Energy Research & Social Science 87 (2022) 102300

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

How far do noise concerns travel? Exploring how familiarity and justice shape noise expectations and social acceptance of planned wind energy projects

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ARTICLE INFO

Keywords:
Social acceptance
Wind turbine sound
Noise annoyance
Proximity
Familiarity
Planning phase

ABSTRACT

Resistance to planned wind projects is frequently associated with expressions of noise concern. Based on two complementary studies, we investigate the underlying drivers of noise concerns. Combining a large national stated preference survey (N = 1217) with an in-depth analysis of revealed preference data resulting from a public consultation process in Switzerland, we find no clear relationship between subjective noise concerns and prospective noise impacts based on residents' proximity to a planned wind project. With the exception of a high-resolution analysis of residents in the immediate surroundings (<1 km) of a planned wind project, both studies seem to suggest that noise concerns travel much farther than what sound propagation models would predict. Rather than the law of physics, (lack of) familiarity with wind energy and issues related to procedural and distributional justice appear to provide a better explanation for the geographical spread of noise concerns. Given the critical importance of social acceptance in the planning phase of wind energy projects, our studies offer important insights for policymakers. Bridging the gap between expected and actual impacts, as well as addressing misconceptions about noise among residents with low familiarity, is key. Neighboring municipalities can play a crucial role and host jurisdictions should consider appropriate measures to manage perceived justice.

1. Introduction

The deployment of renewable energies is key for a successful transition towards a low-carbon energy infrastructure. Installed capacity of wind energy has quadrupled over the last decade to reach 651 Gigawatts in 2019 ([1], p. 131), one of the main reasons being the technology's cost-competitiveness [2], which is set to further improve in the coming years [3]. In addition, public surveys show rather high acceptance rates for wind energy at a global and national level [4–6]. However, at local levels and particularly in contexts where wind energy projects are close to residential areas, their implementation repeatedly faces opposition [7–12]. Across the developed world, local resistance is often associated with concerns about health effects [13], changes in landscape [14–17] or the environment more generally [18–20], as well as issues of distributional and procedural justice [21–23]. Even though a vast majority is in favor of the implementation of wind projects, rather small but vocal opposition, as well as legal action, repeatedly result in wind energy projects being delayed or abandoned [24–28].

Previous literature on social acceptance has assessed public perceptions of wind turbine impacts [14,29]. The results of these studies are essential, as the public's risk perceptions determine policy preferences [30–32]. However, most of these studies have been conducted in the context of existing wind projects. In contrast, only limited attention has been devoted to empirically investigating residents' concerns during the planning phase, which constitutes a critical bottleneck for sustaining social acceptance [33,34]. During the planning phase, residents form expectations about wind turbine emissions, which will shape their opinion about whether a wind project should be built or not and have also been shown to influence actual noise annoyance after turbines have been built [35].

In this paper, we focus on the planning phase and investigate the geographical distribution of noise concerns in order to explore potential

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https://doi.org/10.1016/j.erss.2021.102300
Received 10 July 2020; Received in revised form 14 August 2021; Accepted 7 September 2021
Available online 13 January 2022

reasons for discrepancies between expected and predicted noise levels. Knowing more about opposition due to noise concerns is vital since noise is one of the most polarizing issues [12,36] and also a key factor influencing social acceptance [37]. Concretely, we investigate the relationship between proximity[1] to a planned wind project and concerns about prospective wind turbine noise. This is important because policymakers in several countries, despite a lack of empirical evidence [35], have introduced minimum distance regulations, assuming that there is indeed a positive correlation between proximity and noise concerns.

From a methodological point of view, this paper comprises two complementary studies on social acceptance of planned wind projects in Switzerland. Both investigate the relationship between proximity and wind turbine noise concerns but apply different approaches and data sets. Study 1 is based on a nationwide stated preference survey (N = 1217). Study 2 evaluates revealed preferences in the context of a planned wind project in Oberegg (AI), drawing on qualitative data from position statements received during a public consultation process.

This article adds to the growing body of literature on social acceptance of renewable energy [10,12]. We show that in the planning phase there is no clear relationship between proximity and concerns, except for people living within 1 km of the project, corroborating related literature in the operating phase which does not find such a relationship either [35,38]. In addition, we find a lack of familiarity with existing wind projects to be more powerful in explaining the geographical spread of noise concerns than proximity. These insights are essential for policymaking in terms of designing informed local decision processes. The results may also prove useful for project developers attempting to bridge the gap between expected and actual wind turbine noise.

The remainder of this paper is structured as follows. Section 2 reviews the literature on noise propagation as well as the role of noise concerns and other factors in shaping social acceptance. Sections 3 and 4 present the methods and results of the two empirical studies. In Section 5, we discuss our findings and their relevance in light of the existing literature. Section 6 concludes the paper and offers reflections on policy implications as well as opportunities for further research.

2. Theory and hypotheses

2.1. Distance and wind turbine noise

From a technical point of view, wind turbine noise decreases with distance. More specifically, sound pressure levels decrease by 6 dB for each doubling of the distance from the sound source, unless there are boundaries to reflect sound [39]. The relationship between distance and noise levels can vary depending on different sound types (i.e., aerodynamical and mechanical sound [40][2]) and the characteristics of wind projects (e.g., number of installed turbines [41], topography [42,43], weather conditions [44–46,40]).

Because of the particularities influencing the relationship between distance and noise propagation, it is argued that setback distances[3] should not be exclusively distance-based[4] but rather sound-based[5] [49]. This approach is also recommended in the World Health Organization's (WHO) Environmental Noise Guidelines for the European Region, which advise an average exposure to wind turbine sound below 45 dB L_{den}[6] [50,51]. Binding regulations for wind turbine noise are generally made at national or subnational levels [52,53,54]. Most countries apply industrial noise limits to wind turbines and have not introduced specific regulations for wind turbine sound [55]. In Switzerland as well, requirements for industrial zones, as regulated in the national Swiss Noise Abatement Ordinance[7], apply to wind turbines [56]. Noise level predictions for specific wind projects must pass an environmental impact assessment during the permitting phase [56,57].

We derive our first hypothesis based on technological insights outlined above, suggesting that public perceptions align with the actual relationship between proximity and wind turbine noise emissions. This would imply that concerns about the physical wind turbine impacts are limited to residents living close to wind turbines, while residents living beyond the predicted noise propagation radius should not be concerned about wind turbine noise. Thus, our first hypothesis reads:

H1: *The geographical spread of noise concerns aligns with the propagation of predicted wind turbine noise, in that residents living in greater proximity to a planned wind project are more noise-concerned.*

2.2. Impacts, familiarity, and acceptance

Contrary to our first hypothesis, behavioral research suggests that public perceptions often deviate from expert risk assessments, as the general public often lacks experience with technological risks [58]. Insights from social psychology indicate that familiarity with an object influences preference formation, which in turn influences choices. This is, for example, acknowledged by query theory, which assumes that people evaluate their choice options based on the evidence that they have gained through past experience [59].

