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Predicting the community acceptance of airborne wind energy with the integrated acceptance model: Insights from two test sites

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ABSTRACT

Airborne wind energy (AWE) harnesses higher-altitude winds using kites to generate renewable electricity. As AWE technologies move closer to potential commercialization, understanding how local communities interact with and are affected by these technologies is crucial for socially responsible deployment. Identifying key predictors of community acceptance can help develop targeted measures to address potential impacts while the technology is still adaptable. This study tested the Integrated Acceptance Model (IAM) on survey data from two European AWE test sites. A linear regression analysis revealed that two of the five explanatory variables significantly predicted acceptance: perceived site impacts (e.g., sound emissions, landscape changes, and aviation lights), as well as developer transparency and fairness in site operations. In contrast, attitudes toward the energy transition, perceived economic impacts, and social norms did not predict acceptance. These findings suggest that while AWE developers prioritize technical challenges, attention must also be given to social factors, such as minimizing impacts and ensuring transparent and fair implementation. The results also have important policy implications, highlighting the need for AWE-specific regulations and socially responsible planning practices. Further research is required to investigate additional acceptance predictors, especially if AWE technologies continue to develop toward commercial applications.

1. Introduction

With the revision of the Renewable Energy Directive in 2023, the EU has increased the required share of renewables in EU energy consumption to a minimum of 42.5% by 2030 (Directive 2023/2413, n.d.). The installed wind capacity has to more than double from 204 GW in 2022 to over 500 GW in 2030 to reach the EU target (European Commission, 2023). The emerging renewable technology of airborne wind energy (AWE) could help close the gap by tapping into higher-altitude wind resources, adjusting the operating altitude to fluctuating wind conditions, and producing electricity at sites unsuitable for regular wind turbines (Bechtle et al., 2019; BVG Associates, 2022; Vos et al., 2024). AWE utilizes tethered flying devices known as kites, which either harness higher-altitude winds with onboard generators (i.e., fly-gen concept) or convert the kite's force, as it unwinds the tether from a drum, into electricity during the traction phase (i.e., ground-gen concept; for more details, see Cherubini et al., 2015). Fly-gen systems use fixed-wing kites made from sturdy materials, whereas ground-gen systems can also use soft-wing kites made from flexible membrane wings (Fagiano et al., 2022; Vermillion et al., 2021). Fig. 1 provides an overview of the different systems.

Experience with established renewables shows that challenges in the energy transition are not only technical or economic but also social (Kirkegaard et al., 2023). With the rapid expansion of renewables and the decreasing availability of suitable sites, energy projects are inevitably built closer to people's homes. Sites that unduly affect local communities can lead to resistance, which can delay and hinder renewable energy development, ultimately jeopardizing the energy transition as a whole (Susskind et al., 2022; Temper et al., 2020). Emerging renewables, such as AWE, should therefore be designed and deployed to fit

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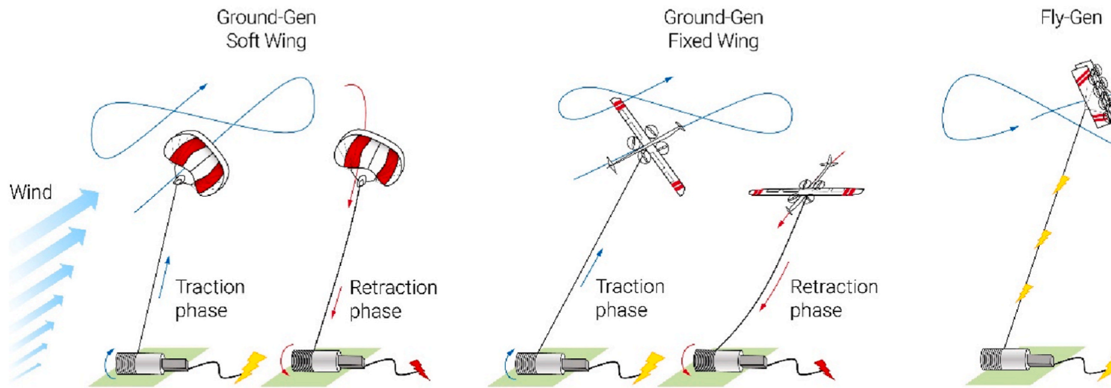

Fig. 1. A schematic representation of different ground-gen and fly-gen airborne wind energy systems (based on Fagiano et al., 2022 in Schmidt et al., 2024).

better with people's lives (Schmidt et al., 2022). Yet, social implications of AWE have received markedly less attention in both research and industry than technical, economic, or policy issues (ibid.). For example, a European Commission study on the challenges of commercializing AWE found that only 7% of the barriers identified by academic, business, and public stakeholders concerned social acceptance (Directorate-General for Research and Innovation & ECORYS, 2018). In contrast, economic viability (25%) and regulatory gaps (24%) were mentioned substantially more often. Not only are the social implications of AWE overlooked, but the sector tends to assume that AWE will face fewer social concerns than wind turbines due to anticipated lower visual, sound, and ecological impacts at higher altitudes (Schmidt et al., 2022). These assumptions are largely speculative, and they risk misinforming design choices, deployment practices, and policy (ibid.). Research such as the present study is thus crucial in drawing the sector's attention to this understudied topic and in empirically identifying the factors predicting acceptance. The timing is opportune: AWESs are already close to commercial prototypes (BVG Associates, 2022; SkySails Power, 2023b), yet remain sufficiently malleable for design adaptations and for social-science insights to inform policymaking and regulations.

