Multi-method Approach to Identify Acceptance-Relevant Characteristics of Renewable Energy Infrastructure

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Abstract. Despite the general positive attitude towards renewables, protests against renewable energy infrastructure continues in Germany. The study aims to explore acceptance-relevant aspects of renewable energy sources and their infrastructure to gain a better understanding for argumentation lines of protesters and supports of renewables. The research followed a two-step procedure, beginning with an extensive focus group study. In the focus groups, participants discussed which aspects of renewables they perceived as problematic or advantageous. Based on the results, an ACA (adaptive conjoint analysis) study was designed as an online study, which 109 people fully completed. The most important attributes which resulted from the study were those that represented direct impact on nature and humans. The studies confirmed current research on energy-related infrastructure, which stress the importance of communicating about possible local impacts on the environment and residents. Methodologically, the study exemplified a user-centered research design based on bottom-up principles, in which qualitative analyses were used to determine attributes relevant to laypersons.

Keywords: Social acceptance · Renewables · Mixed-method approach · Focus group · Conjoint study

1 Introduction

To achieve the goal of a share of 80% renewables for the electricity supply by 2050, a drastic change of the energy landscape in Germany is required. While there is widespread support of renewables in the general public in Germany [1], single infrastructure projects face resistance by local residents. The rejection of energy infrastructure can seriously hinder the diffusion of renewable energy technologies by delaying or even hindering the completion of these projects altogether [2]. Thus, it has been recognized that a socially supported energy transition is needed. Still, the social responses to energy infrastructure are not yet fully understood. This might be due to several reasons: First of all, well-established research

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models of technology acceptance (TAMs) (such as TAM [3]) are not applicable to acceptance of energy infrastructure, as they were developed for small-scale technologies in the workplace and differ to a great extent from renewable energy infrastructure. Therefore, traditional TAMs cannot explain the complexity of acceptance levels in energy infrastructure and other, new approaches are needed. Second, because renewable energy infrastructure is often widely visible and thus impacts the surrounding landscape, it interferes to a much larger extent with peoples' personal spaces. Research suggests that local acceptance towards energy infrastructure is in fact to a large part dependent on non-technical issues such as trust in stakeholders [4] and also needs to be understood against its local background, as "[v]iews are developed in the context of immediate surroundings" [5]. Nevertheless, there are recurring argumentation patterns which frequently occur in the debate about renewable energy infrastructure acceptance in general, many of which are also reasons on which local opposition is based. Among those are, for example, the impact of renewable energy infrastructure on landscape, local flora and fauna, or issues relating to the choice of location. Although these topics have been extensively discussed with regard to specific energy infrastructure projects, only few approaches have been made in which the characteristics and their relative importance for energy source preferences have been discussed independently of the specific energy infrastructure (as advocated in [6,7]).

This paper seeks to contribute to the current research on energy acceptance by empirically analyzing acceptance-relevant characteristics of energy sources across different technologies and by identifying which characteristics contribute most to the preference for an energy source. The research focuses on technology-inherent characteristics to (a) gain a better understanding about acceptance or rejection of energy technologies independent of local context, and (b) provide developers of future energy technology infrastructure with ideas which characteristics could become problematic. An empirical bottom-up procedure is adopted, in which in a first step, the acceptance-relevant characteristics are identified using focus groups, and subsequently quantified with regard to their importance for preferences for energy sources using a choice experiment.

2 Acceptance-Relevant Factors of Renewable Energy Infrastructure

Research on the social acceptance of renewable energy infrastructure shows that there are crucial topics for peoples' acceptance or rejection of renewable energy infrastructure. In the following paragraphs, an overview about the most prominently debated topics with regard to renewable energy infrastructure acceptance will be given in a cross-technological approach, focusing on the three renewable energy sources with the highest shares of produced electricity in 2016 [8], wind energy, photovoltaics (PV) and biomass.

2.1 Landscape Impact

This factor is by far more extensively researched for wind power plants than for biomass or PV [9], although research indicates that the two latter technologies face a similar barrier. The fact that the landscape impact, in visual terms, plays such a big role in the renewable energy infrastructure discussion, particularly for wind energy, is explained on the basis of the invisibility of past energy production. The "energy landscapes", which arise from the change towards more renewables, in contrast, make energy production more visible [10]. For wind energy, visual impact has been identified as acceptance-relevant and is extensively researched, and the importance of an integration of wind power plants in the landscape has been stressed [11]. Studies on collaborative virtual environments and their role in an acceptable wind power planning have taken a practical approach to this potential barrier [12]. The visual impact is not merely an aesthetic issue, but also an economic one, as the influence of wind farms on nearby property prices shows [13].