The literature on social acceptance of wind energy suggests that living next to a wind turbine [6,14,60,61] as well as having been close to one [62] tends to be positively linked to acceptance, except for a minority of residents who persistently hold negative attitudes towards wind energy [33,63]. An important contribution by Wolsink [14], based on a longitudinal analysis, demonstrates that actual wind project impacts tend to be overestimated during the planning, permitting, and construction phases. Thereby, attitudes follow a U-shaped curve as proposed wind projects initially show high acceptance levels but drop in their local acceptance rates during the permitting and construction phase. After commissioning, acceptance tends to rebound to higher levels, although the extent to which this is the case depends on several factors, including perceptions of procedural and distributional justice

[1] When discussing the geographical spread of noise concerns, the social acceptance literature typically refers to "proximity", while more technically focused papers tend to work with the inverse construct, "distance". As a contribution to the energy research and social science literature, we mostly use "proximity" in this paper, except in Section 2.1 where we review the technical literature on noise propagation.

[2] Aerodynamical sound is generated through inflow turbulence and trailing edge sound [40]. Trailing edge sound is heard best outside, close to wind turbines, inflow turbulence noise is the relatively more dominant sound at larger distances and indoors [40]. Mechanical sound can come from a gearbox and cause a specific pitch, which was mostly a relevant source in the case of outdated technologies [40].

[3] Setback distance is the distance between the wind turbine and the noise receptor.

[4] The 10*H* regulation in Bavaria is an example here: This law was introduced in 2014 and regulates that the minimum distance between residential areas and wind turbines must be 10 times the total height of the planned wind turbine [47,48].

[5] A-weighted decibel levels (dB(A)) take into account human hearing sensitivities at different frequencies [40].

[6] L_{den} refers to the day-evening-night level. Thus, L_{den} is an energy equivalent noise level (L_{eq}) for the whole day, including penalties for nighttime noise (10dB(A) between 22.00 and 7.00) and for evening noise (additional penalty of 5dB(A)). [50]

[7] See: https://www.admin.ch/opc/de/classified-compilation/19860372/index.html#app6

[34]. Furthermore, van der Horst [60] show that 24% of respondents changed their view following a wind project's construction as expected impacts did not materialize. Regarding noise emissions, Tabi and Wüstenhagen [36] find that Swiss residents living near a wind project had expected noise emissions and landscape impacts to be considerably more severe than they turned out to be after its construction.

These research insights point to a positive relationship between familiarity with wind turbines and acceptance levels. They also highlight the crucial role of the planning phase for sustaining local acceptance. The challenge is that residents nearby a *planned* wind project may be rather unfamiliar with wind turbines, particularly those living in geographical areas with low wind energy deployment rates. Moreover, wind turbines are often sited in rural areas where other noise sources are relatively limited [41]. As a result, in these cases, residents' risk perceptions are often not shaped by direct experience [36], familiarity [62], or knowledge [64].

Instead, interpersonal communication [65] and media coverage [13,66,67] become important ways of gaining mediated experience. In fact, the discussion about the exposure to and effects of wind turbines is particularly intense prior to construction of wind projects [68,69,70]. As such, concerns of local residents can be strongly influenced by the available information throughout the planning process[8]. Opponents and proponents may try to influence residents' opinions with persuasive communication strategies [72]. The experimental study by Crichton et al. [73] demonstrates the effectiveness of such communication strategies: While negative framing of information prior to wind turbine noise exposure triggered annoyance from wind turbine sound, positive information framing led to significantly lower annoyance levels, even for noise-sensitive individuals.

The preceding paragraphs indicate that physical proximity may be unable to fully explain noise concerns. Insights from risk perception research show that lack of familiarity may result in biased decision-making. Similarly, empirical findings reveal that wind project impacts are expected to be higher during the planning phase than they are actually perceived during the wind project's operational phase. Based on these theoretical and empirical insights, we hypothesize that the overestimation of noise emissions during the planning phase will translate into the geographical dimension. While noise levels increase with proximity, noise concerns do not.

H2: *Lack of familiarity, rather than physical proximity, is linked to noise concerns.*

2.3. Noise annoyance, justice, and acceptance

The social acceptance literature offers a number of compelling explanations for why perceptions of wind turbine impacts, especially with regard to noise, may differ between respondents, and how perceived impacts may influence social acceptance.

Concerning annoyance, studies investigating the impacts of existing wind projects have shown that proximity and sound levels can either not predict noise annoyance [35,74] or are only very weak and empirically unreliable predictors of wind turbine noise annoyance [33,75]. Although a link between sound levels within the 45 dB threshold and noise annoyance cannot be empirically verified, the public discussions around set back distances in several countries seem to imply that the public associates shorter distances with noise annoyance. In contrast to the public perception, several studies suggest that in addition to objective factors, subjective factors need to be considered when studying noise annoyance [33,35,38,75–77]. These factors include attitudes towards wind turbines [33,35,74], noise sensitivity [35,38,76], perceived aesthetic characteristics [38,74] as well as concerns about physical safety [76] and health [77]. The literature on noise annoyance also points to the importance of procedural [35,78] and distributional justice [41,78,79,80], which are also considered central to the social acceptance of wind energy [81,82,83,84]. Procedural justice focuses on the fair involvement of different stakeholders in the decision process [21,85,86]. Distributional justice relates to the fair distribution of costs and benefits among involved stakeholders [21,85,86], including local residents, project developers, the communities and society as a whole [87].

When it comes to the link between justice and noise annoyance, previous studies have found that procedural and distributional justice can influence how the affected population perceives wind turbine impacts. As for procedural justice, studies have shown that the planning process itself can affect sound annoyance after the wind park has been built [33,35]. Pohl et al. [33] find that perceiving the planning phase as stressful, unfair in terms of one's own or the community's interest can be relevant factors for wind turbine noise annoyance. Results by Hübner et al. [35] suggest that process fairness (in their European sample) and process stress (in their US sample) are important aspects for explaining noise annoyance.

In terms of distributional justice, Songsore and Buzzelli [13] find perceptions of injustice to be related to health risk perceptions. Other studies indicate that residents who are financial beneficiaries of a local wind project may be less likely annoyed by wind turbine noise than non-beneficiaries [41,78,79,80]. This could partly be due to a selection effect, where residents who decide to invest tend to have positive attitudes towards a wind project, which is less probable for residents unwilling to invest [88,79]. Another possible explanation for the gap in noise annoyance between the two groups is non-beneficiaries' feeling of resentment towards beneficiaries [41]. The underlying driver of this second explanation may either be a sense of exclusion by local networks [89] or envy, a feeling of discontent aroused by another person's or group's possessions [47]. This social-psychological phenomenon was previously studied by Adams [90], who suggested that social inequity can determine behavior and cognitive processes. In the context of wind energy, Walker and Baxter [22] have suggested that envy at the municipal level may shape the dynamics of community acceptance. Feelings of injustice may occur between inhabitants of the host municipality of a planned wind project, who benefit from the operator's tax payments, and their peers in adjacent municipalities, who are facing a comparable visual impact but cannot expect financial benefits. These dynamics may also be influenced from a procedural justice perspective if citizens of the host jurisdiction have the final say in siting decisions.

Based on these empirical and theoretical insights, we look at the moderating influence of justice on the relationship between proximity and noise concerns. We thereby focus on the municipal level and investigate differences between the host and adjacent municipalities, located at the same distance from the wind project, and expect relatively more noise concerns to originate from neighboring municipalities.