The first-ever field study on the community acceptance of an AWE test site is a starting point for deriving recommendations for AWE development and deployment (Schmidt et al., 2024). In line with research on established renewables (Aaen et al., 2022; Firestone et al., 2018; Gölz & Wedderhoff, 2018; Hoen et al., 2019; Hübner et al., 2019; Mulvaney et al., 2013; Pohl et al., 2018; Rand & Hoen, 2017; Slattery et al., 2012), the study found that site impacts on residents and nature (i.e., sound emissions, landscape changes, aviation lights, and ecological impacts) and dissatisfaction with procedural aspects (e.g., perceiving the developer as untransparent and the operation as unfair) were related to more negative attitudes toward the AWE site. While the findings are useful, more research is needed to substantiate them and identify which factors predict acceptance most strongly, especially across AWE sites and regions. Understanding the main acceptance drivers is crucial for formulating effective and targeted measures.

The most parsimonious[1] framework to date for predicting the local acceptance of renewable energy projects is the Integrated Acceptance Model (IAM; Hübner et al., 2023). Local or community acceptance refers to residents' attitudes towards a given local renewable energy project (Wüstenhagen et al., 2007), ranging from negative through neutral to positive. By synthesizing the wealth of existing energy acceptance research, the IAM offers five overarching categories that can substantially explain residents' attitudes towards a local project (see Fig. 2): (1) economic impacts (Baxter et al., 2013; Hoen et al., 2019; Leiren et al., 2020; C. Walker et al., 2014), (2) energy transition attitudes (Breitschopf & Burghard, 2023; Kirchhoff et al., 2022; Sonnberger & Ruddat, 2017), (3) resident and nature impacts (Aaen et al., 2022; Fergen & B. Jacquet, 2016; Hübner et al., 2019; Mulvaney et al., 2013; Pohl et al., 2021; Rand & Hoen, 2017; Slattery et al., 2012), (4) the planning process (Gross, 2007; Hoen et al., 2019; Hogan, 2024; C. Walker & Baxter, 2017), and (5) social norms (Huijts et al., 2012; Johansson & Laike, 2007; Jones & Eiser, 2009; Read et al., 2013; Sokoloski et al., 2018). Specifically, the IAM predicts that local acceptance is higher when residents perceive more positive impacts of the project on the local economy, have more positive attitudes toward the energy transition, experience fewer negative project impacts on residents and nature, perceive the planning process more positively, and expect the local community to approve the project. While the IAM can substantially predict local acceptance across wind energy projects (R^2_{adj} between 0.76 and 0.78; Hübner et al., 2023), it is essential to consider context-specific aspects, such as through place-based approaches (Devine-Wright & Peacock, 2024).

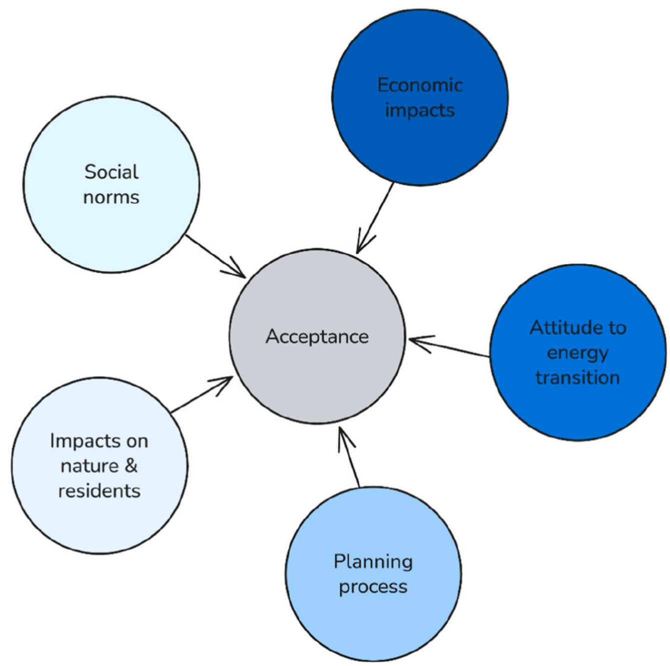

Fig. 2. The Integrated Acceptance Model (IAM) comprises five key predictors of community acceptance (based on Hübner et al., 2023).