Although more prominent in the wind energy debate, studies have identified the issues of location choice and visual impact also in the context of biomass plants. A location near an industrial estate is favored over one close to residential areas, as the visual impact on the landscape, here due to the chimneys of the plant, is perceived to be negative [14]. Like in the context of wind energy, this also resulted in the fear of decreasing property values [14].

While the installation of PV on rooftops is not as drastic a change to the landscape compared to biomass plants or wind power plants, still, the installation also has a visual impact and could also indirectly affect the surrounding landscape, for example when trees need to be cut or are not allowed to be planted because of possible shadowing [9]. When large-scale PV systems are considered, similar siting issues with regard to landscape impact arise like for wind power and biomass plants. Because of the larger size of the construction and the placement in the landscape, the choice of location can then also affect the social acceptance of a PV plant [1,15]. This parallel is further underlined by efforts to transfer visual impact assessment known from wind power plants also to PV plant planning [16].

2.2 Environmental Impact

Related to questions of landscape impact and siting decisions are impacts on the environment, flora and fauna, by renewable energy infrastructure. Although generally a means to protect the environment by using more renewables instead of fossil fuels, renewable energy sources and their associated infrastructures are not unanimously viewed as environmentally friendly when their direct surroundings are concerned. This is termed "green-on-green conflict" [17] and especially prominent in the wind power debate. In this context, the protection of birds and bats is cited as a reason to oppose to wind farm projects [18,19], but environmental concerns, such as a negative impact on the local ecosystem and wildlife, have also been documented in the context of biomass [14,21] and PV plants [1].

2.3 Impact on Humans/Physical Wellbeing Concerns

Besides impact on landscape and the natural environment, local residents have displayed concerns regarding their physical wellbeing in the direct surroundings of renewable energy infrastructure, for example because of acoustic, odor, or visual emissions. While the issues of health and wellbeing in the context of PV has predominantly been covered from a theoretical perspective in relation to occupational health [23] or potential EMF hazards [24], it is not known to occur in acceptance-related discourses. This is different for wind energy, for which acoustic emissions [25,26], shadow cast [26] or infrasound [27] are frequently cited as reasons for non-acceptance of wind power plants by local residents [28]. Also for biomass plants, "long-term uncertainties about the general health impacts caused by the plant" [14] play a role for social acceptance. There are concerns about the waste used in the incineration plant being hazardous to humans [20], as well as odor [14,20,22] and noise emissions [14] that could disturb local residents.

2.4 Social Context

While the factors introduced above refer to inherent qualities of the renewable energy sources and associated infrastructure, other factors which have been identified to play an important role in the local acceptance of renewable energy infrastructure refer to the social context in which the development of a renewable energy plant is embedded. This concerns the stakeholders involved, the decision making process, ownership of the plant and also the relation of residents to the site in question (referred to as "place attachment", [29]).

Trust in stakeholders and a perceived procedural fairness of the decision making process, both closely intertwined [30], have been identified as important drivers for the acceptance of local renewable energy developments, most notably in the wind power context [31]. It has been shown that these motives outplay so called "backyard motives" (NIMBY: not in my backyard) as reasons to oppose [32]. The strong relation between fairness, trust and local acceptance has also been identified in the context of biomass [20] and case studies showed indeed that a lack of trust, missing information and transparency and can lead to the failure of aspired projects [14,21]. One reason for this is the lack of involvement of the local communities in the decision process, resulting in top-down decisions, in which the local community is left with a feeling of bearing the costs of other people's benefit [14,33]. This is closely connected to issues of ownership: In the context of wind energy, Warren and McFayden came to the conclusion that community ownership of wind power plants can significantly increase acceptance [34], and this was also advocated in regard to renewable energy projects in general [35]. Besides the relation of the local community to the project and the project developers, the relation to the location of the renewable energy plant has recently gained importance in the discussion about renewable energy acceptance. It is argued that rather than NIMBY, the threat of disruption of the relation to the landscape which provides identification for those closely attached to a place can explain opposition to renewable energy projects [29].

2.5 Conclusive Derivation of Research Questions and Empirical Procedure

Considering the research on the social acceptance of renewable energy sources and their infrastructure, it is evident that there are common acceptance-relevant aspects across technological contexts. This is supported by empirical studies which have compared different renewable energies with regard to specific attributes [1,36]. It can be concluded that social acceptance aspects are of great importance for the success of the energy transition, also for future energy technology development, and that a closer analysis and understanding of these factors independent of the specific technological context is needed. This refers for example to the empirical weighting of the factors, to gain a better understanding of the relative importance of the aspects. To this end, an empirical choice-based questionnaire is applied as research method in this paper.