H3: *Noise concerns peak just beyond the borders of the host community.*

3. Study 1: Noise concerns in a stated preference context

3.1. Survey and sample

Study 1 draws on a large-scale survey (N = 1250) conducted in April 2019 on acceptance of low-carbon technologies and policies among the Swiss population, which focused on acceptance of wind energy projects,

[8] Average European pre-construction lead times are 4.5 years [71], whereas in Switzerland it may take up to 10 years or more [24].

including questions about geographical proximity to planned and existing wind projects as well as associations that people relate to wind turbines [5,91].

The focus on Switzerland is interesting for several reasons. As a densely populated country, it presents an exemplary case of how the dynamics of community acceptance can affect investor interest and wind energy goals set by the national government. Furthermore, it is particularly interesting to study wind turbine noise concerns: With only 41 larger wind turbines (>600 kW) operating nationwide [95,96], large parts of the population do not have first-hand experience with the noise impacts of the technology leaving room for perceptions being shaped by the communication of wind project developers and opponents. At the same time, in line with the goals included in the country's Energy Strategy 2050 [97], >700 wind turbines are currently being planned [98].

After eliminating N = 1 respondent due to missing values for the demographic variables resulting in a sample of N = 1249, we exclude two groups of respondents from the overall sample (N = 1249), resulting in a final sample of N = 1217 respondents (seeTable 1). Due to their very low number (N = 6), we remove respondents with positive noise associations (e.g., "quiet"). We also exclude respondents who indicated they had no idea whether they are used to seeing wind turbines in their immediate environment (N = 26). While we expect respondents to know whether they live near an *existing* wind project, it may be reasonable that they are unsure about living near a *planned* wind project, as the latter is not visible and at an early stage of project development, no public announcements may have been made. As such, we did not exclude people who are unsure whether they live within a 5 km radius of a planned wind project from our sample. For a detailed overview of the sample funnel see Table A-1, whereby we outline the operationalization of the variables used for the analysis in Section 3.2.

3.2. Measures

3.2.1. Proximity to a planned wind project

In Study 1, the independent variable *proximity to a planned wind turbine* is operationalized based on responses to the following question: "Is a wind project planned to be built close to your home (<5 km)?"; answer options being "yes", "no", or "I do not know". The 5 km cut-off value corresponds to previous studies investigating the effect of wind turbine impacts, including sound impacts, on local acceptance (for Switzerland see [78]; for Germany & Switzerland see [99]). Based on their responses, we categorized respondents into three groups, namely respondents "not nearby a planned wind project", those living "nearby a planned wind project", and those "unsure" about living within 5 km of a planned wind project.

3.2.2. Familiarity with existing wind projects

To investigate the relationship between familiarity with existing wind projects and noise concerns, we categorize respondents into groups based on their response to the following statement: "I am used to seeing wind turbines in my immediate environment." Answer options ranged from "I fully disagree" to "I fully agree" on a 4pt. scale, and respondents had a fifth option to indicate that they "have no idea". Respondents indicating that they agree or fully agree were labeled as living "nearby an existing wind project", while those indicating that they disagree or fully disagree were labeled as "not nearby an existing wind project".

3.2.3. Noise concerns

The dependent variable is based on responses to the following survey question: "What are the first thoughts or images that come to mind when you think of wind energy? Please write only one thought or image per line." We systematically coded the respective text data for answers referring to wind turbine noise emissions. Respondents' thoughts

Table 1
Study 1, Sample characteristics.

Variables		Sample (N = 1217)	Swiss Population[b]
Gender	Female	50%	51%
	Male	50%	49%
Age	15–19	6%	6%
	20–29	15%	15%
	30–44	25%	25%
	45–59	27%	27%
	60+	28[c]%	26%
Region (excl. Ticino)	Western Switzerland (French-speaking)	31%	25%
	Alps & Prealps	25%	24%
	Swiss Plateau West	20%	22%
	Swiss Plateau East	25%	29%
Political Attitude[a]	SVP	27%	29%
	SP	21%	19%
	FDP	17%	16%
	CVP	12%	12%
	BDP	4%	4%
	GLP	6%	5%
	Grüne	7%	7%
Education	Low/medium	54%	56%
	High	46%	44%

[a] 7% of respondents indicated that they do not have a party preference.
[b] Information on the Swiss population is based on Swiss Federal Office of Statistics [92] for age, gender and education; on Swiss Federal Office of Statistics [93] for region; and on Swiss Federal Office of Statistics [94] for the distribution of political parties.
[c] The percentages for age, region and political attitudes do not add up to 100%, because we rounded to whole numbers.

appeared spelled out as words or short statements (e.g., "noise"; "Currently rather suspicious for reasons of noise"). We categorize respondents into two groups, the first one containing respondents without wind turbine noise associations (N = 997), the second one comprising respondents with negative wind turbine noise associations (N = 220).

3.3. Data analysis and results

3.3.1. Proximity to a planned wind project and noise concerns

To find out whether proximity to a planned wind project correlates with noise concerns, we conduct a crosstab analysis as well as a chi-square test.

The crosstab analysis gives a first indication that proximity to a planned wind project and noise concerns are unrelated.Fig. 1 shows no remarkable differences in the relative frequency of noise concerns between the three groups of respondents living within, those living beyond a 5 km radius, and those unsure about their proximity to a planned wind project. Concretely, 18% of the 121 respondents living within a 5 km radius of a planned wind project think of noise emissions, while 82% do not. These results are very similar for the remaining two groups: 19% of residents living beyond a 5 km radius (N = 797) and 15% of residents unsure about living near a planned wind project (N = 299) reveal noise concerns.

A chi-square test confirms that there is no statistically significant association between *proximity to a planned wind project* and *noise concerns* ($\chi^2(2) = 1.997$, p = 0.368).

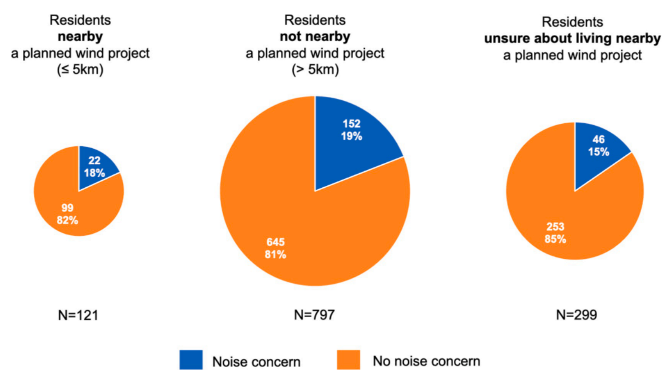


Fig. 1. Proximity to a planned wind project and noise concerns.

