 2016; Huttunen et al., 2022; Jaradat et al., 2024). Relying on citizens' acceptance of renewable energy projects is crucial for energy policymakers to achieve successful decarbonization efforts in energy systems. Inaccurate assessments of socio-political acceptance regarding renewable energy expansion can become particularly problematic as this may result in corresponding infrastructure projects being stalled or even halted. However, gauging socio-political acceptance is complex, as research demonstrates that physical, social, cultural, and institutional contexts shape and constrain individuals' attitudes and choices. Simple opinion polls and surveys often fail to capture the nuances of socio-political acceptance. Therefore, there is a pressing need for advanced approaches to elicit and understand public attitudes and behaviors.

Feedback interventions are regarded as powerful instruments to act and decide in line with their preferences (Tiefenbeck et al., 2018, 2019) but so far have hardly been applied in the context of gauging socio-political acceptance of renewable energy expansion. Taking feedback interventions to the digital realm opens up new opportunities in broader social contexts by enabling the visualization of information, personalization of content, and creation of immersive experiences. These capabilities can effectively draw citizens' attention to the potential implications of renewable energy projects, supporting a comprehensive evaluation of citizens' values, attitudes, and preferences. Thus, digital feedback interventions can transform and advance traditional opinion polls and surveys, providing comprehensive insights into public attitudes and behaviors. Further, digital feedback interventions may contribute to citizens' deliberation in the context of renewable energy expansion by facilitating interactive communication between relevant stakeholders. Recent studies have proposed digital information visualization techniques and digital feedback as decision aids to educate citizens and inform their preference construction (Aubert et al., 2022, 2023; Aubert and Lienert, 2019; Laurila-Pant et al., 2019). Building on this research, we aim to use digital feedback interventions to prompt citizens with visualizations of the implications of renewable wind energy expansion. This personalized approach will help us gain deeper insights into how information about the location and number of wind turbines affects socio-political acceptance, promoting a participatory democracy paradigm (Aubert et al., 2023; Aubert and Lienert, 2019). Governments incorporating such digital feedback interventions to measure socio-political acceptance and adjust energy policies may find that their actions face fewer negative reactions and receive more public support. Providing policymakers and renewable energy project developers with tools for visualization and feedback empowers citizens to engage with complex information in an accessible way. Personalized feedback on the implications of renewable wind energy expansion actively includes citizens in decision-making, transforming them from passive recipients of information to active participants who can influence outcomes based on their preferences and values. Finally, transparent visualization of data and outcomes builds trust between citizens and policymakers or renewable energy project developers, enhancing credibility and fostering a sense of ownership and trust in the decisions being made. Therefore, we pose the following research question: *How do digital feedback interventions affect the formation of citizens' acceptance of renewable energy expansion?*

For the purpose of this study, we focus on citizens' acceptance of renewable wind energy in Germany. Specifically, we conducted an online experiment with German citizens, asking them what percentage of the current coal-fired electricity generation they would replace with renewable wind energy, assuming they had freedom of choice. Respondents then immediately receive visualized feedback on the number and location of wind turbines required to replace their preferred proportion of coal-fired electricity generation. Our results demonstrate that digital feedback interventions can act as a "sensor" for socio-political acceptance, informing citizens about energy policy outcomes and providing valuable insights for policymakers and the public alike.

2. Prior research and theory

2.1. Social acceptance of renewable energy

The social acceptance of renewable energy policies represents a critical prerequisite for a wide-ranging transformation of energy systems towards decarbonization (Ellis et al., 2023). An interdisciplinary and three-dimensional approach to social acceptance, as proposed by Wüstenhagen et al. (2007), distinguishes between socio-political, community, and market acceptance (Dermont et al., 2017; Wüstenhagen et al., 2007): First, socio-political acceptance relates to refers to social acceptance on the most general level and includes the general approval or support of policies and technologies by political stakeholders and the broader public (Dermont et al., 2017; Wolsink, 2020; Wüstenhagen et al., 2007). Second, community acceptance addresses the acceptance of siting decisions and renewable energy projects by local stakeholders, e.g., residents or regional authorities (Dermont et al., 2017; Wüstenhagen et al., 2007). Third, market acceptance involves economic aspects, such as technology adoption by market actors or technology diffusion (Dermont et al., 2017; Wüstenhagen et al., 2007).

Socio-political acceptance is particularly relevant for the successful decarbonization of energy systems (e.g., Devine-Wright and Wiersma, 2020; Karakislak and Schneider, 2023; Müller et al., 2023). This relates both to the acceptance of energy policies as well as the implications following such policies (e.g., the construction of renewable power plants). Energy policies often involve several factors that influence citizens' socio-political acceptance, such as perceived benefits, risks, and trust in the entities responsible for policy implementation. Additionally, the deployment of new technologies and infrastructure is typically driven by policy decisions. For example, renewable energy projects are often a direct result of energy policies aimed at reducing greenhouse gas emissions. Therefore, studying the socio-political acceptance of energy policies provides a foundation for understanding reactions to the resulting technological implementations.

In the absence of socio-political acceptance, citizens' opposition to the implementation of energy policy measures and renewable energy projects, expressed by protests, petitions, or legal actions, can delay, increase costs, or prevent much-needed advancements in the decarbonization of energy systems (Devine-Wright and Wiersma, 2020). As prior research demonstrated, a multitude of factors influence socio-political acceptance, including political ideologies, public opinion on renewable energy policy, media coverage, and the perceived fairness of policy incentives and regulations (Devine-Wright, 2005; Sovacool and Lakshmi Ratan, 2012; Wüstenhagen et al., 2007). Additionally, socio-cultural aspects such as individuals' hedonic, egoistic, altruistic, and biospheric values are critical determinants of environmentally relevant attitudes, preferences, and actions (Steg et al., 2014a, 2014b). Values shape attention, accessible knowledge, the importance assigned to consequences, evaluations of situations, and considered alternatives (Steg et al., 2014a; Stern and Dietz, 1994). In environmental contexts, values guide attention to value-congruent information, influencing beliefs, attitudes, preferences, norms, and support for environmental protection (Steg et al., 2014a; Stern and Dietz, 1994). Understanding citizens' values and concerns in the context of renewable energy policies is a crucial task for policymakers, as values and concerns directly influence support or opposition. Ignoring citizens' acceptance risks project delays or cancellations and can undermine broader goals of sustainable development and environmental protection. Therefore, effectively engaging with citizens and aligning policies with their values is crucial for successful renewable energy development.