A second aspect that is evident from the literature review is the nature of the acceptance-relevant factors. There are factors which focus more on the specific integration of renewable energy projects within the local context, and there are factors which refer to technology-inherent characteristics, independent of the local context (e.g., onshore wind power plants will always emit noise from rotating blades, and PV plants will require specific resources for their production, regardless of where they are located). This paper focuses on technology-inherent characteristics, to analyze those aspects which make a technology preferable or not, independent of the local context. In this sense, the analysis is aimed at technology developers, in order to provide indicators about potentially problematic aspects, also for future energy infrastructure development. Consequently, the definition of social acceptance in this paper refers to broad socio-political acceptance of a technology rather than community acceptance [9].

3 Explorative Identification of Acceptance-Relevant Factors of Energy Infrastructure

The aim of the study was to identify factors or characteristics of renewable energy sources and their corresponding infrastructure which are discussed with regard to their social acceptability and to analyse their relative importance. The first step of the empirical research thus comprised of a explorative phase in which a broad range of factors was collected in a bottom-up approach, adding to the results of the literature review, to ensure that the attributes selected for the choice tasks in the second stage of the research procedure reflected the general public's concerns.

3.1 Method

As method to capture publicly discussed characteristics of renewable energy infrastructure, focus groups were chosen. Focus groups are used in initial stages of research, in which it is important to provide participants an open format to voice their concerns and wishes rather than providing predefined answering formats. In focus groups, a group of interested participants discusses the research topic in an open talk moderated by an experienced researcher along guiding questions. The results of the focus groups then served as basis for the choice of attributes in the conjoint study.

Research Design. Interested laypersons were invited to participate in discussion groups, which were moderated by an experienced researcher and voice-recorded. In the focus groups, they discussed perceived benefits and drawbacks of renewable energy infrastructure, mostly focusing on photovoltaics, wind energy and biomass. The recorded discussions were later analyzed based on qualitative content analysis [37].

Structure of Discussion. The general procedure was as follows: first, participants were introduced to renewable energies and the relevance of their public acceptance. It was explained to them that to develop sustainable sources of energy, the public opinion is important in order to facilitate their widespread diffusion and achieve a socially supported energy revolution with the public's interest in mind. To develop socially acceptable technology, public interests should be integrated as early as possible in the technology development process, and the participant's involvement in the discussion groups would help researchers understand their concerns. The discussion then started with general questions on renewable energy infrastructure. In this introductory phase, groups 1 and 2 were asked for their experience with renewable energy infrastructure (focusing on wind energy, solar energy and energy from biomass) and groups 3, 4 and 5 were asked for spontaneous associations with different types of energy sources (wind energy, solar energy, water energy, energy from biomass, geothermal energy, nuclear energy, fossil fuels). Groups 1 and 2 were subsequently asked for their impression on the usefulness of the different types of renewables, as well as advantages and disadvantages. Groups 3, 4 and 5 were asked to list the most important characteristics of different types of renewables. Finally, both groups were encouraged to imagine that they could choose renewables to supply their home(town) with electricity. They were asked which renewables they would choose for this purpose and why.

3.2 Sample

In total, five focus groups (FG) were conducted, the number of participants of each group ranged from 5 to 7. In total, 27 persons took part. The participants covered various demographic groups based on gender, age, educational background and residential situation (Table 1).

3.3 Results

As the research focus was laid on the aspects participants used for their evaluation of different energy sources, the results will be structured according to

Table 1. Demographic details of focus group participants (Numbers in cells indicate to how many participants per FG a criterion applied, some participants did not disclose all demographic information)

		FG No.				
		1	**2**	**3**	**4**	**5**
Gender	Male	3	2	2	1	2
	Female	4	3	3	4	3
Age range	<20				2	
	21–30 years	1	5	3	1	3
	31–40 years					1
	41–50 years	1				
	51–60 years	5			1	
	61–70 years			2		1
Educational background	Basic school leaving certificate	1				
	Vocational training	2				
	Qualification for university entrance		3	3		3
	University degree	3	2			2
Residential situation	Countryside				5	
	Town	6				
	City	1	5	5		5

the characteristics participants used to compare and evaluate different types of renewables. The characteristics reported below were used in reference to wind energy, energy from biomass, solar energy (PV), water energy and geothermal energy.

Recycling and Production: Participants discussed in how far the technologies required for the generation of electricity and heat from renewables would be sustainable with regard to their production and recycling. Here, it was for example argued that wind, geothermal energy, solar energy and water energy would not produce any waste during operation and were thus seen as favorable (FG 3 and 4). On the other hand, the problem of recycling specific components such as the PV panels and rotor blades of wind turbines was also discussed (FG 1, 2 and 5). For PV, the need of rare material for production (such as silicon) was mentioned as disadvantage (FG 2 and 5). In contrast to this, it was seen as an advantage of biomass that it could serve as a recycling method for waste itself (FG 3 and 4).