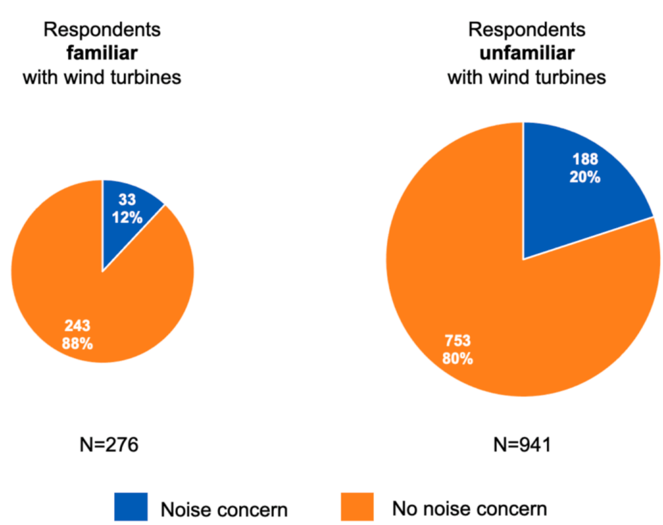


Fig. 2. Familiarity with an existing wind project and noise concerns.

3.3.2. Familiarity and noise concerns

Next, we investigate whether residents used to seeing existing wind turbines in their immediate environment differ from those not used to seeing them in terms of noise concerns. In this case, the chi-square test reveals that residents who are familiar with wind energy are significantly less likely to mention noise concerns ($\chi^2(2) = 10.130$, p = 0.001). Fig. 2 shows that 12% of those respondents (N = 276) mention wind turbine noise. In contrast, for respondents unfamiliar with seeing wind turbines (N = 941), the relative frequency of noise concerns increases to a significantly higher share of 20%.

3.3.3. Proximity, familiarity, noise concerns, and other covariates

We further conduct a multivariate analysis on the effect of proximity to a planned wind project, familiarity, and other covariates, including age (15–29, 30–44, 45–59, 60+), gender, education (high/low), language region (French-/German-speaking), political attitude on the likelihood that respondents mention wind turbine noise concerns. The binary logistic model turned out to be statistically significant ($\chi^2(10) = 39.375$, $p = 0.000$, $n = 1217$).

The results of the multivariate analysis (see Table 2) confirm that proximity to planned wind turbines, which we have entered into the model as a dummy variable, cannot explain noise concerns. In contrast, familiarity with existing wind projects has a significant effect on the dependent variable, whereby unfamiliar residents are 97% more likely to be concerned about noise.

Language region ($p \leq 0.001$), age ($p \leq 0.05$), and gender ($p \leq 0.05$) also have a significant effect on negative noise associations. For one, French-speaking respondents are 87% more likely to indicate noise concerns than German-speaking respondents. Second, respondents in the age group of 15–29 are 37% less likely to mention noise emissions compared to respondents in the age group 60+. Third, female respondents are 39% more likely to express noise concerns than men.

4. Study 2: Noise concerns in a revealed preference context

4.1. Data and sample

Study 2 draws on qualitative data from a public consultation process[9] for the planned wind project Oberegg with two turbines of 4.2 MW each[10], located in the Swiss canton of Appenzell Inner-Rhodes (AI) (Fig. 3). This allows us to investigate the relationship between proximity and noise concerns based on revealed preferences of individuals who engage in opposition, which is rare in the context of social acceptance of wind energy. As stated preferences do not always translate into action, it is important to differentiate between action and non-action against/in favor of a wind project [100,101].

The data set at hand offers a unique opportunity to explore the relationship between proximity and noise concerns, as it includes data on objectors' place of residence, which tends to be sensitive information in the context of a public consultation process and is therefore often not publicly available. Anyone, regardless of his or her place of residence, was able to have a say in the consultation process. This is interesting from a distributional justice point of view because the project is located right at the border to two other cantons: Appenzell Outer-Rhodes (AR)

[9] The consultation was open for a seven-week period in April/May 2018.

[10] See: https://www.appenzellerwind.ch/projekt-oberegg/facts-figures/

Table 2
Binary logistic model on the likelihood that respondents mention wind turbine noise concerns.

Variables	B	S.E.	Wald	Df	Sig.	Exp(B)	95% C.I. forExp(B)	
							Lower	Upper
Proximity to a planned wind project								
nearby (vs. not nearby)	−0.084	0.267	0.098	1	0.755	0.920	0.545	1.554
unsure (vs. not nearby)	−0.245	0.190	1.664	1	0.197	0.783	0.540	1.136
Familiarity unfamiliar (vs. familiar)	0.676	0.211	10.293	1	0.001	1.967	1.301	2.973
Gender female (vs. male)	0.331	0.154	4.636	1	0.031	1.393	1.030	1.883
Region French- (vs. German)	0.624	0.161	14.925	1	0.000	1.866	1.360	2.560
Education low (vs. high)	−0.136	0.157	0.751	1	0.386	0.873	0.642	1.187
Pol. att. SVP (vs. other parties)	0.193	0.168	1.332	1	0.249	1.213	0.874	1.685
Age								
15-29-year olds (vs. 60+)	−0.468	0.228	4.208	1	0.040	0.626	0.400	0.979
30-44-year olds (vs. 60+)	−0.363	0.211	2.954	1	0.086	0.696	0.460	1.052
45-60-year olds (vs. 60+)	−0.116	0.196	0.351	1	0.553	0.890	0.606	1.308
Constant	−2.153	0.283	57.783	1	0.000	0.116		

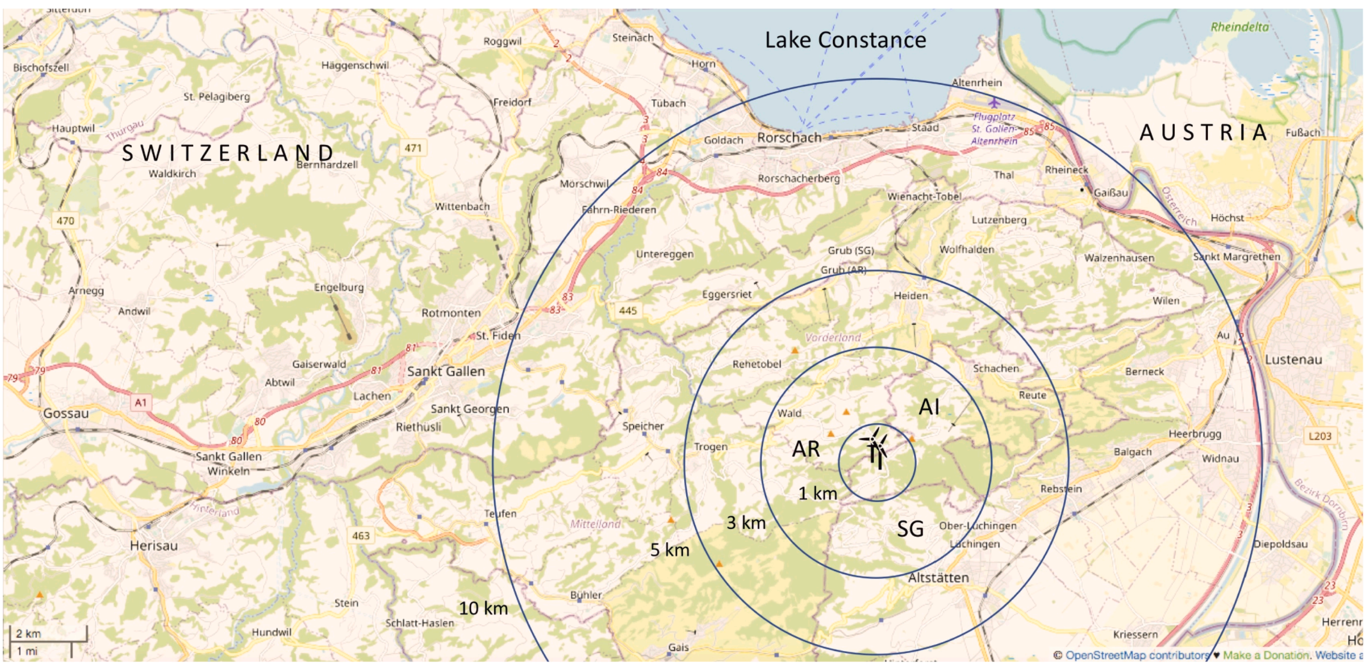


Fig. 3. Case study location in Appenzell Inner-Rhodes (AI) at the border of Appenzell Outer-Rhodes (AR) and St. Gallen (SG) (Source: own illustration based on www.openstreetmap.org).