Traditional methods for gauging public opinion, such as opinion polls and surveys, are commonly used to assess socio-political acceptance. However, these methods often feature limited capabilities to capture the complexity and depth of community sentiments and values. Consequently, there is a pressing need for advanced approaches that provide a more nuanced understanding of public attitudes and behaviors (Owens and Driffill, 2008). Such methods can offer deeper insights and more accurate assessments of socio-political acceptance. With this study, we address this research gap as emphasized by Owens and Driffill (2008) and set out to develop and evaluate digital feedback interventions for assessing socio-political acceptance of renewable energy development.

2.2. Leveraging digital feedback for understanding socio-political acceptance

Digital feedback interventions provide new means for eliciting and understanding public attitudes and behaviors. Digital feedback interventions enable citizens to investigate the implications of political initiatives and provide the foundation for interactive, personalized, and immersive tools for public engagement. Feedback Intervention Theory (FIT), proposed by Kluger and DeNisi (1996), describes how and under what circumstances feedback interventions successfully affect behavior or performance in tasks (Kluger and DeNisi, 1996). The most relevant constituents of FIT for our work are: First, behavior is regulated by feedback comparisons to individual standards, i.e., the individual beliefs that determine preferences and behavior (Kluger and DeNisi, 1996; Warren et al., 2011). People use feedback to evaluate their behavior relative to their standards. If a feedback-standard discrepancy is perceived, people react to feedback in a targeted manner to attain the standard by adjusting their behavior. Second, attention is assumed to be limited following a wide spectrum of behavioral theories as proposed by Martino et al. (2006), Kahneman (2003), or Simon (1955). Thus, only feedback-standard discrepancies that receive attention actively participate in behavior regulation. Third, feedback interventions alter the locus of attention and, therefore, can affect behavior. As feedback interventions are often perceived to have potentially serious implications for the self, they receive considerable attention steering toward individual standards. Hence, a feedback intervention's elements allow individuals to compare their behavior with the standards meaningful to them and – if a feedback-standard discrepancy is perceived – to adjust their behavior to attain the standard (Ableitner et al., 2018; Kluger and DeNisi, 1996).

In the context of digital feedback interventions, information visualization amplifies human cognition as much as it enables individuals to retrieve or use information (Card, 2009; Chan, 2001; Hargreavesn et al., 2010; Ware, 2004). Information visualization operates based on improving the visual prominence of particular information and offers a certain degree of interaction (Cappa et al., 2020; Yi et al., 2007). The purpose of such interaction is to reduce complexity and help users process information and gain new insights (Cappa et al., 2020; Figueiras, 2015; Sunstein, 2019). To this end, visual feedback interventions make the ramifications of a given decision salient in real-time.

This suggests that digital feedback interventions that function through visual feedback are an effective strategy to support citizen deliberation by making complex information accessible and engaging, which can help citizens understand the implications of renewable energy development (Cappa et al., 2020; Lurie and Mason, 2007).

While the information-deficit model suggests that public opposition stems from a lack of knowledge and that supplying information will correct this deficiency (Bidwell, 2016; Gross, 1994), social science research has criticized this model for its simplistic view, demonstrating that knowledge and attitudes are not always directly correlated (Bidwell, 2016). Instead, public values, the context in which information is provided, and the manner in which it is received play crucial roles in shaping public attitudes and acceptance (Bidwell, 2016; Butler et al., 2015). Against that background, digital feedback interventions have the potential to go beyond simple information dissemination by providing interactive, personalized, and immersive experiences that engage individuals at a deeper level and involve them in a meaningful dialogue about renewable energy projects.

Beyond merely informing, digital feedback interventions can serve as effective tools for analyzing and exploring the conditions under which socio-political acceptance is achieved. They offer multiple opportunities to engage users, making information interactive and accessible. These features allow users to explore different scenarios and outcomes, fostering a deeper understanding of the implications of renewable energy projects. They allow for real-time feedback and adjustments, making it possible to identify and address specific concerns and values of citizens. By enabling citizens to visualize and interact with data related to renewable energy projects, they can provide a platform for citizens to see the tangible impacts of renewable energy developments on their local environment, thereby facilitating a deeper understanding of the socio-political acceptance determinants. By providing a comprehensive and engaging way for citizens to understand and evaluate renewable energy projects, these interventions can play a crucial role in measuring citizens' buy-in and identifying rationales for opposition. Addressing corresponding concerns proactively fosters a sense of inclusion and cooperation, which is essential for the successful execution of renewable energy projects.

Against that background, this study aims to evaluate the effect of digital feedback interventions on citizens' acceptance of renewable energy development. Specifically, we focus on the socio-political acceptance of renewable wind energy in Germany. Despite a generally high socio-political acceptance for renewable wind energy, socio-political acceptance tends to drop when the aesthetic and geographic implications of wind energy development become apparent, such as the number and location of the wind turbines that will need to be built (Weber et al., 2017). Therefore, the impact of newly constructed wind turbines is understood to be one of the most important motives for local opposition, which can lead to a critical halt in the expansion of renewable energies (e.g., Wolsink, 2018, 2007). To prevent a critical halt in the expansion of renewable energies and contribute to a successful wide-ranging integration of renewable energy electricity generation, understanding and addressing socio-political acceptance issues is critical.

This, in turn, may elicit to what extent citizens accept the expansion of renewable wind energy knowingly of the number and location of wind turbines required to increase the electricity generation based on renewable wind energy. Providing citizens with visual feedback makes such implications more apparent, potentially leading to a reduction in socio-political acceptance, which – if not being addressed sufficiently by relevant stakeholders – may result in a significant obstacle to renewable wind energy expansion. This results in our first hypothesis.

H1. *Overall, citizens reduce their acceptance of renewable wind energy when they receive visual feedback on the number and location of required wind turbines.*

To date, researchers have suggested that feedback interventions that receive sufficient attention will make individuals think of new information with regard to their personal values, leading them to revise their preferences accordingly (Ableitner et al., 2018; Kluger and DeNisi, 1996). For visual feedback interventions to be effective in encouraging the introspection necessary to gauge socio-political acceptance, individuals need to thoroughly reflect on the information provided. We theorize that engagement with said feedback leverages a person's cognitive abilities to process information (Dimara and Perin, 2020). We thus hypothesize.