Emissions: A large part of the discussion centered around optical, acoustic, and olfactory “emissions” which would be disruptive to the direct surroundings, most notably neighbors, of a renewable energy plant. Flickering shadows were mentioned as a disadvantage of wind energy (FG 1, 2, 3 and 4), as well as the noise from rotating wind turbines (FG 1, 2, 3, 4 and 5). Ultrasound was also attributed to wind energy, which could harm animals and humans in the vicinity (FG 1 and 4). For biomass, possible odor nuisance was discussed (FG 1 and 2). In contrast to this, it was seen as an advantage of PV that no such emissions were to be expected (FG 2).

Use of Resources During Operation/Operation Costs: For wind energy, it was seen as an advantage that it does not "use up" resources during operation (FG 2, 5). Geothermal energy, on the other hand, was believed to cool the earth (FG 3 and 5). Using resources during operation was seen as a major disadvantage of biomass (FG 1, 2), the discussion here also focused on the resources itself, whether they could also be used as crops to produce food or how the resources in turn need space in the landscape to grow (FG 2). Another concern connected to the use of resources was their transport to the biomass plant, which would lead to a lot of traffic (FG 2).

Choice of Location/Dependence on External Factors: Another argument which was discussed by the participants of the focus groups was the choice of a location for the energy infrastructure and how, depending on which type of renewable energy was chosen, this depended on various external factors. The independence from specific conditions was rated an advantage for a biomass power plant, because it was argued that it could be fueled with different resources (FG 1). In contrast to this, wind and PV are more dependent on natural, local conditions, such as wind speed and solar radiation. Especially for wind farms, participants argued that finding location is difficult because wind farms needed to be away from residential and nature conservation areas (FG 1, 2). The dependence on local conditions was also mentioned as a counterargument for geothermal energy (FG 3).

Efficiency/Costs: Although the participants expressed a lack of knowledge about the costs of energy that would result from the different sources, they found wind energy to be favorable because it was regarded cheap (FG 3 and 5), apart from offshore wind parks (FG 2). Biomass was also considered cheap (FG 2), in comparison to PV, similarly hydropower was found to have low costs (FG 3 and 5). PV, wind and geothermal energy were considered inefficient (FG 5), although some also thought wind energy to be the most efficient of the sources discussed (FG 1 and 2). Geothermal energy was perceived as very expensive, especially because of high investment costs (FG 5). PV was considered inefficient for the north of Germany (FG 1 and 2). Participants argued that because of less hours of sunshine than in more southern countries, it would not be of much practical use.

Space Requirement: A further issue which participants discussed with regard to the acceptability of an energy source was the space which the corresponding infrastructure would need. It was, for example, discussed critically that for the usage of biomass to generate electricity and heat, large fields of, e.g., corn are needed (FG 1). Also for PV, the large space that was assumed to be needed was considered a major disadvantage (FG 1 and 2, 5), although it was also argued that sheep could still graze between the PV panels (FG 2). When PV would be installed on roofs, the fact that no additional space would be needed was seen as positive (FG 1). It was regarded as an advantage of wind farms that the space which is sealed permanentely was small and that the space inbetween the single turbines could still be used for farming (FG 1 and 2). The space needed was also considered a major disadvantage of hydropower, participants referred to large dam projects, for which they knew that residents were relocated (FG 4 and 5). Geothermal energy was rated with mixed results regarding space, while some participants argued that large space was needed (FG 5), others knew that only little boreholes were necessary (FG 5).

Baseload Capability/Security of Supply: The ability to provide energy to secure the baseload energy supply was discussed as advantage of several renewable energy sources. Biomass, for example, was rated positively in this respect, as most participants argued that there would always be waste to fuel the plant (FG 2 and 4), although others were skeptical if this was the case (FG 5). For PV, on the other hand, although generally perceived positively, the fact that it cannot secure supply any time of the year was seen as a negative characteristic (FG 1, 2, 3 and 4), the same was true for wind energy (FG 1, 2, 4 and 5). In FG 4 and 5, it was discussed, however, that a combination of wind energy and PV would probably generate enough electricity, as there would "sometimes [be] a bit more, sometimes a bit less, but never nothing at all". In this context, the possibility of electricity storage was also discussed. The ability to supply energy to cover the baseload was seen as a positive trait of hydropower, although not all participants were convinced this was true for hydropower (FG 5). In FG 3, geothermal energy was rated positively because of its "constant availability" (FG 3).