Other frameworks for the social acceptance of renewables exist, but

[1] Parsimony, also known as the principle of simplicity, is a fundamental concept in psychology. It emphasizes the importance of adopting the simplest explanation or solution for understanding a problem or phenomenon. A parsimonious model aims to use the smallest and most straightforward set of parameters to represent the data accurately.

they extend beyond the community level and are not predictive (Sovacool & Ratan, 2012; Upham et al., 2015; Wüstenhagen et al., 2007), only focus on one implication of local renewable developments (Devine-Wright, 2009; Gross, 2007), are not parsimonious (Hoen et al., 2019; Huijts et al., 2012), or concern hypothetical or proposed rather than existing sites (Bidwell, 2013; G. Walker et al., 2010). Given the different scopes and limitations of other frameworks, the IAM appears to offer greater explanatory power for understanding the community acceptance of AWE. While the IAM has so far been applied only to data from wind farms, it synthesizes broad, well-established acceptance determinants for renewables (i.e., impacts, procedural fairness, economic effects, social norms, and energy transition attitudes) rather than technology-specific features. This makes it appropriate for novel or unfamiliar renewables, such as AWE, provided the constructs are measured in a technology-appropriate way (e.g., referring to AWE aviation lights rather than obstruction lights as for wind turbines). Prior environmental psychology research has applied theory-driven models to early-stage or pilot energy technologies (e.g., tidal energy and hydrogen fuel), indicating the field's precedent for studying novel deployments with established constructs (Devine-Wright & Howes, 2010; Huijts et al., 2014).

Currently, no commercial AWE developments exist, so we must focus on actively used AWE test sites. Thus, this study investigates the extent to which the IAM predicts acceptance of AWE test sites. There are presently only a few active AWE test sites in Europe that are regularly used and close to residential areas (Airborne Wind Europe, 2024). Besides, the population density around such sites tends to be low because they must be located in open, flat areas due to present operation and safety principles (Salma & Schmehl, 2023; SkySails Power, 2023a). The spatial setting makes it difficult to recruit a large enough sample at a single test site to calculate an adequately powered IAM. Therefore, we pool part of the data collected in a previous study at a German site (Schmidt et al., 2024) with unpublished data from an Irish site (DEM-AWE, n.d.). The Irish site features an AWE system (AWES) that is very similar to the one used in the German study, increasing the comparability of the data.

2. Method

In this section, we describe the similarities and differences between the German and Irish studies in terms of three main aspects of the methodology: the investigated AWE test sites, the survey design, and participant recruitment. Additionally, we present the sample characteristics and explain the statistical analyses used.

2.1. Test sites

Both test sites are situated in open, relatively flat areas in semi-rural regions. At both sites, ground-gen soft-wing AWESs flying in figure-of-eights are tested (see Fig. 3). Different prototypes were used at the German site before the data collection, with wing surface areas ranging from 40 to 160 m^2 (Junge et al., 2023). The kite's flight altitude was approximately 200 to 400 m, and the rated power output was up to 200 kW (ibid.). At the Irish site, only one prototype was tested, featuring a wing surface area of 60 m^2, a flight altitude of up to 350 m, and a rated power of 30 kW (Kitepower, n.d.). The German site had been in operation for approximately 2.5 years at the time of data collection (Junge et al., 2023), whereas the Irish site had been active for only about half a year (DEM-AWE, n.d.). Accordingly, the total operation time at the German site was substantially longer than at the Irish one. Both test sites had temporary permits for research and development (R&D) projects (ibid.). However, while no public participation process was organized in Germany, and the neighbors were only informed after the testing had started, the Irish site underwent the regular permitting procedure for wind energy developments in Ireland (DEM-AWE, n.d.; Schmidt et al., 2024). This included a public announcement of the proposed site before application, community outreach to every home within a 2-km radius prior to planning, and a public consultation period, during which residents could submit written comments. The German site was established and is used by a regional AWE developer, whereas the Irish site was developed by a multinational energy company and is used by a foreign AWE developer. These contextual differences may shape residents' evaluations. We therefore take them into account when discussing the pooled results, and we complement the pooled regression with a sensitivity analysis excluding the Irish cases (see Section 3.2).

2.2. Recruitment

In the German study, all adults within a 5-km radius of the test site who were familiar with the site were eligible to participate. To recruit participants, we posted letters to and called all identifiable addresses within 2.5 km of the site, placed announcements in local media as well as on social media/websites, and distributed leaflets to houses within a 2 km radius (Schmidt et al., 2024). The recruitment occurred between May and June 2022. In the Irish study, any adult residing in the wider county could participate. However, only residents living within a 5-km radius of the site who had perceived the AWES before were asked about their experience with the site. Approximately 500 adults resided within the 5-km radius (Central Statistics Office, 2022).[2] The participant recruitment focused on the major town closest to the site and occurred in two phases: a main phase and a follow-up phase. During the main phase in April 2024, we announced the research through regional media, social media, a local information event, and flyers in local shops. Paper questionnaires with the option to access the web version were distributed to about 140 households in town and along the roads adjacent to the site. Residents who completed the paper questionnaire could return it to a secure mailbox installed at the local supermarket. During the follow-up about two months later, questionnaires were posted to 39 houses closest to the site (within a 2-3 km distance), as few responses had been received from direct site neighbors. About one month later, door-to-door visits occurred to a subset (i.e., 19) of the same households to remind them about the survey.