H2a. *Citizens who engage in a focused way with visual feedback on the number and location of required wind turbines are more likely to reduce their acceptance of the expansion of renewable wind energy.*

Prior research has already indicated the effectiveness of digital feedback interventions in the context of sustainability, for instance, regarding demand-oriented energy management (Cappa et al., 2020), sustainable nutrition choices (Berger et al., 2020; Lembcke et al., 2019; Michels et al., 2021), car-sharing (Schrills et al., 2020), or socially responsible investments (Gajewski et al., 2021). In such pro-environmental decision situations, one's ecological attitude is an important factor in one's preferences (Bidwell, 2013; Cappa et al., 2020). An individual with a strong ecological attitude is more willing to approve pro-environmental policies, even if their implications entail personal disadvantages (Attari et al., 2009; Dietz et al., 2007; Rhodes et al., 2017). This results in the second aspect of our second hypothesis.

H2b. Citizens with a strong pro-ecological attitude are less likely to reduce their acceptance of renewable wind energy when they receive visual feedback on the number and location of required wind turbines.

While a person's ecological attitude refers to a general and global environmental perspective, place attachment denotes how attached one is to one's local environment. Many scales measure identification with one's local environment as a significant determinant of preferences regarding pro-environmental policies (Bergquist et al., 2020; Jorgensen and Stedman, 2001; Stedman, 2006). People who are very attached to their local environment and identify strongly with it may perceive energy policies that affect the appearance of their local environment as a threat (Devine-Wright, 2009). Place attachment may, therefore, evoke negative attitudes as a form of protective action to oppose new developments that disrupt emotional attachments and threaten place-related identity (Bidwell, 2013; Devine-Wright, 2009; Devine-Wright and Batel, 2017; Wolsink, 2007). This leads to the third aspect of our second hypothesis.

H2c. Citizens who are very attached to their area of residence are more likely to reduce their acceptance of renewable wind energy when receiving visual feedback on the number and location of required wind turbines.

3. Methodology and data

Before our experiment, we pre-registered (but not published) details of the experimental design and statistical analyses at aspredicted.org (Bogert et al., 2021). Furthermore, we validated our experimental design with reference to the ethics directive of the German Association for Experimental Economic Research.

3.1. Application context

Replacing fossil fuels with renewable energy sources is crucial for the success of global efforts against climate change, as energy systems are the primary source of greenhouse gas emissions (International Energy Agency, 2023). Germany is at the forefront of national efforts to foster a renewable energy transition (International Energy Agency, 2020). The country has introduced legislation that requires the end of coal-fired electricity generation by 2038 (BMU - Federal Ministry for the Environment Nature Conservation and Nuclear Safety, 2020; BMWi - German Federal Ministry for Economic Affairs and Energy, 2020). To this end, Germany has pledged to press forward with renewable energy development to ensure the future reliability of the electricity supply (Agora Energiewende, 2019). Despite a broad consensus among German citizens that keeping coal in the ground is necessary to avert the climate crisis (Rinscheid, 2020; Rinscheid and Wüstenhagen, 2019), this new legislation has become a point of contention: miners demand job protection, while many local initiatives oppose plans for new wind turbines and associated high-voltage power lines (Neukirch, 2020; Weber et al., 2017). We aim to tackle these challenges by developing a digital feedback intervention that operates based on information visualization and helps policymakers to effectively gauge socio-political acceptance. For the purpose of this study, we focus on wind energy as a representative issue of the expansion of renewable energies in Germany (International Energy Agency, 2020), and for the aforementioned reason of salience, we will take a particularly close look at the geographical distribution of wind turbines, which can affect citizens individually (e.g., due to impacts on the visual landscape). The location of wind turbines is a central factor influencing citizens' acceptance (Devine-Wright and Wiersma, 2020; Wolsink, 2007, 2018). Recent studies confirm that 89% of German citizens express general support for the transition to renewable energies, and 79% acknowledge the importance of moving forward with the expansion of renewable wind energy to reach ambitious energy policy goals (Agora Energiewende, 2020; Onshore Wind Energy Agency, 2020). However, to name but one example of lacking socio-political acceptance in the context of project execution, 66% of German citizens endorse regulatory interventions that impose requirements for a high minimum distance between wind turbines and residential areas, which in many cases stalls the construction of new wind turbines (IAAS, 2019). This caused a public controversy, demonstrating how important it is to build energy policy initiatives on the foundation of socio-political acceptance and engage with citizens proactively to prevent policy implementation barriers.

3.2. Participants

In total, 620 German citizens participated in our online experiment. All of them were recruited by a professional research panel and received monetary compensation. The distribution of participants was representative of the German population in terms of gender, age, and region (i.e., the federal state of residence). Instructional manipulation check questions (Kane and Barabas, 2019; Oppenheimer et al., 2009) involved selecting a specific answer on a 7-point Likert scale and answering a simple calculation task. The manipulation check reduced the sample to 518 citizens. We included citizens who cognitively engaged with feedback interventions by using the interactive features of the digital feedback intervention (i.e., who adjusted the slider's default value). This reduced the sample to 430 citizens (52% female). Appendix A details the sample characteristics.

3.3. Procedures

We conducted an online experiment to collect data. While an analysis of existing data could have been used to focus on the current state of citizens' socio-political acceptance of renewable wind energy, we specifically opted for an experimental approach, allowing us to analyze socio-political acceptance before and after placing a digital feedback intervention. Since the primary focus of this study is to evaluate how digital feedback interventions affect citizens' preferences and, therefore, socio-political acceptance, our experiment adhered to a within-subjects design that comprised three chronological stages (Field and Hole, 2003; Friedman and Sunder, 1994). To ensure an effective design of our digital feedback intervention, we followed a well-established development process for behavioral interventions as defined by Mirsch et al. (2017) and operationalized design principles of Liu et al. (2017). Appendix B details the design process.

At the experiment's first stage, participants entered their German residence's postal code. They were then presented with a statement informing them that "In 2019, coal-fired electricity generation covered about 30% of German electricity consumption" (AG Energiebilanzen, 2020). We requested all participants submit their preference on the proportion of coal-fired electricity generation that they would substitute with renewable wind energy within the next five years – assuming they had freedom of choice. An adjustable slider ranged from 0% to 100%, allowing participants to submit their initial preference.[3]

[3] Please note that the initial position of the adjustable slider was 0%, corresponding to replacing none of the coal-fired electricity generation capacities with renewable wind energy in the next five years.

We combined several sources of information to calculate the locations of existing and new wind turbines in Germany in the backend of the experiment. In so doing, we relied on.