Visual Appearance/ Impact on Landscape: The question if and how a specific type of energy plant would impact the landscape was frequently discussed in the focus groups, most notably with regard to wind energy. For large-scale PV on open fields, its visual impression was seen as negative (FG 1, 2, 5), as a "disruptive element in nature" (FG 2). The possibility to install PV on rooftops was thus regarded an advantage (FG 1), but overall, PV was seen as having a rather low visual impact and thus not be too disturbing (FG 1, 2, 4). For wind energy, the impact on landscape was more decisive, as participants also felt it could have a negative effect on property value (FG 1). Opinions were mixed with regard to the perceived beauty of wind turbines in the landscape, ranging from "ugly" to "beautiful" (FG 1 and 2), while in other groups, they were unanimously criticized for their negative impact on landscape (FG 3, 4 and 5). For hydropower, on the other hand, its visual appearance was a fact that contributed to the positive image, it was regarded "aesthetic" (FG 3), although large-scale projects like pumpwater storage were also mentioned, which, according to the participants, impact landscape to a great extend (FG 3 and 4).

Construction: Furthermore, when evaluating the different renewable energies, the effort required for the construction of the plant was taken into account by the participants of the focus groups. For biomass, they assumed that it would be cheaper than building a PV plant (FG 2), while for PV, they argued that "you need lots of material to built it" (FG 1). For wind power plants, they discussed that the construction of the turbines and the transport of the single components of the turbine as complex (FG 1 and 2). In opposition to PV, however, no rare materials would be used for construction (FG 2). Geothermal energy, which was perceived positively because of its unobtrusive nature, was attributed to a very complex and expensive construction procedure (FG 3), which some participants mentioned as the reason to reject this technology (FG 3).

Ecological Effects: Despite being considered “green” themselves, some of the renewable energy technologies were associated with major effects on the nature surrounding them, animals as well as plants. An increasing focus on corn as fuel for biomass plants was feared to produce monocultures (FG 2, 3, 4), as well as heavily impacting landscapes ecologically that were formerly used for different purposes. PV plants in the open landscapes were also thought to impact nature, especially natural growth of plants, because “nature that grows between the panels is not really natural” and it was discussed whether the space could still be used for letting animals graze (FG 1, 2). The impact on animals was mostly discussed for wind turbines, harm to birds and bats was considered a major drawback for this technology (FG 1, 3, 4, 5), as well as the possible impact of offshore wind power on sea animals (FG 1, 4). In opposition to this, the fact that relatively little ground would be sealed was seen as an advantage of wind power (FG 1 and 2, see also “Space requirement”). The negative impact on animals was also one of the drawbacks that was associated with hydropower: participants worried about fish being harmed by the turbines (FG 4). In addition, nature would be changed on a large scale when dams would be built (FG 3). Concerning geothermal energy, participants were unsure whether groundwater quality would be at risk in those areas as some feared “leaking fluids which contaminate the groundwater” (FG 5). Besides, “cooling down” the earth (FG 3 and 5) was associated with changed to the ecosystem.

Further factors which were discussed only with relation to single technologies or mentioned by single participants included the *lifetime of a plant*, the *trust in the technology*, the *possibility to use it at household level* (PV), the *maturity of the technology* (geothermal energy) and the *effect of incidents* (e.g., breaking rotor blades on wind turbines).

Summarizing the results of the prestudy, it was apparent that many different factors were taken into account when renewable energy technologies were discussed. The discussion revealed insights in this variety of arguments, however, to identify trade-offs between the different factors and quantify preferences, a large-scale quantitative survey approach was needed as a second step.

4 Confirmative Weighting of Acceptance-Relevant Factors of Energy Infrastructure

As a follow-up on the qualitative prestudy the aim of the study was to quantify preferences and to analyse which of the factors was most important.

4.1 Method

Rather than a traditional survey, a conjoint survey was chosen. Conjoint analysis was developed in the 1960ies by Luce and Tukey [38]. In conjoint analyses, participants rate entire products consisting of different attributes rather than single attributes in isolation. This way, real-life decisions are more closely mimicked than in traditional surveys, where attributes are often rated in a stand-alone manner, without acknowledging possible trade-offs between attributes. By presenting several different products to participants, they are forced into a choice situation in which they have to state their preference for one (or none) of the products. All products consist of the same attributes (e.g., size, price, color), however, the levels in which the attributes are manifested can be different between products (e.g., for attribute color, product 1 is blue and product 2 is red). By analyzing participants' choice behavior, the importance of an attribute for the choice and the impact of specific levels of this attribute on the overall attractiveness of a product can be calculated. Market Simulator tools furthermore allow for a specification of the overall most preferred product and the simulation of market shares of different products.