2.3. Survey design and measures

In the German study, we administered the questionnaire during structured interviews, whereas in the Irish study, respondents self-administered the questionnaire due to resource constraints. For the Irish study, we used a shortened, translated version of the German questionnaire (Schmidt et al., 2024). Notably, the German study included a qualitative component (reported in Schmidt et al., 2024), which provided convergent evidence for the IAM constructs examined in this study. In particular, respondents frequently referred to directly experienced impacts (notably visual and sound-related aspects) and to process-related considerations, such as fairness and transparency of developer communication, consistent with the quantitative constructs assessed in both surveys. Qualitative insights from the German study also informed the design of the Irish survey, specifically in our adjustment of the economic impacts measure (see below under (4)). In the following, we describe the items used to assess the six constructs of the IAM in both studies: (1) community acceptance, (2) impacts on residents, (3) planning process, (4) economic impacts, (5) social norms, and (6) attitudes toward the energy transition. In addition to the IAM constructs, we also assessed safety concerns, as safety risks are often considered to be a major acceptance factor by the AWE sector (Schmidt et al., 2022). While safety is not one of the IAM's core categories, the IAM is intended to be applied flexibly and allows for the inclusion of

[2] The estimate is based on the number of residents 20 years and older living in the census areas, which approximately match the 5-km recruitment radius around the test site.

Fig. 3. The airborne wind energy systems in operation at the German site (left) and the Irish site (right). A drone captured the photo at the German site, while the photo at the Irish site was taken from the ground, differently affecting the perception of the kites' sizes (Courtesy of SkySails Group and Kitepower B.V.).

technology-specific considerations where relevant. We therefore examined whether safety concerns can help predict residents' acceptance of AWE test sites.

(1) Community acceptance was operationalized as attitudes toward the local AWE site and assessed by two pairs of opposite adjectives on 7-point bipolar scales ranging from −3 (“very bad”/“very useless”) to +3 (“very good”/“very useful”). Usefulness referred to the general utility of AWE as a renewable technology. The items' average was used as an indicator for acceptance ($r = 0.82$, $p < .001$, n = 71). An attitudinal scale was used rather than a behavioral one because behavioral measures might underestimate acceptance, as opponents are more likely to act on their opinion than supporters. Furthermore, the test sites offered few opportunities to act because respondents typically found out after project approval was granted; however, attitudes are established predictors of behavioral intentions in environmental psychology research (e.g., Theory of Planned Behaviour).

(2) For visual impacts, respondents were asked whether they perceived aviation lights[3] from home, and how much it annoyed them.[4] Similarly, for sound emissions, respondents stated whether they heard sounds from the AWES and, if so, how much it annoyed them. Annoyance was rated on 5-point scales from 0 (“not at all”) to 4 (“very”). Landscape impacts, on the other hand, were assessed by two pairs of opposite statements on 7-point bipolar scales ranging from −3 (“compromises the landscape very much”/“very unfitting for the regional landscape”) to +3 (“makes the landscape much more attractive”/“very fitting for the regional landscape”). We recoded the landscape impact scores into a 4-point scale to compute a total impact score. The items' average was used as the total landscape impact score ($r = 0.85$, $p < .001$, n = 63). The maximum scores for noise annoyance, aviation light annoyance, and the total landscape impacts were then used as indicators for total impacts on residents. The maximum rather than the average score was used because respondents typically do not feel annoyed by all impacts. Averaging across impacts would thus underestimate the annoyance experienced for a specific impact. Perceived site impacts on nature were not measured in the Irish sample and were, therefore, not included in the total impact factor.

(3) Because no public planning process had occurred for the German site (see Section 2.1) and the IAM's categories are intended to be adapted to the research context, we operationalized the planning process variable as ‘fairness & transparency’. Specifically, respondents rated the fairness of the site's operation, the developer's openness and transparency, and their satisfaction with the developer's efforts to inform them about the site on 5-point scales from 0 (“not at all”) to 4 (“very”). Exploratory Factor Analysis (EFA) confirmed the unidimensionality of the scale, with all primary factor loadings exceeding 0.70, and internal consistency rated as good (Cronbach's $\alpha = .86$). The items' average was, therefore, used as a total score.

(4) In the German study, respondents were asked to anticipate how a hypothetical commercial deployment of AWE would affect the local economy. Because German respondents struggled to imagine the effects, the Irish sample was asked to report the impacts of the existing AWE site on the local economy. In both cases, respondents rated the impacts on four economic sectors using 7-point bipolar scales: agriculture, tourism, property values, and remaining economic branches. The total economic impacts correlated significantly with acceptance in both samples ($r = 0.54$, $p < .001$, n = 52, and $r = 0.51$, $p = .002$, n = 24, respectively). EFA confirmed the unidimensionality of the scale in the combined sample, with all primary factor loadings exceeding 0.65, and internal consistency rated as good (Cronbach's $\alpha = .80$).

(5) To assess social norms, participants were asked to estimate how the local community evaluates the AWE site on a 7-point scale ranging from −3 (“disapproves very much”) to +3 (“approves very much”).