1) Custom street maps retrieved from the Mapbox data platform (mapbox, 2020)
2) Coordinates of existing wind turbines, as presented by OpenStreetMap (OpenStreetMap, 2023)
3) Information about average wind speeds at 80 meters above ground, provided by the German Weather Service (German Weather Service, 2004), which we correlated with the hub height of wind turbines (Fraunhofer IEE - The Fraunhofer Institute for Energy Economics and Energy System Technology, 2020) to predict suitable locations for potential new wind turbines
4) Technological characteristics of commonly used wind turbines to define the prospective electricity generation, given location-specific wind speeds (International Electrotechnical Commission, 2019)
5) Economic factors, such as minimum wind speeds, required to allow for an economically viable wind turbine operation at a specific location (Dupont et al., 2018)
6) Legal factors, such as minimum distances from wind turbines to residential areas (BMWi - German Federal Ministry for Economic Affairs and Energy, 2020)
7) Aggregated coal-fired electricity generation in Germany (AG Energiebilanzen, 2020)

Participants gave their preferences to determine both the number and the positioning of newly required wind turbines at the most suitable locations, those being identified concerning the highest wind speeds in a given area to ensure efficient fulfillment of electricity demand. This method allowed us to ensure that all participants received immediate feedback in the form of visual information reflecting their individual preferences. They could then see the real-world ramifications on the maps. Participants who were not satisfied with the outcome were free to

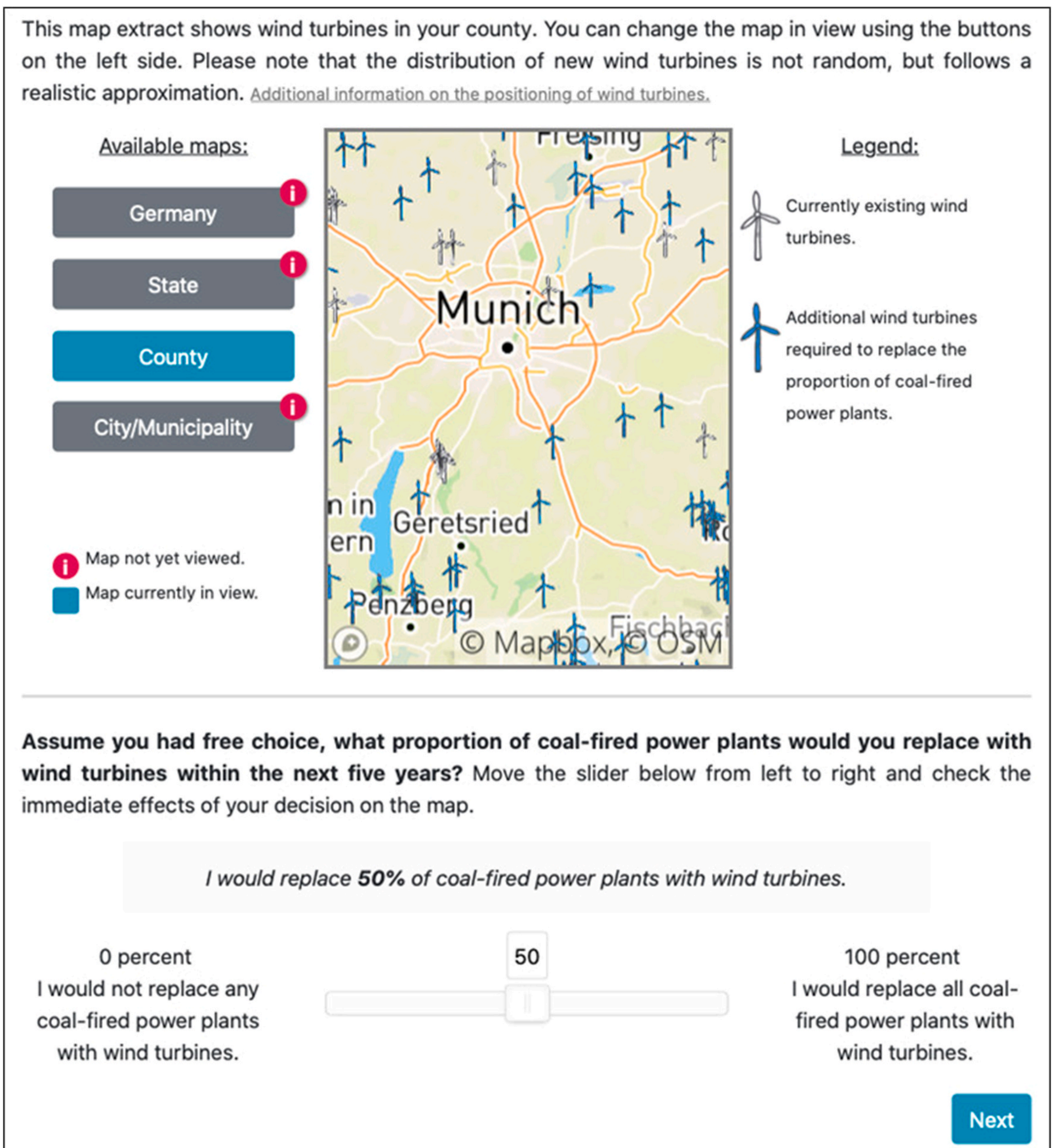

Fig. 1. Illustration of the second stage of the online experiment (exemplary Munich postal code).

alter their preferences with the adjustable slider and visually track the respective consequences on the maps. Once citizens felt the outcomes conformed to their preferences, they could opt to proceed. Fig. 1 illustrates the graphical user interface of this central part of the experiment.

At the third and final stage of the experiment, we provided participants with a comparative view of the maps at all four scales to let them see everything at a single glance. The number and location of the illustrated wind turbines corresponded with the participants' final preferences as articulated at the first stage of the experiment. Again, participants had the chance to revise their preferences with the slider and view the implications on the maps. Once participants were satisfied, the final preferences were logged. Fig. 2 illustrates the interface used in the third stage of the online experiment.

Upon completion of the online experiment, we collected additional survey-based data. Please note that we chose a transparent digital feedback intervention, informing participants about the motives and methods used. Participants received a detailed introduction to all functionalities before interacting with the maps and adjustable slider. At any point in the experiment, it was possible to access further information on the assumptions made for the scenario. Likewise, it was possible at any point of the experiment to have all the information presented on the maps explained, should a participant require this. This was done with the awareness that non-transparent feedback interventions have been heavily debated because they manipulate people's behavior in subtle and covert ways without the targeted individual noticing the manipulation (Bruns et al., 2018; Michels et al., 2021; Schubert, 2017).