Research Design. For the conjoint analysis to adequately reflect consumers' wishes, a careful selection of attributes is required in order to include the relevant decision factors. Attributes for the conjoint analysis were therefore based on the results of the qualitative prestudy rather than theoretically derived. The attributes were also chosen according to a second criterion, which was operational practicability. This refers to the requirement that the attribute needs to be translatable in a (visual) form which can easily be understood by survey participants. This second requirement led to the exclusion of the factors *Efficiency/Costs*, *Visual appearance* and *Construction*. *Costs* were excluded because participants showed difficulties in assessing costs of energy infrastructure and it was also not clear if they referred to total costs or costs that the consumer needs to pay. Resulting, the attributes presented in Table 2 were included in the conjoint analysis.

As a specification of the conjoint survey, the adaptive conjoint analysis (ACA) was chosen. "Adaptive" refers to the trait that the choice-questions asked are adapted to each respondent individually, so that subsequent questions built on the previous answers of the participant. The ACA is superior to a choice-based conjoint study when a large number of attributes (more than five [39]), is analyzed, because the choice-task would become too complex if all attributes are involved at the same time. In an adaptive conjoint analysis, all attributes are first evaluated separately, while the choice tasks in the later stage of the survey only include those attributes which were evaluated as most relevant in the first part. This way, the attributes that need to be processed at the same time in the choice task are kept at a minimum. Besides being more easily processable, the adapted choice task is more relevant to participants, as they only need to take into account those attributes which are important to them. Additionally, because

Table 2. Attributes and levels used in the ACA study

Attributes	Levels
Space requirement	High, medium, low
Recycling and production	Environmentally friendly, partly environmentally friendly, not environmentally friendly
Autarky	High degree, medium degree, low degree
Resources needed during operation	High amount, medium amount, low amount
Choice of location	Free choice, depending on climatic factors, depending on regulations and climatic factors
Emissions	No emissions, noise, odor, noise and odor
Immediate environmental effects	No effects on plants and animals, harmful for animals, harmful for plants, harmful for animals and plants

the tasks the respondent has to solve vary, ACA are more divers compared to CBC analysis, where respondents solve the same task type several times.

Questionnaire: The questionnaire consisted of the conjoint analysis part, as well as questions on demographics and user characteristics.

Demographics: To be able to interpret the results of the choice-tasks against the sample characteristics, participants were asked for their age, gender, educational degree and current or most recent occupation. Furthermore, they were asked whether there was an energy plant (such as wind turbines, biomass plant etc.) within view of their home (yes/no), whether they were engaged in an animal or environmental protection action group (yes/no), and where their permanent place of residence was located (urban or rural area).

Attitudinal Characteristics: The questionnaire also included several questions on participants attitudes, e.g., towards the environment or technology in general, which are not part of the following analysis.

Conjoint Analysis: In the beginning, participants were given a short information text about the scenario which they should imagine. They were asked to imagine themselves in the situation of a major of a municipality, who needs to decide which renewable energy plant should supply the municipality with electricity in future years and thus be newly built in the municipality. Rather than choosing the new energy plant directly, however, they should decide which characteristics of the renewable energy plant are most important for this choice. Subsequently, the participants were introduced to the attributes and their levels, while at the same time demonstrating the icons which would be used in the conjoint tasks.

In the following rating task, the participants rated the desirability of each level of an attribute on a seven-point scale (1 = not desirable at all, 7 = very desirable).

Then a choice task was presented, in which participants had to indicate how strong they preferred one of the two alternative energy sources presented to them on a 9-point scale (1 = strongly prefer option A, 9 = strongly prefer option B). The energy sources were defined by two attributes, with all other (not presented) attributes being equal, based on the participants' previous choices of desirability (Fig. 1). Participants had to solve seven of such choice tasks.

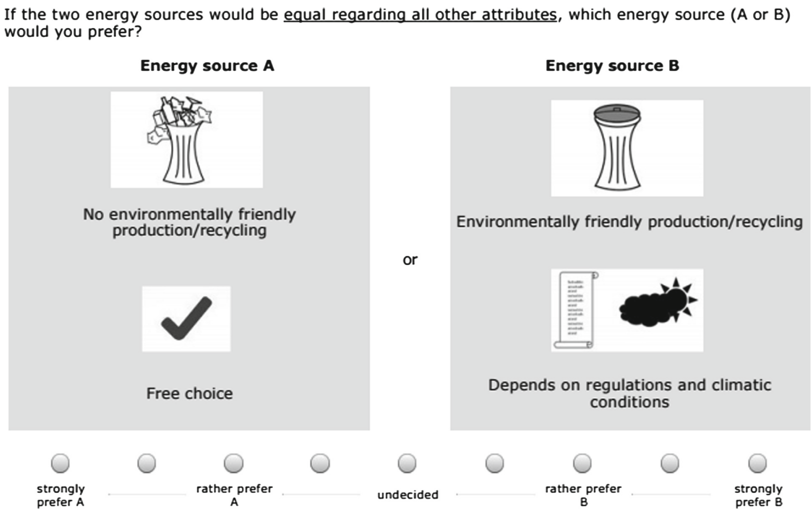

Fig. 1. Choice task with two attributes

Following, participants solved seven more choice tasks, where the energy sources presented were defined by three attributes. A final choice task consisted of indicating a preference for one of two energy sources defined by four attributes. For the choice tasks, a prohibition was installed that prevented the levels "Odor and noise emissions", "odor emissions" and "noise emissions" from appearing together with the level "free choice of location", based on the theoretical assumption that whenever an energy infrastructure would produce those emissions, legislations would be in place which, for example, define safety distances to residential areas or natural conservation areas.