and St. Gallen (SG). The center of the host municipality, Oberegg AI as well as the center of the two neighboring municipalities, Wald AR and Altstätten SG, are all approximately 3 km away from the proposed wind project location. Although all three municipalities can expect to carry similar impacts, they differ with regard to the distribution of financial benefits and their influence on the decision process (cf. Section 4.2.3). Thus, we further investigate how this location at the border of three cantons impacts the level of noise concerns in neighboring municipalities.

Fig. 4 shows an overview of the sample of Study 2. In total, 433 individuals or households[11] participated in the public consultation process. Eliminating the 38 individuals or households submitting a statement in favor of the wind project leaves us with a sample of N = 395 objectors against the wind project.

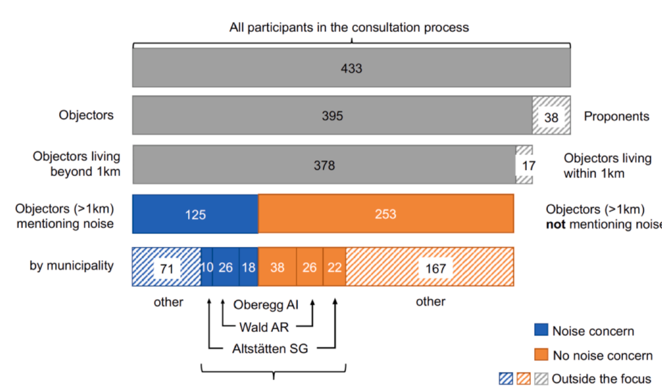


Fig. 4. Overview of sample (Study 2).

For our analysis of distributional justice, we are also interested in distinguishing between objectors who can expect to be most likely physically affected by the prospective wind turbine noise and those who

[11] We count multiple individuals living in the same household as a single vote. 32 institutions (e.g., neighboring municipalities, cantons and the Austrian State government of Vorarlberg) also participated in the consultation process, but for consistency reasons, our dataset focuses on responses by individuals or households.

live farther away. N = 17 of the objectors live within 1 km of the planned wind project, while N = 378 of the objectors live farther away.

4.2. Method and measures

4.2.1. Proximity to the wind turbine

Data on place of residence from objections was publicly available at the municipal level. Street-level addresses were not disclosed in the cantonal report. Objections originated from different municipalities belonging to the host and neighboring cantons, as well as more distant locations inside and outside of Switzerland.

We measure the distance between each respondent's residence and the planned wind project using an application based on OpenStreetMap (www.luftlinie.org). We operationalize the place of residence based on the location of the center of the municipality. The wind project's location is defined as the center between the two wind turbine sites (47.403000, 9.522194). We round the resulting air-line distance to full kilometers. Among all objectors, the smallest distance on municipality-level is 3 km, the largest distance is 9429 km. Among those mentioning noise concerns, the smallest distance is 3 km, the largest distance is 460 km[12].

As the place of residence at municipality level is not sufficiently fine-grained to investigate noise concerns among those living closest to the wind project, we created a higher-resolution data set of all households located within a 1 km radius of the planned wind turbines based on a publicly available phone directory (tel.search.ch). This allows us to differentiate between residents living within a 500 m radius of the closest wind turbine, who are most likely to be affected by wind turbine noise [102], and those living within the 500–1000 m radius. According to the project's environmental impact assessment [102], the former may hear wind turbine noise of about 40 to 45 dB(A), which corresponds to the noise exposure threshold for households set by the World Health Organization (WHO) and the Swiss Federal Office for the Environment (FOEN). The latter may still hear wind turbine sound, but according to the project's environmental impact assessment will be exposed to noise levels between 35 dB(A) and 40 dB(A). The phone directory shows that a total of N = 10 households within a 500 m radius, and N = 40 households (including some companies and restaurants) are located within a 1 km radius. For each of the people living within 1 km of at least one of the two wind turbines, we measure the distance (rounded to 10 m) between their residence and the closest of the two wind turbine locations (which are 400 m apart from each other). Subsequently, we compare this high-resolution data set to the data set from the public consultation process, allowing us to identify whether the respective households objected against the planned wind project.

4.2.2. Noise concerns

In Study 2, we measure the dependent variable, noise concerns, based on whether individuals submitted or supported a position statement that mentions wind turbine noise emissions as an argument to object to the planned wind project. We code for any words, sentences, or paragraphs that refer to *wind turbine noise emissions* in the text document.

4.2.3. Justice at the municipal level

We investigate the role of justice at the municipal level by comparing the number of noise concerns, both absolute and relative to population size, originating from the three municipalities located closest to the wind turbine. Specifically, we compare the host municipality Oberegg (Appenzell Inner-Rhodes) with the two neighboring municipalities Altstätten (St. Gallen) and Wald (Appenzell Outer-Rhodes), all of which are located at approximately the same distance (3 km) to the planned wind project. While the neighboring municipalities are faced with similar impacts (e.g., landscape change), only inhabitants of the host municipality can expect to benefit from the wind project's corporate tax income. Also, even though the consultation process was open to everyone, it is up to the political authorities of the host canton to decide on the implementation of a wind project [103]. Following our prediction (see H3), this may lead to perceived injustice by the residents of the two neighboring municipalities vis-à-vis residents of Oberegg. Thus, we expect relatively more noise concerns to originate from Wald AR and Altstätten SG than from Oberegg AI.

4.3. Data analysis and results

4.3.1. Proximity to the planned wind project and noise concerns

135 out of the total 395 objectors mentioned noise concerns. Fig. 5 illustrates the share of objectors mentioning noise concerns (y-axis) by the proximity to the planned wind project in kilometers (x-axis). Given that in the objection data, the residence location is provided at the municipal level, Fig. 5 does not allow us to make a more fine-grained analysis of those living within the 3 km radius (see Fig. 6 for the analysis of the group living within 1 km of the planned wind project).

Fig. 5 reveals that 21% of noise objectors (29 out of 135) live at distances farther away than 10 km. Also, more than half (53%) of the 135 noise worries originate from distances farther away than 3 km. Combining this information with insights from our second data set, in which we find 10 noise objectors to live within a 1 km radius, suggests that 93% (125 out of 135) of the total noise concerns were voiced by individuals for whom the prospective physical impact is likely going to be below discernible levels. These results indicate that, while there is a tendency that noise concerns increase with proximity, wind turbine noise concerns are much more widespread geographically than their prospective physical impact.