(6) Attitudes toward the energy transition were assessed by four pairs of opposite adjectives on 7-point bipolar scales ranging from −3 (“very bad”/“very uneconomical”/”very poorly implemented”/”very unfair”) to +3 (“very good”/“very economical”/”very well implemented”/“very fair”). EFA showed that more than 50% of the non-redundant residuals exceeded 0.05, indicating a suboptimal model fit. Removing the third item (“The energy transition is poorly/well implemented”) markedly improved the fit indices, while Cronbach's alpha remained virtually unchanged (from $\alpha = .82$ to $\alpha = .80$). The item's relatively high factor loading ($\lambda = 0.66$) suggests that it captured a related but slightly distinct aspect of attitudes, likely reflecting evaluations of the political-administrative context rather than general attitudes toward the energy transition. Therefore, the scale was reduced to three items, representing a more homogeneous construct with good internal consistency. The average of the items' scores was used as the attitude score.

(7) Safety concerns were assessed by asking respondents to rate the extent to which they worried about the safety risks of the AWES on a 5-point scale from 0 (“not at all”) to 4 (“very”).

[3] Questions about aviation lights only applied to the German site because no nighttime flights had occurred at the Irish site before the data collection.

[4] The questionnaires also included questions about the perception of shadow and corresponding annoyance, but due to concerns about the items' validity, shadow annoyance was not considered in the data analysis. Excluding the variable did not change the results because the maximum values of all participants remained the same.

2.4. Sample characteristics and comparison

Table 1 presents the characteristics of the samples separately and combined. The average age of German participants was 10 years higher than that of the Irish participants. In fact, the German study oversampled older residents (Schmidt et al., 2024), whereas the Irish sample was representative of the estimated average age of the adult local population (Central Statistics Office, 2022). The percentage of women was somewhat higher in the German than in the Irish study, but it was representative of the local population (Statistikamt Nord, 2023). The proportion of women in the Irish study (45%) was slightly lower than that of the underlying population (51%; Central Statistics Office, 2022). The education level was higher in the Irish than in the German study but comparable to the national average (Central Statistics Office, 2023). In contrast, the education level in the German study was somewhat higher than the national average (Statistisches Bundesamt, 2021). Demographic variables tend to show limited and inconsistent associations with attitudes towards wind projects (Rand & Hoen, 2017). The low percentages of respondents working in the wind energy industry were comparable across the two samples. However, while one-third of the German sample received financial benefits from local wind energy projects, nobody in the Irish sample did. Finally, respondents in the German study lived closer to the test site.

Although the two samples differed somewhat in demographics (especially age, household size, and whether respondents received financial benefits from local wind projects), pooling of the two subsamples was not based on the assumption that they were equivalent. In principle, pooling does not require similar samples; it requires that the relationships between predictors and acceptance are not driven by a single context in a way that alters the overall pattern. We pooled the data to obtain sufficient cases to estimate the IAM regression at a development stage where site-level samples tend to be small. The pooled model is intended to describe the overall pattern observed across the combined sample, rather than to make strong claims about the equivalence of the two sites. To assess whether the pooled results are disproportionately influenced by the small Irish subsample (n = 8), we also re-estimated the model using only the German subsample as a sensitivity check (see Section 3.2).

After combining the data, the pooled sample had a slightly to somewhat positive attitudes toward the local AWE site, was slightly to somewhat affected by site impacts, evaluated procedural aspects as somewhat fair and transparent, rated economic impacts as neither negative nor positive, expected the community to be slightly approving of the site, and had slightly positive attitudes towards the energy transition (see Table 2).

Table 1
Characteristics of the German and Irish samples, separately and combined.

	German (*N* = 54)	Irish (*N* = 20)	Combined (*N* = 74)
Age (*M*, *SD*, range)	60.87 (12.29)	50.65 (15.90)	58.42 (13.84)
	34–85 n = 54	26–81 n = 17	26–85 n = 71
Gender			
Male	51.9 % (28)	30 % (6)	45.9 % (34)
Female	48.1 % (26)	45 % (9)	47.3 % (35)
Undisclosed	0 % (0) n = 54	25 % (5) n = 20	6.8 % (5) n = 74
Highest educational level			
Tertiary	40.8 % (22)	64.7 % (11)	46.5 % (33)
Secondary	51.9 % (29)	35.3 % (6)	49.2 % (35)
Primary	7.4 % (3) n = 54	0 % (0) n = 17	4.2 % (3) n = 71
Employed in the wind energy industry	3.7 % (2) n = 54	5.9 % (1) n = 17	4.2 % (3) n = 71
Receiving financial benefits from local wind projects	33.3 % (18) n = 54	0 % (0) n = 17	25.4 % (18) n = 71
Distance from AWE site[a]			
1-2 km	50 % (27)	35 % (7)	45.9 % (34)
2-3 km	48.1 % (26)	35 % (7)	44.6 % (33)
3-4 km	1.9 % (1)	20 % (4)	6.8 % (5)
4-5 km	0 % (0) n = 54	10 % (2) n = 20	2.7 % (2) n = 74

Note. The numbers in brackets behind the percentages indicate the frequency count. [a]The distances were measured from the approximate location of the AWES ground stations. During short periods of the operational cycles, the kite at the German site could fly up to at most 680 m closer to houses, and the kite at the Irish site up to at most 250 m closer.