3.4. Measures

We measured three dependent variables that reflect the socio-political acceptance of renewable wind energy: First, the percentage of wind energy that participants intended to use as a substitute for current coal-fired electricity generation at the start of the experiment, which is to say, before the feedback intervention (variable name: *initial preference*). We measured the *initial preference* on a scale from 0% to 100%. Second, the percentage of wind energy that participants intended to use as a substitute for coal-fired electricity generation at the end of the experiment, which is to say after the feedback intervention (variable name: *final preference*). Again, we measured the *final preference* on a scale from 0% to 100%. We had to account for the possibility that the *initial preference* of a participant may significantly affect their *final preference* if for no other reason than that they may try to be consistent. Since this

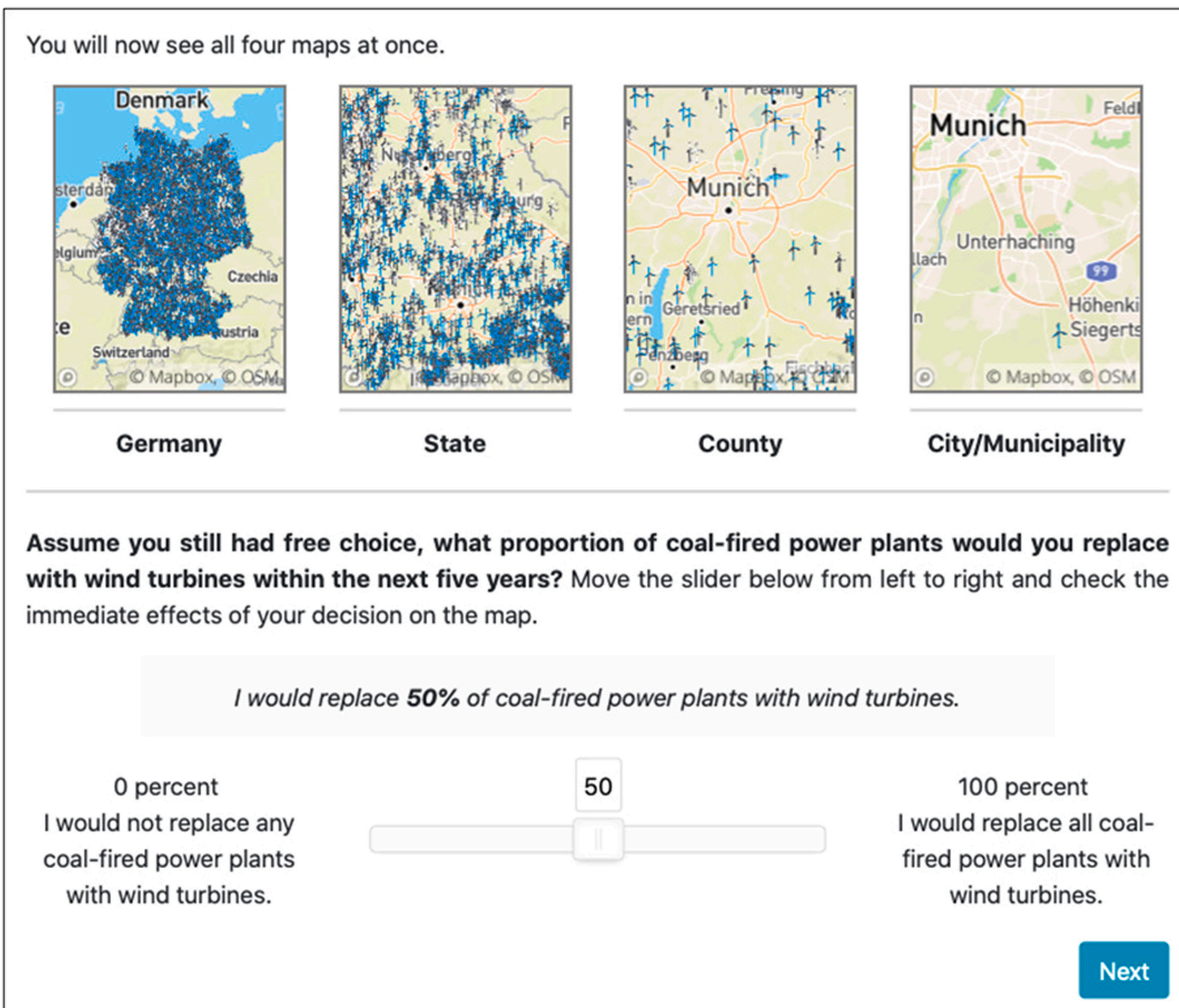

Fig. 2. Illustration of the third stage of the online experiment (exemplary Munich postal code).

study focuses on the potential of digital feedback interventions to affect socio-political acceptance (measured through citizens' preferences), it was crucial to take note of each participant's baseline preference – i.e., their *initial preference* – as well as their *final preference*. Third, we calculated the difference between the *initial preference* and the *final preference* (variable name: *delta preference*). This *delta preference* indicates the extent to which participants revised their initial preference. In this case, we measured that variable on a scale from −100% to 100%.

As independent variables, we measured the participants' *ecological attitudes* by using a seven-item version of the New Ecological Paradigm (NEP) scale (Bidwell, 2013; Dunlap et al., 2000; Whitfield et al., 2009). We classified participants who scored above the sample average as having an *ecological worldview* and those who scored equal to the average or below it as having an *exemptionalist worldview.* In addition, we used the Sense of Place (SOP) scale to measure their *place attachment* to their current place of residence (Jorgensen and Stedman, 2001; Stedman, 2006). We classified participants with a score above the sample average as *attached* and those with scores equal to the average or below it as *non-attached*. Appendix C provides details of the measurement scales and their reliability. To analyze how participants' engagement with the online experiment affected their preferences, we measured the following independent variables: First, we measured the number of times a participant reevaluated a preference using the adjustable slider before submitting a final preference (variable name: *slider modifications*). When this number was above the sample average, we noted that the participant had a *high slider interaction*, whereas those with a number equal to the average or below it had a l*ow slider interaction*. Second, we measured how often participants viewed each of the four maps at the second stage of the experiment (variable name: *map views*). When this number was above the sample average, we noted that this participant had a *high map interaction*, as opposed to those whose number was equal to the sample average or below it, in which case we noted that they had a *low map interaction.* See Appendix D for a detailed description of our sample with regard to control and independent variables.

We used sociodemographic information for our control variables. To this end, we asked participants to specify their *gender*, *age*, and level of *education*, all of which we encoded as categorical variables (Field and Hole, 2003). Furthermore, we used their postal code to differentiate between types of locations. Participants had to state whether they live in 1) the *country* or the *city*, 2) the *north* or the *south* of Germany, those areas being differently affected by wind turbines (German Wind Energy Association, 2020), and 3) regions that had *coal* or *no coal* mining (accounting for current controversies regarding).