For the next finding shown in Fig. 6, we have drawn on our high-resolution data set of residents living closest to the planned wind turbines (within 1 km), thus focusing on the group of residents that will most likely expect to hear wind turbine sound. The results reveal that within the 1 km radius of the planned wind project, proximity does seem to matter: 10 households are located within 500 m of one of the two wind turbines, where residents can actually expect to hear the wind

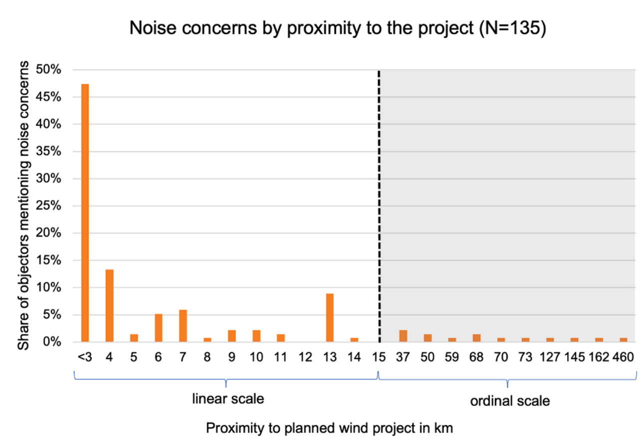


Fig. 5. Share of noise objectors in relation to the proximity (in km) to the planned wind project.

[12] One respondent participating in the public consultation process resides in Rio de Janeiro (Brasil) and one in Paris (France). All other respondents reside in Switzerland, <200 km away from the project.

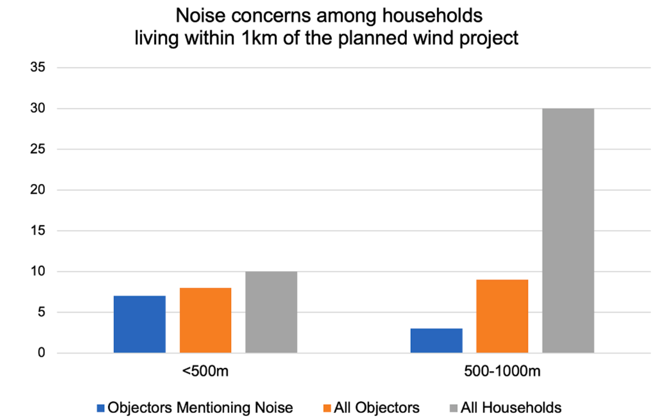


Fig. 6. All households, all objectors and all objectors mentioning noise concerns living within 500 m vs. 500–1000 m of the planned wind project.

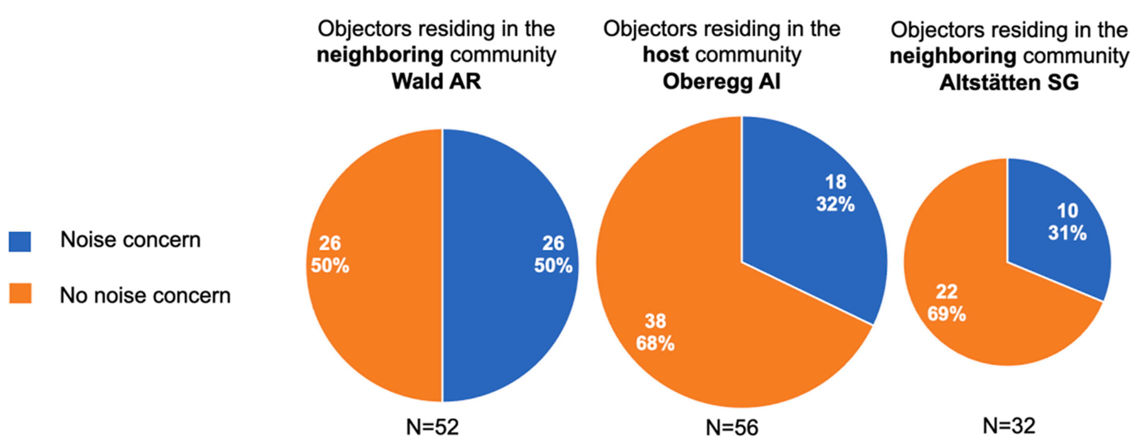
turbines. 8 out of those 10 households objected to the planned wind project, and 88% (7 out of 8) of them voiced noise concerns. This share drops to 33% (3 of the 9 objectors) for households located between 500 and 1000 m from the wind project (see Fig. 6), where prospective wind turbine noise emissions are lower.

In sum, proximity seems to be linked to noise concerns to some extent when focusing on those living within 1 km of the planned wind turbines (see Fig. 6). At the same time, when looking at the overall samples in Study 1 and 2, noise concerns can travel a lot farther than the prospective impact of actual noise propagation (see Fig. 5 and Study 1).

4.3.2. *Proximity, justice at the municipal level, and noise concerns*

We now turn to the objectors living in one of the three neighboring municipalities, which are all located within the 3 km radius. To explore whether justice among the three neighboring municipalities can help to understand the voiced noise concerns, we compare the number of (noise) objections among residents of Oberegg AI, Wald AR and Altstätten SG. For this analysis we focus on those objectors who live beyond a 1 km radius and thus, according to the wind project's environmental impact assessment, can expect to be exposed to noise below 35 dB(A) [102].

Fig. 7 shows the 140 objectors residing in the three municipalities and >1 km away from the project.[13] We differentiate between objectors who raised noise concerns and those who did not. The descriptive results suggest a disproportionate share of noise concerns in one, but not the other of the two neighboring municipalities. When it comes to the share of noise concerns relative to all objections in the respective municipality, chi-square[14] tests reveal borderline significant results, indicating that objectors from Wald AR seem to be more likely to voice noise concerns compared to objectors from Oberegg AI ($\chi^2(1) = 3.561$, $p = 0.059$) and Altstätten SG ($\chi^2(1) = 2.844$, $p = 0.092$). Looking at noise concerns per inhabitant, the difference between Wald AR and the other two municipalities becomes more pronounced: In Wald AR 3.0% of inhabitants voiced noise concerns. This share drops to 1.0% in Oberegg AI, and just 0.1% in Altstätten SG. Chi-square tests reveal that the differences between Wald AR and Oberegg AI ($\chi^2(1) = 15.658$, $p < 0.001$),



Municipality	Wald AR	Oberegg AI	Altstätten SG
No. of inhabitants (Dec 31, 2019)	872	1'889	11'877
Population density (inhab./km^2)	127.9	128.8	303.7
Objectors (absolute / relative to population)	52 (6.0%)	56 (3.0%)	32 (0.3%)
…of which noise concerned (absolute / relative to population)	26 (3.0%)	18 (1.0%)	10 (0.1%)

Fig. 7. Justice among municipalities and noise concerns (Population data as of December 31, 2019: https://www.bfs.admin.ch/bfs/de/home/statistiken/bevoelkerung.assetdetail.12247151.html).

[13] As described in Fig. 4, N=17 objectors living within 1 km of the project are excluded from this analysis.