2.5. Statistical analyses

We applied a linear multiple regression analysis to test whether the IAM predicts the acceptance of AWE in this study. A power analysis with G*Power assuming an alpha error probability of 0.05 and a large effect size (Hübner et al., 2023) showed that for power levels of 0.95 and 0.80, sample sizes of 63 and 43, respectively, would be sufficient to observe a significant regression model for the IAM (Faul et al., 2007). Adding safety concerns as a sixth predictor would increase the required sample sizes to 67 and 46, respectively. Due to missing data, we included 51 cases in the regression model (50 in the model with safety), which satisfies the threshold for a power of 0.80. Assumptions of linear regression were inspected (i.e., independence of observations, normality, linearity, no multicollinearity, and homoscedasticity). Due to heteroscedasticity and outliers in the data, we used heteroscedasticity-consistent standard errors (HC4) in the regression (Hayes & Cai, 2007; Kaufman, 2013; Rosopa et al., 2013; Uchôa et al., 2014).

3. Results

In this section, we first report bivariate correlations between acceptance and the study variables. We then present the multiple regression model based on the five IAM categories in the combined sample, followed by a sensitivity check using the German subsample. Finally, we report an exploratory model that adds safety concerns as a technology-specific predictor.

3.1. Correlation results

The regression analyses aimed to predict acceptance from the five IAM categories: impacts on residents, ‘fairness & transparency,’ economic impacts, social norms, and attitudes toward the energy transition. In addition, we examined safety concerns as a technology-specific variable in a separate model, given that safety risks are frequently assumed to influence community responses to AWE. As shown in Table 3, acceptance was significantly correlated with each of the five IAM predictors; these variables were therefore entered as predictors in the regression model. Impacts on residents showed the strongest (negative) correlation with acceptance, followed by ‘fairness & transparency’ and social norms (both positive). Economic impacts and attitudes toward the energy transition were both moderately and positively correlated with acceptance. The correlation results align with the IAM's predictions. Safety concerns were also significantly correlated with acceptance and were therefore examined as an additional predictor in a second, exploratory regression model. The intercorrelations between the predictors ranged from 0.30 to 0.57 (all p's < 0.05), remaining below the threshold of 0.70, and the tolerance values in the regression model exceeded 0.1. This indicates that the predictors were sufficiently distinct (Hair et al., 2013).

3.2. Regression results

We estimated three models. First, we ran the regression model on the combined sample using the five IAM predictors. Second, given the small Irish subsample in the combined sample (n = 8), we re-estimated the

Table 2
Descriptive statistics of the IAM constructs for the German and Irish samples, separately and combined.

Variable	German			Irish			Combined		
	n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Acceptance of the local AWE site[a]	54	1.87	1.33	19	1.26	1.47	71	1.71	1.38
Impacts on residents[b]	54	1.12	1.16	11	1.91	1.51	65	1.29	1.30
Fairness & transparency[b]	47	2.10	1.17	17	1.98	1.23	64	2.07	1.17
Economic impacts[a]	52	0.29	0.77	19	−0.18	1.32	71	0.16	0.96
Social norms[a]	52	1.06	1.53	19	0.26	1.73	71	0.85	1.61
Attitudes toward the energy transition[a]	54	1.51	1.20	19	0.33	1.82	73	1.20	1.47
Safety concerns[b]	53	0.57	0.95	19	1.47	1.74	72	0.81	1.26

[a] Response scale: −3 to +3.
[b] Response scale: 0 to 4.

Table 3
Correlations between acceptance and the predictors in the combined sample.

Variable	*r*	*p*	*n*
Impacts on residents	−0.74	<0.001	64
Fairness & transparency	0.56	<0.001	63
Economic impacts	0.48	<0.001	70
Social norms	0.53	<0.001	70
Attitudes toward the energy transition	0.38	<0.001	72
Safety concerns	−0.38	<0.001	71

model using only the German subsample as a sensitivity check. Third, we estimated an exploratory model on the combined sample that added safety concerns to the IAM predictors.

1) **Main model.** The regression model with the IAM predictors was statistically significant and explained a substantial share of variance in acceptance ($R^2_{adj} = 0.69$, Table 4). Impacts on residents emerged as the strongest predictor of acceptance, followed by 'fairness & transparency'. Thus, residents' acceptance of the AWE site was most strongly predicted by reported annoyance from sound emissions, landscape impacts, and/or aviation lights, as well as by residents' evaluations of operational fairness and developer transparency. Social norms and attitudes toward the energy transition did not significantly predict acceptance in the regression model. While economic impacts did not reach conventional statistical significance ($p = .271$), the standardized coefficient (β = 0.271) suggests a potential association that may warrant further investigation.
2) **Sensitivity check.** We re-estimated the IAM model using only the German subsample (n = 43), which met the previously reported sample size threshold for 0.80 power. The key results remained substantively unchanged: impacts on residents (β = - 0.691) and 'fairness & transparency' (β = 0.270) continued to be statistically significant predictors with the same directional effects as in the combined sample. Effect sizes differed modestly, with a somewhat larger effect for impacts and a slightly smaller effect for 'fairness & transparency' in the German-only sample (seeTable A.1). Social norms, attitudes towards the energy transition, and economic impacts remained non-significant. The adjusted R^2 was somewhat higher, with 0.76. Taken together, this sensitivity check tentatively suggests that the Irish subsample does not drive the pooled associations.
3) **Exploratory model.** Finally, we estimated an exploratory model that included safety concerns in addition to the five IAM predictors (Table 5, n slightly reduced due to missing safety data). The overall pattern of results remained unchanged: Impacts on residents and 'fairness & transparency' were the only statistically significant predictors. Social norms, attitudes towards the energy transition, and economic impacts remained non-significant. Further, safety concerns did not significantly predict acceptance. In other words, although safety concerns were negatively correlated with acceptance, this association did not persist in the regression model, suggesting that safety concerns did not explain unique variance in acceptance beyond the core IAM predictors. Given the limited statistical power of this extended model, these results should be interpreted with caution.