4. Results

4.1. Comparative analysis of the participants' initial and final preferences

To evaluate whether the digital feedback intervention significantly impacts citizens' acceptance of renewable wind energy, we compared each participant's initial and final preferences. We included parametric and non-parametric tests, using the one-sided *t*-test for paired samples and the non-parametric Wilcoxon signed-rank test (Field and Hole, 2003). Since non-parametric tests are not always acceptable substitutes for parametric tests when certain assumptions are not met, and since both of these statistical analyses and their combined application are common, we applied both tests (e.g., Qiu and Kumar, 2017; Scheffel et al., 2011; Wolf et al., 2012). In addition to statistical significance testing, we estimated the impact of initial preferences on final preferences. Such an assessment of effect size is an essential part of rigorous statistical practice and a necessary companion to tests of statistical significance (Mohajeri et al., 2020). Each statistical test has its effect size index (Cohen, 1992). In t-tests, the absolute value of Cohen's *d* is typically used as this effect size index. Specifically, Cohen's *d* can be negative, positive, or zero, reflecting the direction and magnitude of the effect, with zero indicating no effect as the means of the compared groups are equal. In line with Cohen (1988), we evaluated an effect size as small if $|d| \geq .20$, as medium if $|d| \geq .50$, and as large if $|d| \geq .80$. The effect size in the Wilcoxon signed-rank test is the rank correlation coefficient *r*, calculated by dividing the z statistic by the square root of the total number of observations. The absolute value of *r* varies from zero to close to one. We evaluated an effect size as small if $|r| \geq .10$, as medium if $|r| \geq .30$, and as large if $|r| \geq .50$ (Cohen, 1992).

Table 1 reports the *t*-test and Wilcoxon signed-rank test results regarding significance and effect size. Our results indicate a notable difference between the participants' average initial and final preferences. After engaging with the digital feedback intervention, they intended to replace a significantly lower percentage of coal-fired electricity generation. This significant adjustment applies to most subgroups of the independent variables. Only participants younger than 35 years and those living in Germany's coal-mining regions did not significantly adjust their preferences during the experiment (no consistent significance according to both tests). Most observed differences between participants' initial and final preferences are small to medium in effect size. For participants younger than 35 years with an *exemptionalist worldview,* the *t*-test reports negligible effect sizes. Overall, we conclude that socio-political acceptance decreases once participants receive visual feedback about the geographical distribution of wind turbines, which supports our H1. However, participants do not overturn their decisions entirely, as small to medium effect sizes in Table 1 indicate.

4.2. Analysis of the participants' preference revisions

We conducted a multiple linear regression analysis to examine how participants rationalized their preference revisions. Table 2 presents estimated coefficients and p-values for the multiple linear regression analysis concerning the differences between initial and final preferences, i.e., the *delta preference*. The variance explained was 22% ($R^2 = .218$).

The regression results indicate a significant negative coefficient for the number of *slider modifications* that participants made before submitting their final preference. The results also indicate that the *number of maps viewed* by the participants in the second stage of the online experiment had a significant adverse effect on the extent to which individual preferences were revised. This lends credence to the hypothesis that participants' engagement with visual feedback is a strong determinant of preference revisions, supporting H2a.

As for H2b and H2c, however, the regression results support neither of those hypotheses. The participants' *ecological attitude* and degree of *place attachment* had no significant impact on the extent of individual preference revisions. Instead, their initial preference had a significant positive effect on the value of preference revision. In other words, those with a high *initial preference* were more likely to revise their responses to the visual feedback.

The results indicate a significant positive coefficient for the number of slider modifications participants made before submitting their *final preference* and no significant effects regarding any of the sociodemographic control variables, except for the categorical variable indicating whether a participant's age is below 35 and their residence is in northern or southern Germany. Specifically, results indicate that those younger than 35 were less likely to revise their preferences downwards, while citizens from southern Germany were more likely to do so.

5. Conclusion and policy implications

In democratic countries, the social acceptance of policies is a critical factor in their development and enactment. In many cases, however, members of the public perceive policy issues to be vague, highly complex, or unfamiliar (Bernhard and Freeder, 2020; Sudo et al., 2013). This study explores the potential of digital feedback interventions to elicit citizens' acceptance of renewable wind energy development by visualizing corresponding implications in the form of the anticipated

Table 1
Results of the *t*-test and Wilcoxon signed-rank test.

Variable	Description	Mean *initial preference* [%]	Mean *final preference* [%]	*t*-test		Wilcoxon signed-rank test	
				p-value	effect size |*d*|	p-value	effect size |*r*|
full sample	−/−	65.321	58.893	c	.308 (small)	c	.259 (small)
gender	*male*	66.380	59.827	c	.311 (small)	c	.282 (small)
	female	64.329	58.018	c	.305 (small)	c	.243 (small)
age	*<35*	63.020	59.918	.053	.165 (negligible)	.068	.119 (small)
	35–64	65.296	58.330	c	.373 (small)	c	.300 (medium)
	>64	67.588	59.177	b	.318 (small)	c	.304 (medium)
education	*no higher education*	65.050	59.282	c	.272 (small)	c	.229 (small)
	higher education	65.932	58.015	c	.395 (small)	c	.336 (medium)
country/city	*countryside*	64.584	58.504	c	.303 (small)	c	.223 (small)
	city	66.615	59.577	c	.317 (small)	c	.319 (medium)
north/south of Germany	*north*	64.748	58.639	c	.289 (small)	c	.269 (small)
	south	66.855	59.573	c	.337 (small)	c	.247 (small)
coal/no coal region	*no coal region*	65.455	59.082	c	.303 (small)	c	.270 (small)
	coal region	64.049	57.098	a	.353 (small)	.054	.154 (small)
ecological attitude	*ecological worldview*	75.135	64.995	c	.442 (small)	c	.388 (medium)
	exemptionalist worldview	57.329	53.924	b	.183 (negligible)	b	.143 (small)
place attachment	*attached*	67.857	61.798	c	.289 (small)	c	.250 (small)
	un-attached	62.177	55.292	c	.330 (small)	c	.269 (small)

Note.
[a] $p < .05$.
[b] $p < .01$.
[c] $p < .001$.

Table 2
Multiple linear regression results for *delta preference*.