4.2 Sample

Originally, 152 participants had taken part in the study. Because the data quality increases when complete sets of answers are used, only the 109 complete questionnaires were considered for further analysis. Among those, 57.8% were female, 42.2% male. Respondents were between 17 to 65 years old (Mean = 32.6 years). 75% had completed university education.

4.3 Results

The results of the ACA analysis are presented in Tables 3 and 4. The ACA analysis showed that overall, the local impact of renewable energy sites was most important for the preference of a renewable energy source (Table 3. This is shown by the fact that the attributes "environmental impact (local)" and "emissions (local)" were the two most important attributes for choosing a presented energy source. The two attributes represent an impact on both, nature and humans in the direct surroundings of the energy source facility. They were followed by the attributes "Recycling and production" and "Resources during operation". Least important were the "Space requirement", "Autarky" and "Choice of location".

Regarding the specific part-worth utilities of the levels (Table 4, the preferences showed a natural preference pattern where the most positive level received the highest preference and the least positive level received the lowest preference. This applied to the attributes "Space requirement", "Recycling and production", "Autarky" and "Resource consumption during operation", as well as "Choice of location". For the attribute "Emissions (local)", the least preferred level was "Noise and Odor", followed by "Noise emission" and "Odor emission", respectively. The most preferred level was "no emissions". Thus, unsurprisingly, a combination of both emissions, noise and odor, had the most negative impact on the overall preferability of a scenario. Additionally, noise annoyance was perceived more negatively than odor emissions. Concerning the environmental impact, a similar pattern emerged like for the emissions: a combination of harm to animals and plants was the least desired option, and "No effects" was the most preferred option. "Harm to animals" was less preferred than "Harm to plants".

Summarizing the results of the empirical study, it was found that the relative importance of the local impact on environment and humans (operationalized by "emissions") was the most important criterion for participants regarding their preference for an energy source.

5 Discussion

The aim of the study was to quantify the relative importance of acceptance-relevant attributes of energy sources and their corresponding infrastructure. The conjoint study revealed "local environmental impact" followed by "local emissions" as most important criteria for the preference of an energy source. The importance of environmental impact supports findings by Alvarez-Farizo and Hanley, who identified a negative impact on flora and fauna as "significant social costs" [44]. Regarding the ecological impact in detail, harm to animals was less accepted than harm to plants. It is likely that this result reflects peoples concerns for birds and bats in the vicinity of wind turbines. This topic was not only frequently mentioned in the focus groups, it is also often cited as a

Table 3. Average importances of attributes

Attribute	Importance (%)	SD[a]	Lower 95% CI[b]	Upper 95% CI
Space requirement	11.19	2.75	10.67	11.71
Recycling and production	15.87	2.77	15.35	16.39
Autarky	10.62	3.64	9.94	11.31
Resources during operation	15.60	2.98	15.04	16.16
Choice of location	8.35	3.29	7.74	8.97
Emissions (local)	16.76	3.96	16.01	17.50
Environmental impact (local)	21.61	3.86	20.88	22.33

[a]Standard deviation
[b]Confidence interval

drawback to the acceptance of wind turbines [15,18]. Thus, a negative impact on local wildlife by renewable energy infrastructure should be avoided, as it is very likely to evoke opposition. On a different note, it has been shown that the active engagement of environmental protection groups in the planning process of wind turbines can foster acceptance [40]. Contrary to previous findings, ecological impacts on plants, such as a threat to species diversity, were mentioned in the focus groups and discussed as a potential barrier to widespread acceptance, while Upham and Shackley found this aspect to be of marginal importance [41].

Local emissions (noise and odor) were the second most important criterion for the choice of an energy source which corroborates the intense focus group discussions in this regard. It seems surprising that this factor, which concerned humans, was regarded less important than ecological impacts. One explanation for this mismatch could be that participants might be aware of planning regulations which ensure a certain distance to residential areas, for example for wind power plants, and thus the noise and odor emissions would not affect residents as badly. Still, it is known from other infrastructure contexts that human wellbeing is critical for social acceptance [42,43], which is underlined by the importance given to this attribute and the discussion of nuisance through emissions by energy sources in the focus groups. Planners should thus be aware of the high impact of fear of health and wellbeing concerns on the acceptance of new (energy) infrastructure. While these emissions had only been operationalized as "noise" and "odor" in the conjoint study, local air pollution (from traffic) also presents a type of emission which was identified as an important reason to object to a biomass plant [41]. A follow up study should therefore expand the attribute emissions to include also air pollution.