4. Discussion

We pooled data from resident surveys at two AWE test sites to assess whether the Integrated Acceptance Model (IAM), which has successfully explained wind project acceptance, could also predict residents' attitudes toward AWE. Pooling the data helped achieve a large enough sample size to estimate an adequately powered regression model.

The IAM explained residents' acceptance of AWE sites, as evidenced by an adjusted R^2 of 0.69. However, this result primarily stemmed from two of the five included IAM predictors: perceived impacts on residents and 'fairness & transparency'. Perceived impacts on residents capture the degree of annoyance experienced from landscape impacts, sound emissions, and aviation lights. 'Fairness & transparency' reflects residents' perceptions of how fairly the site operation is and how

Table 4
Regression predicting the acceptance of local AWE sites with the IAM in the combined sample (n = 51; $R^2_{adj} = 0.69$).

Effect	Beta	*Robust SE*	95% CI		*p*
			LL	*UL*	
Intercept	1.768	0.462	0.838	2.698	<0.001
Impacts on residents	−0.538	0.169	−0.880	−0.197	0.003
Fairness & transparency	0.297	0.136	0.023	0.570	0.034
Economic impacts	0.271	0.218	−0.169	0.711	0.221
Social norms	0.076	0.092	−0.110	0.261	0.415
Attitudes toward the energy transition	0.034	0.105	−0.178	0.246	0.747

Note. SE = standard error; CI = confidence interval; *LL* = lower limit; *UL* = upper limit.

Table 5
Exploratory regression predicting the acceptance of local AWE sites with the IAM plus safety concerns in the combined sample (n = 50; $R^2_{adj} = 0.70$).

Effect	Beta	*Robust SE*	95% CI		*p*
			LL	*UL*	
Intercept	1.751	0.3542	1.038	2.465	<0.001
Impacts on residents	−0.558	0.112	−0.783	−0.332	<0.001
Fairness & transparency	0.331	0.123	0.084	0.579	0.010
Economic impacts	0.300	0.171	−0.045	0.644	0.087
Social norms	0.050	0.095	−0.141	0.241	0.601
Attitudes toward the energy transition	0.008	0.101	−0.196	0.212	0.936
Safety concerns	0.012	0.120	−0.230	0.255	0.918

Note. SE = standard error; CI = confidence interval; *LL* = lower limit; *UL* = upper limit.

transparently the developer communicates. Unlike prior applications of IAM in wind energy research (Hübner et al., 2023), residents' acceptance of the AWE sites did not depend on their attitudes toward the energy transition or the extent to which they perceived other community members as approving or disapproving of the site (i.e., social norms). Although economic impacts did not meet the statistical threshold for significance in the regression model ($p = .271$), the nearly medium-sized regression coefficient suggests that this factor may still relate meaningfully to acceptance. A sensitivity analysis excluding the Irish cases (n = 8) yielded the same pattern: impacts on residents and 'fairness & transparency' remained significant predictors with consistent directional effects. This pattern of results may reflect the fact that, at early-stage test sites, acceptance is primarily shaped by factors that residents can directly observe and experience. At the same time, it may also reflect that some relevant factors were not consistently tested across both sites (e.g., economic impacts, nature impacts) and that additional place-based variables may be needed to fully capture acceptance processes across regions.

The finding that economic impacts failed to achieve statistical significance in the regression could be explained by the fact that the variable was measured differently in the two studies, which could have introduced incongruency in the data: participants at the German site were asked to consider how a hypothetical commercial deployment of AWE in the region might affect the local economy. However, interviews revealed that respondents found it challenging to imagine these impacts. In response, participants at the Irish site assessed the actual impacts of the AWE test site on specific economic sectors, including agriculture, tourism, property values, and other branches. Due to its remote location in the peatlands and temporary, non-commercial operation, the test site had little impact on the first three sectors. Furthermore, residents might not have been aware of the test site's limited but real economic contributions to other sectors, such as employing two local workers and supporting local businesses through staff's use of amenities like shops and accommodation (DEM-AWE, n.d.). The relatively neutral ratings in both studies suggest uncertainty about tangible economic impacts, which may help explain why this variable did not significantly predict local acceptance.