Hypothesis	Variable	Description	Coefficient	p-value
	intercept		11.579	c
H2a	*slider modifications*	number of slider modifications	−1.228	c
	map views	number of times a map is viewed	−.929	b
H2b	*ecological attitude*	*ecological worldview*	−2.466	.165
		exemptionalist worldview		
H2c	*place attachment*	*attached*	−2.084	.211
		non-attached		
Control	*initial preference*	initial slider position [%]	−.170	c
	Gender	male		
		female	−.917	.584
	Age	<35	5.830	a
		35–64	1.235	.539
		>64		
	Education	no higher education		
		higher education	−2.825	.109
	country/city	countryside		
		city	2.344	.167
	north/south of Germany	north		
		south	−4.001	a
	no coal/coal mining region	not a coal mining region		
		coal mining region	−.929	.746

Note.
[a] $p < .05$.
[b] $p < .01$.
[c] $p < .001$.

geographical distribution of wind turbines. We conducted an online experiment asking German citizens to state their preferences on the percentage of coal-fired electricity generation they wish to replace with renewable wind energy. Once citizens expressed their preferences, we presented them with the digital feedback intervention. They received real-time feedback along with the option to revise their initial preference. Our statistical results indicate three significant findings of relevance to the stated hypotheses:

First, participants tended to reduce the proportion of renewable wind energy, which they had stated as the ideal compensation for today's coal-fired electricity generation (H1). This reduction accounts for approximately six percentage points, as the 65% average initial preference dropped to a 59% average final preference. Thus, the presented information on the geographical distribution of wind turbines has an adverse effect on citizens' acceptance of renewable wind energy. This holds regarding all sample cross-sections, the exceptions being participants below the age of 35 and those living in coal mining regions. At the same time, however, small to medium effect sizes indicate that the digital feedback intervention does not entirely make people overturn their acceptance.

While our study primarily addresses the socio-political acceptance of renewable wind energy, we recognize the potential of digital feedback interventions in the context of community acceptance issues (Wüstenhagen et al., 2007). For instance, digital feedback interventions could be applied in contexts related to community acceptance where previous research has highlighted phenomena such as the "individual gap," as discussed by Bell et al. (2005), or the "U-shaped curve" of attitudes, as proposed by Wolsink (2007). The "individual gap" refers to the disparity where an individual supports renewable energy in general but opposes specific local renewable energy developments, often due to perceived personal impacts, which can contribute to the broader "social gap" between public support and the successful implementation of renewable energy projects (Bell et al., 2005). The "U-shaped curve" in attitudes toward renewable energy projects relates to an empirically observed pattern where public attitudes are initially very positive when not faced with a local renewable energy project, become less positive during the phase of project announcements and proposals, and then become more positive again after the project's construction (Windemer, 2023; Wolsink, 2007). While socio-political acceptance can influence community acceptance by shaping the broader narrative and policy environment, both phenomena are more directly tied to the experiences and perceptions of the local community. By designing digital feedback interventions that focus on specific renewable wind or other projects related to energy infrastructure, citizens could receive targeted information about potential consequences on an individual level relevant to community acceptance. Such digital feedback interventions could inform and empower citizens to explore and articulate their preferences regarding the implementation of such projects. Although our study presents a broader public opinion scenario and rather relates to the socio-political level of social acceptance, further research could develop digital tools and interventions that address community acceptance in contexts that are closely related to renewable energy projects on a local level.

Second, the extent to which participants revised their acceptance depends on their engagement with the digital feedback intervention. Participants were more likely to revise their initial preference regarding wind energy if they gave their focused attention to the visualized ramifications of their stated preferences, then used the adjustable slider, and visually tracked how those ramifications changed on the four maps (H2a). Those results lend credence to prior research (Hargreavesn et al., 2010; Tiefenbeck et al., 2019), as they highlight the capacity of visual feedback to amplify cognition by enabling attentive participants to explore information, reach new levels of understanding, and weigh their political options (Dimara and Perin, 2020; Figueiras, 2015). However, please note that this correlation may not indicate causality. There might be other causal factors, such as technological affinity, which triggers a high interaction with the digital feedback intervention and, in turn, leads to an increased revision of preferences.

Third, the *participants' ecological attitude and place attachment* had no significant effect on the extent to which they revised their preferences (H2b and H2c). In contrast, both factors significantly affected their willingness to replace higher shares of coal-fired electricity generation (i.e., *initial* and *final preference*). Although current research has indicated that a positive *ecological attitude* makes a person more enthusiastic about renewable wind energy (Bidwell, 2013), general environmental beliefs do not prevent people from revising their initially stated acceptance of renewable wind energy. During the experiment, we found no significant effect of *place attachment* on these preferences after the participants had received visual feedback. Prior research suggests that visual impacts on a person's local environment are key factors affecting acceptance (Bergquist et al., 2020; Devine-Wright, 2009; Devine-Wright and Batel, 2017). This observation might result from participants not being directly confronted with visual impacts on their homes (e.g., an image of their home with a wind turbine in the background). Instead, they viewed maps that included their current place of residence, which may not have elicited the same level of concern.

Further, our findings particularly have implications for policymakers and members of the public. Our study encourages policymakers to favor digital feedback interventions when addressing critical societal challenges, such as mitigating adverse climate change effects. Utilizing digital feedback interventions can enhance citizen engagement in renewable energy expansion. Digital feedback interventions promote transparency in decision-making processes by providing citizens with accessible and comprehensible information about the implications of their choices, fostering trust between governments and the public. By sensing citizens' acceptance of renewable energy, policymakers can anticipate and proactively address concerns early, potentially leading to increased acceptance and support for energy policies, even if associated consequences affect citizens individually. Further, insights from experiments similar to the one conducted in this study can inform the design of energy policies, allowing policymakers to tailor strategies that resonate with citizens' values and ultimately enhancing the effectiveness of climate change mitigation efforts. Therefore, the digital feedback intervention presented in this paper opens novel avenues for implementing transparently communicated legislation grounded on socio-political acceptance, which – if addressed sufficiently – may result in less opposition to the implementation of new legislation.