[14] No cell frequencies were below 5.

Wald AR and Altstätten SG ($\chi^2(1) = 242.205$, $p < 0.001$) as well as between Oberegg AI and Altstätten SG ($\chi^2(1) = 60.589$, $p < 0.001$) are statistically significant.

5. Discussion

5.1. The relationship between proximity and noise concerns

5.1.1. Noise concerns travel farther than noise

The results of our representative stated preference survey (Study 1) as well as those of the overall sample of our case study (Study 2) provide initial evidence to reject H1. In Study 1, the share of respondents mentioning wind turbine noise does not differ significantly between those living within a 5 km radius of a planned wind project (18% mention noise) and those living beyond a 5 km radius (19% mention noise). The multivariate analysis confirms that noise concerns do not limit themselves to residents living nearby a planned wind project, but rather travel beyond a 5 km radius. The analysis of the overall sample of the case study supports the finding that noise concerns travel much farther than what noise models would predict. 93% (125 out of 135) of noise objectors live beyond a 1 km radius. According to the environmental impact assessment of the planned wind project, the large majority of objectors cannot expect to be exposed to noise levels above 35 dB(A), suggesting a rejection of H1[15]. The results for proximity support previous studies about existing wind projects suggesting that proximity and actual noise levels cannot explain noise annoyance [33,35,74]. Along these lines, a study conducted in the US by Haac et al. [38] found modeled sound levels at residences in proximity to existing wind projects to be an excellent predictor of noise perception (i.e., hearing sound), but not a good predictor of noise annoyance. The latter has been more clearly linked to subjective variables [35,38].

5.1.2. Proximity matters to an extent

Study 2 allowed us to take a closer look at households living within a 1000 m radius of the closest wind turbine. Within this group, a clear majority of the objectors living within a 500 m radius mentioned noise concerns, whereas those living within 500–1000 m of the planned wind project did so to a much lesser extent. Thus, within closer distances (<1000 m), noise concerns seem to increase with proximity, bringing residents' noise concerns in line with expert judgements of actual impacts. Given that Haac et al. [38] found that more than two thirds of respondents were able to hear wind turbine sound levels above 40 dB (A), which corresponds to the noise levels that residents within 500 m of one of the two turbines can expect to be exposed to, noise concerns reflect expected noise levels. Also, the international average Community Tolerance Level (CTL) for wind turbine noise calculated by Michaud et al. [76] based on six field studies, indicates that the share of highly annoyed residents increases from approx. 2% at 35 dB(A) to approx. 4% at 40 dB(A) and approx. 10 % at 45 dB(A) levels. In their dose–response analysis Haac et al. [38], find comparable results. Despite the fact that even at 45 dB(A) levels the vast majority (i.e., approx. 90%) is not highly annoyed, the CTL by Michaud et al. [76] does suggest that those living within 500 m of one of the two wind turbines are somewhat more likely annoyed by the noise. As such, a potential explanation for the contrasts in our findings between the overall sample and the high-resolution sample of Study 2 could be that residents who live closest to the wind turbines expect to be more likely affected by the turbines and therefore are better informed about the planned wind project's impacts than those who expect to be less likely affected.

In sum, our findings on the relationship between proximity and noise concerns suggest, that when dealing with noise concerns we need to differentiate between those residents living closest to the wind turbines and the more general populations (i.e., the sample of objectors living >1 km away in Study 2 and the nationwide sample in Study 1).

5.2. The role of familiarity

In contrast to proximity to a planned wind project, we find significant results for the variable familiarity with existing wind projects, for the nationally representative sample in Study 1: People used to seeing wind turbines in their immediate environment were significantly less likely to mention wind turbine noise worries. Thus, lack of familiarity seems to be a good explanation for why people think about noise emissions. These insights support the theoretical prediction of H2.

The multivariate analysis also points to differences between the French- and German-speaking parts of Switzerland. This difference may be connected to the current exposure of these regions to planned wind projects[16]. Residents nearby planned wind projects are most exposed to ongoing debates about potential wind turbine impacts including noise emissions [(69, p. 1477),70,72] (cf. Section 2.2). With increasing direct exposure to planned projects, the general public may perceive both the negative noise concerns and the objective information about the predicted noise level more strongly (i.e., information and disinformation will be balanced). Exposure to media reports or local debates can influence what comes to people's minds when thinking of wind projects and may partly explain the difference between French- and German-speaking residents.

This second main finding of Study 1, namely that familiarity with wind turbines will lower the likeliness of negatively associating wind turbines with noise, supports earlier studies focusing on social acceptance, which suggest that individuals overestimate wind turbine impacts prior to the commissioning of a wind park [14,36] or if they lack familiarity [62]. As noise annoyance studies focus on the operational phase of wind projects, and thus residents in these study samples tend to be familiar with wind turbines, we cannot directly compare our results on noise concerns. However, our finding does parallel with those of noise annoyance studies in that subjective factors seem to be more important than objective factors (see e.g., [38]).

5.3. The role of justice

Our third hypothesis predicted noise concerns to peak just beyond the borders of the host community. In contrast, in Study 2 we find that the share of noise concerns is higher in one (Wald AR), but not the other of the two neighboring municipalities (Altstätten SG) compared to the host community (Oberegg AI) itself. Thus, we cannot confirm H3. There are several potential reasons for the comparatively larger number of (noise) objections from Wald AR. For one, a key spokesperson of the opposition group, "Pro Landschaft AI/AR", resides in Wald AR. Secondly, small municipalities like Wald AR might be more susceptible to collective opinion swings than larger ones such as Altstätten SG. Thirdly, Appenzell Inner-Rhodes and Appenzell Outer-Rhodes used to be part of the same jurisdiction before splitting up along religious lines in mediaeval times, leading to a degree of historic rivalry. Such longstanding intergroup relations have been shown to influence social acceptance [105]. Finally, residents of less urbanized municipalities such as Wald AR may be more sensitive to noise emissions (see e.g., [42]), which may explain why less noise concerns originate from Altstätten SG. Although the results on the role of justice are somewhat conflicting, the difference between Wald AR and Oberegg AI does insinuate that taking procedural

[15] Previous research has shown that a minority of residents who live farther away still report noise annoyance [33]. To address this issue, wind project developers should consider adequate noise mitigation measures such as winglets, shark fins and turbulators [104].

[16] While there is no official database of planned wind projects, there have been attempts to map the projects that are in the pipeline, showing the higher number of planned wind projects in the French-speaking part of Switzerland: http://fr.windparkkarte.ch

and distributional justice at the municipality level into account may be critical to the success of a wind project.

6. Conclusions, implications, and future research

This article adds to the literature on social acceptance of wind projects by studying noise concerns during the planning phase, which poses the most challenging project phase for sustaining the acceptance of wind projects [14]. Our central aim was to investigate whether residents living near a planned wind turbine are more likely to be concerned about wind turbine noise than those living farther away. We have also explored alternative explanations for a potential discrepancy between expected and predicted noise levels. Prior studies have found noise to be a central issue driving opposition against wind projects [12,36], yet insights on the dynamics of opposition in the planning phase are rare. Our findings may build a basis for policymakers to design local wind project siting decisions and for project leaders to come up with strategies to address noise concerns.