Regarding the use of resources during the operation, it is interesting to note that this was only perceived as a *negative* aspect (in both, focus groups and choice task). Conversely, in the context of a biomass plant, the use of resources such as wood from local forests, that helps to maintain these, was seen as an additional local value [20].

Table 4. Part-worth utility values

Attribute	**Level**	**Utility**	**SD**[a]	**Lower 95% CI**[b]	**Upper 95% CI**
Space requirement	Large	−40.54	12.39	−42.86	−38.21
	Moderate	4.35	10.37	2.40	6.30
	Small	36.19	10.93	34.14	38.24
Recycling and production	Environm. friendly	51.62	10.55	49.64	53.60
	Partly environm. friendly	7.11	10.45	5.15	9.07
	Not environm. friendly	−58.73	11.87	−60.96	−56.50
Degree of autarky	High	31.60	19.75	27.89	35.31
	Moderate	5.35	9.12	3.64	7.06
	Low	−36.95	16.78	−40.10	−33.80
Resource consump.	High	−56.73	13.35	−59.24	−54.22
	Moderate	5.41	9.81	3.57	7.25
	Low	51.32	12.58	48.96	53.68
Choice of location	Legislation and climate	−16.40	21.92	−20.51	−12.28
	Climatic conditions	−0.68	12.02	−2.94	1.57
	Free choice	17.08	30.20	11.41	22.75
Emissions (local)	Noise and Odor	−49.58	15.43	−52.48	−46.69
	Noise	4.58	14.30	1.90	7.27
	Odor	−20.37	16.92	−23.55	−17.19
	No emissions	65.37	17.68	62.05	68.69
Environm. impact (local)	Harmful for plants and animals	−62.56	12.96	−64.99	−60.12
	Harmful for animals	−20.84	12.42	−23.18	−18.51
	Harmful for plants	−4.90	10.89	−6.95	−2.86
	No effects	88.30	17.71	84.98	91.63

[a]Standard deviation
[b]Confidence interval

Considering the results from the literature which emphasize the importance of trust in the stakeholders involved, it can be deduced that for existing projects, a transparent communication about ecological impacts and local emissions is of vital importance. For future technology development, non-obtrusive energy technologies with little to no impact on their immediate surroundings are to be preferred.

Methodological Discussion: In the choice tasks, the impact on landscape was not translated in a single attribute, as it was not feasible to depict and describe this factor independent of the specific energy source and independent of a specific location. Landscape impact had been extensively discussed in the focus groups as advantage or disadvantage of certain energy sources and is in line with the literature that has also identified landscape impact as important for acceptance. Contrary to expectations, the two attributes related to landscape impact ("space requirement" and "choice of location") were only of minor importance in the choice tasks. This could mean that the aspect of landscape impact was not operationalized ideally in the choice task and thus received less attention than expected.

Additionally, our choice task did not involve the factors referring to the social context, such as procedural issues like involved stakeholders, trust in these and the experience of a fair decision process. The focus on characteristics of the technology itself rather than the circumstances of the implementation process was due to the focus of technology development in this paper, thus addressing issues which can be influenced by technology developers. Procedural issues occur in the specific implementation phases of a project, in which the technology development is already finished, thus they are out of scope of engineers working in technology development. On the one hand, the results of the study can thus contribute to the research on the general acceptability of specific renewable energy technologies, independent of local circumstances. On the other hand, they can provide insight for technology developers for future (energy) infrastructure by identifying the most important characteristics of an energy technology. Still however, it will be a future research duty to include procedural issues as they have been identified as crucial to the local acceptance of renewable energy infrastructure.

The rather biased sample presents a further limitation to the results, which should be taken into account for the interpretation. Focusing on a young sample in the ACA study, however, had the unintended benefit on focusing on a generation which will live with this energy infrastructure in their surroundings in the future, thus providing an informative target group.

6 Conclusion

The conjoint study showed that for the general acceptance of energy sources, environmental impact plays the most important role, followed by impact on humans by emissions such as noise and odor. In the focus groups, landscape impact and visual appearance of the site were also intensively discussed as critical. Future development of energy infrastructure should take these findings into account and aim at developing non-obtrusive technologies. For existing technologies, the results support findings that impacts on humans and nature are sensitive topics which need to be communicated in carefully designed communication strategies.

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