It is important to note, however, that our study has several limitations. The first concerns the renewable energy scenario chosen to design our digital feedback intervention. In the context of renewable wind energy, multiple variables might affect socio-political acceptance, such as the effects of wind energy expansion on greenhouse gas emissions, electricity prices, or regional labor markets. For the sake of a clear research design, however, we focused on the geographical distribution of wind turbines and its effect on socio-political acceptance. On a reflective note, and in line with prior research results, we understand that the geographical distribution of wind turbines might primarily be perceived as an adverse outcome of renewable energy development (as compared to associated reductions in greenhouse gas emissions). Thus, we invite future research contributions to evaluate how additional implications, including both the benefits and drawbacks of renewable energy development illustrated by digital feedback interventions, may affect socio-political acceptance. Second, we recognize that the world is not as simple as replacing coal-fired electricity generation with wind turbines in energy systems. Many other factors play a role in this context (e.g., availability of electricity storage technologies). However, we transparently communicated our assumptions to the participants, and overall, we were interested in the underlying mechanism between digital feedback interventions and social acceptance. The third limitation of this study concerns the design of the digital feedback intervention. We provided only one of many possible design specifications (Lukyanenko and Parsons, 2020). Upon revising their preferences, participants could switch between four personalized maps to track the respective consequences. This design was inspired by the leading literature in the field and was chosen for this experiment to ensure meaningful engagement among the participants (Meske and Potthoff, 2017; Mirsch et al., 2018; Schneider et al., 2018). We invite fellow researchers to empirically verify further design specifications that drive engagement with the digital feedback intervention. Future studies could, for instance, engage participants more deeply by allowing them to alter several parameters of renewable energy expansion. Future researchers may also be well-advised to improve customization by demanding more input from participants to generate more individualized feedback. Finally, we acknowledge that the design of the digital feedback intervention may introduce biases among survey participants. For instance, the initial slider position in our experimental design (set at 0%) could have created an anchoring effect. Therefore, we call for further research to examine the factors that may cause biases, potentially distorting the results obtained from tools like the one presented in this study, which utilize digital feedback interventions to measure socio-political acceptance.

The Grand Challenges, such as providing affordable and clean energy, can only be resolved as we all understand what it takes to be part of the solution. Our study highlights the effectiveness of digital feedback interventions in helping citizens explore the consequences of policy change and learn about alternatives. Thus, our study contributes to a deepened understanding of the context in which digital feedback interventions can provide valuable insights into citizens' acceptance of renewable energy and, therefore, inform decision-making on energy policies. On a reflective note, however, we acknowledge that visual feedback interventions are powerful instruments that can significantly affect socio-political acceptance. As such, they should be developed and handled with care to avoid manipulative abuse. We call on future researchers to understand how different facets of visual feedback influence socio-political acceptance and to validate the extent to which our results can be applied to other political contexts beyond those of energy policy and renewable energy. Our study serves policymakers and the greater public alike in these practical ways while promoting a paradigm of inclusive democracy and argument-based reasoning as the joint foundation of societal change.

CRediT authorship contribution statement

Felix Wagon: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Investigation, Formal analysis, Data curation, Conceptualization. **Gilbert Fridgen:** Writing – review & editing, Validation, Supervision, Funding acquisition, Conceptualization. **Verena Tiefenbeck:** Writing – review & editing, Validation, Supervision, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Data availability

Data will be made available on request.

Appendix A. Sociodemographic sample characteristics

Sociodemographic Variable	Absolute Frequency	Relative Frequency [%]
Gender		
Male	208	48
Female	222	52
Other	0	0
Age		
<12	0	0
12-17	0	0
18-24	37	9
25-34	61	14
35-44	78	18
45-54	83	19
55-64	69	16
65-74	54	13
>74	48	11
Education		
no formal school qualification	0	0
primary or secondary school	14	3
middle school	55	13
high school	51	12
completed apprenticeship	163	38
higher secondary vocational school	15	3
bachelor	46	11
master or diploma	77	18
doctorate	7	2
habilitation	2	0
German federal state		
Baden-Wuerttemberg	55	13
Bavaria	62	14
Berlin	21	5
Brandenburg	12	3
Bremen	3	1
Hamburg	10	2
Hesse	34	8
Mecklenburg-Western Pomerania	11	3
Lower Saxony	42	10
Northrhine-Westphalia	90	21
Rhineland Palatinate	23	5
Saarland	7	2
Saxony	26	6
Saxony-Anhalt	12	3
Schleswig-Holstein	12	3
Thuringia	10	2

Appendix B. Artefact development process described in Mirsch et al. (2017) for digital nudges and operationalization in the context of our digital feedback intervention

	1. Define	2. Diagnose	3. Select	4. Implement	5. Measure
Process as described by Mirsch et al. [88]:	Definition of goal and context	Understanding of choice-behavior to determine relevant psychological effects	Selection of appropriate feedback intervention to alter choice behavior	Design and choice architecture	Evaluation
Process operationalization in our study:	Choices in the context of renewable wind energy in Germany	Sub-optimal choices as options appear vague, highly complex, or unfamiliar	Selection of a digital visual feedback intervention	Design according to design principles of Liu et al. [89]	Evaluation via online experiment

Appendix C. Reliability of constructs ecological attitude and place attachment

Construct	Cronbach's Alpha	Mean	SD	Item (disagree/agree) [a]
ecological attitude	.777	5.477	1.111	When humans interfere with nature, it often produces disastrous consequences
		5.754	1.099	Humans are severely abusing the environment
		4.493	1.505	The earth has plenty of natural resources if we just learn how to develop them [b]
		3.209	1.544	The balance of nature is strong enough to cope with the impacts of modern industrial nations [b]
		3.316	1.740	The so-called "ecological crisis" facing humankind has been greatly exaggerated [b]
		5.633	1.229	The earth is like a spaceship with very limited room and resources
		5.316	1.441	If things continue on their present course. we will soon experience a major ecological catastrophe
place attachment	.937	5.105	1.474	It is my favorite place to be
		4.907	1.518	I really miss it when I am away too long
		4.988	1.479	I feel happiest when I am there
		4.858	1.509	It is the best place to do the things I enjoy

[a] 7 = Strongly agree, 6 = Agree, 5 = More or less agree, 4 = Undecided, 3 = More or less disagree, 2 = Disagree, 1 = Strongly disagree.
[b] Disagreement with reverse coded items indicates ecological worldview.

Appendix D. Description of survey participants (N = 430)

Variables	Categories	Absolute Frequency	Relative Frequency [%]
gender	male	208	48.372
	female	222	51.628
age	<35	98	22.791
	35–64	230	53.488
	>64	102	23.721
education	no higher education	298	69.302
	higher education	132	30.698
country/city	countryside	274	63.721
	city	156	36.279
north/south of Germany	north	313	72.791
	south	117	27.209
coal/no coal mining region	coal mining region	389	90.465
	no coal mining region	41	9.535
ecological attitude	ecological worldview	193	44.884
	exemptionalist worldview	237	55.116
place attachment	attached	238	55.349
	non-attached	192	44.651
slider modifications	high slider interaction	200	46.512
	low slider interaction	230	53.488
map views	high map interaction	188	43.721
	low map interaction	242	56.279

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