6.1. Conclusions and implications for policy and practice

First, our findings in both studies show that outside the immediate vicinity (<1 km) of a project there is no clear correlation between proximity to a planned wind project and noise concerns, suggesting that noise concerns travel farther than the predicted noise levels. More specifically, Study 1 has shown that residents living within a 5 km radius of a planned wind project are not more likely to have noise associations than residents living farther away. Similarly, in Study 2, we have found noise concerns to spread far beyond the prospective impact of noise propagation. 93% of all noise concerns voiced in a public consultation process originated from individuals living beyond 1 km of the planned wind project. 21% of noise objectors even live much farther away (>10 km from the planned wind project).

At the same time, our study demonstrates the value of taking a closer look. Creating a high-resolution data set of the population around a planned wind project, our results, which are, however, based on a rather small sample size, give first hints that, among residents living within 1 km of the project, there is a difference between those living within a 500 m radius (and are therefore likely to be exposed to noise of 40–45 dB(A)) and those living within the 500 m to 1 km radius (more likely to be exposed to noise of 35–40 dB(A)). 88% (7 out of 8) of the closest objectors express noise concerns, while that is the case for only 33% of the slightly more remote neighbors opposing the wind project.

The challenge for project developers, therefore, is twofold: Addressing the plausible noise concerns of the closest neighbors, even if they are limited in numbers, should be a key priority. On the other hand, convincing those living farther away, who may be unaware that they are unlikely to be affected by discernible levels of turbine noise, is an equally important task that is moderated by dynamic processes of (inter-)group communications.

The former challenge may be addressed by assuring distributional justice, including legislation about local benefit-sharing. In cases like the one we investigated in Study 2, where expected impacts cross political boundaries, this may create additional challenges. Especially in countries with fine-grained legislative structures, such as Switzerland, this might be supported by some degree of inter-regional compensation. Furthermore, it is important to make use of technological solutions such as winglets, shark fins and turbulators to improve wind turbine noise quality, which seems to be effective in reducing related noise annoyance [104,106].

As for the latter challenge, namely closing the gap between noise concerns and expert judgments about wind turbine noise, policymakers, and project developers may draw on the findings of Study 1 showing that residents familiar with wind turbines are less likely to be concerned about wind turbine noise. Increasing familiarity, either through organizing excursions for residents to visit existing wind turbines in other regions or by creating simulations or virtual reality experiments [107], may be a promising avenue to address noise concerns. When thinking about how to transfer existing field research on wind turbine noise to the general public, it might also prove useful to include those who are less concerned about noise (e.g., the group of younger respondents (15–29-year-olds)) in a very early stage of the planning process.

Finally, it is important to be aware that noise concerns do not spread in a vacuum. Perceptions matter and apart from being informed or uninformed, residents of local communities will also be exposed to deliberate efforts aimed at shaping noise perceptions, sometimes based on emotionally powerful, yet inaccurate metaphors. In the specific context of Study 2, the opponents repeatedly claimed that wind turbines were "loud as a chain saw" [108], whereas the official environmental impact assessment suggested the vast majority of residents would be exposed to sound levels of less than 40 dB(A), which is similar to sound levels experienced in a library. In such contested environments, persuasive communication efforts early in the process to prevent the spread of misinformation and fear are key to ensure evidence-based decision making.

6.2. Limitations and further research

In designing our research, we carefully tried to balance the strengths and weaknesses of complementary research methods. Being mindful of the limitations inherent in each of the studies provides relevant starting points for further research. Study 1 allowed us to draw on a large, national sample, but working with stated preference data inherently leads to a degree of hypothetical bias. The majority of our respondents indicated that they actually do not live within 5 km of a currently planned wind project, which is natural given that wind projects tend to be sited away from major population centers, but may limit respondents' ability to accurately predict noise concerns that might arise once they are actually exposed to a real project nearby (including active communication by opponents). Future research working with large national samples could conduct a randomized controlled trial where some respondents are exposed to information prompting the salience of noise concerns to see whether differences arise. Another limitation of Study 1, similar to some of the extant social acceptance literature (e.g., [109]), is that defining proximity as living within a 5 km radius of a planned project may miss some of the important nuances that occur among the most affected population. To address this concern in Study 2, we engaged in a unique high-resolution analysis of noise concerns among the population living within the 500 m and 1 km radius of a planned wind project. Although this comes at the expense of smaller sample size and leads to an exponential increase in data collection effort, zooming in to such level of detail provides new insights about processes of social acceptance and highlights the key role of a small number of salient stakeholders in making or breaking a project. Further research may try to replicate such fine-grained local analysis in different settings, including comparisons over time to discern some of the dynamic processes of local acceptance.

Furthermore, in both of our studies we used distance as a proxy for prospective sound levels. This proved to be valuable as we were interested in noise concerns in a context where wind turbine sound is not yet existent. It is, however, important to consider that, in addition to distance, actual sound propagation also depends on factors including ground cover [110], meteorological conditions [44,45,46], prevailing winds [111,112], background sounds [111], topography [42,43] and obstructions [43]. While in Study 1 we were not able account for these additional factors, in Study 2, we were able to relate our distance proxy to the noise models of the Oberegg wind project's environmental impact assessment [102]. Future research adopting a longitudinal design could compare noise concerns in the planning context with actual impacts during the operation phase. A very interesting research project could also entail focusing on how noise concerns evolve and change after construction, even in larger distances. These proposed research designs would provide a novel connection between our work and previous research investigating actual noise annoyance among residents near existing wind projects (e.g., [35,38]).

Finally, we focused on a unique project setting in Study 2 where a wind project was planned close to three municipalities belonging to different jurisdictions (cantons). While our third hypothesis predicted a peak in noise concerns right outside a host community's borders due to distributional justice issues, this seemed to hold true for one but not the other of the two neighboring communities, which raises interesting questions for further research. How do factors like the communication tactics and local origin of key proponents and opponents, as well as historic intergroup conflicts [105], influence processes of social acceptance? And do noise concerns indeed spread differently within large and small municipalities as our case study seems to suggest? Further research replicating our study in different geographical settings, potentially also spanning national borders, could shed light on these important questions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors wish to acknowledge financial support from the Swiss Competence Centers for Energy Research (SCCER CREST), funded by Innosuisse. Data collection for Study 1 was financially supported by Raiffeisen Switzerland and SwissEnergy. The authors would like to thank attendees of the Swiss national wind energy conference 2020 for feedback on an earlier draft of our work, as well as researchers at the Chair of Management of Renewable Energies at the University of St. Gallen for comments on a draft version of the paper.

Appendix

Table A-1
Study 1, sample funnel.

Original sample	**1249**	100%
- Respondents with *no* noise associations	1021	
- Respondents with noise associations	228	
○ Negative noise associations	222	
○ Positive noise associations	6	
Reduced sample excl. pos. noise associations	**1243**	99.5%
- Respondents *not* nearby an existing wind project	941	
- Respondents nearby an existing wind project	276	
- Unsure	26	
Final sample excl. pos. noise associations & excl. respondents unsure about living near an *existing* wind project	**1217**	97.4%
- Respondents *not* nearby a *planned* wind project	797	
- Respondents nearby a *planned* wind project	121	
- Unsure	299	

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