One possible explanation for the lack of explanatory power of energy transition attitudes is that AWE is not yet commercialized and, as a result, is not seen as contributing to renewable energy goals (BVG Associates, 2022). For example, electricity generated at the Irish site was stored in on-site batteries rather than fed into the grid (DEM-AWE, n.d.). Additionally, due to AWE's relative immaturity, laypeople find it challenging to estimate how much energy it can produce and whether it could substantially contribute to the energy transition. (Schmidt et al., 2024). In general, while established wind energy is a cornerstone of the energy transition, the addition of AWE represents a change to the current transition paradigm. It is therefore plausible that attitudes towards the energy transition affect the acceptance of AWE differently from those towards established wind energy.

Regarding social norms, prior research has shown that residents opposing a planned wind energy project tend to be more vocal and active than those who support it or are neutral (Firestone et al., 2018; Hübner et al., 2020; Liu et al., 2022; Sokoloski et al., 2018). By openly presenting its concerns, the so-called loud opposing minority gains the attention of the local public and media more easily, thereby shaping the discourse about a project (Bednarek-Szczepańska, 2023; Bjärstig et al., 2022; Diamond et al., 2024). The distorted discourse can negatively influence public opinion and the perception of prevailing local norms regarding renewable developments (Read et al., 2013; Sokoloski et al., 2018). However, due to their smaller scale, temporary nature, and limited operational hours, it can be assumed that the AWE test sites were less subject to public debate than the average commercial wind farm. Residents may, therefore, find it more challenging to assess how other community members view the site. This difficulty became evident during the interviews with participants at the German site, where no public planning process had taken place, and thus there had been no formal forum for people to be exposed to others' opinions. While the planning process for the Irish site was public, the COVID-19 pandemic limited the community engagement that could take place. Additionally, as test sites do not generate profits, concerns about unequal benefit distribution, which often dominate discourses around commercial wind projects, are less prominent (Baxter et al., 2013; Brannstrom et al., 2022; Leer Jørgensen et al., 2020). These circumstances might explain why social norms did not predict the acceptance of the AWE sites.

Despite the markedly different planning processes – no formal public participation at the German site versus a standard public consultation process at the Irish site – procedural aspects were evaluated as somewhat fair and transparent at both locations. This finding suggests that regional and contextual factors influence the perception of fairness. The relatively positive evaluation of procedural aspects at the German site, despite the lack of formal participation, may be attributed to the favorable context in North Frisia, Germany. The region has a long, positive history of renewable energy projects, characterized by high levels of local ownership. This history has fostered perceptions of both procedural and distributive fairness, leading to generally more favorable attitudes toward renewable energy and the energy transition (Chezel & Nadaï, 2019; Süsser & Kannen, 2017). Residents' positive views on local energy projects likely transferred to the evaluation of the AWE test site. Furthermore, the credibility of the local mayor, who played a prominent role in realizing the AWE test site and making the region a leader in community-owned renewable energy, may have positively influenced residents' perception of the site's fairness (Karakislak & Schneider, 2023).

In contrast, the evaluation of procedural fairness at the Irish site, despite the public planning process, may be negatively impacted by broader frustrations with the energy transition in Ireland. Plans for large-scale wind energy export and the rapid shift away from peat-based electricity have caused widespread discontent due to a perceived lack of distributive and procedural justice (Banerjee & Schuitema, 2022; Brennan et al., 2017; Lennon & Scott, 2017). Additionally, the area around the Irish site has a long history of resistance to energy projects, including wind farms (Siggins, 2018; Slevin, 2019; SLR Consulting et al., 2014). Public discontent with past projects and the transition as a whole could spill over to new renewable technologies like AWE and local pilot projects (Cuppen et al., 2020). Since the developer of the Irish site was, at the time of data collection, a multinational company pushing for large-scale wind deployment in Ireland, residents may hold a less favorable view, despite the formal public planning process. With this in mind, it is important to re-emphasize that the pooled regression describes the *associations* observed in the combined sample. The contextual differences between sites are discussed here to interpret the *descriptive pattern* in procedural evaluations and to underscore that place-based factors, such as trust in responsible actors, place attachment, and prior experiences with energy projects, may help explain additional variation in acceptance beyond the constructs examined here.

In an exploratory model, we added safety concerns as a technology-specific predictor, as safety risks are often considered a key acceptance barrier in the technical and economic AWE literature (Schmidt et al., 2022). In the combined sample, safety concerns were negatively correlated with acceptance but did not predict it. This is an important empirical finding because safety is often emphasized as a barrier to acceptance in the engineering field, yet it has rarely been empirically tested among residents. The findings suggest that, in these test-site contexts, perceived safety risks did not explain unique variance beyond more proximal predictors, such as experienced impacts and 'fairness & transparency". However, qualitative findings from the German study indicate that residents' understanding of the AWES varied considerably, including misconceptions about its components, such as the assumption that the kite consists only of fabric and would therefore be harmless in a crash, despite a heavy control unit suspended beneath it (Schmidt et al., 2024). This may have introduced uncertainty into the measurement of safety concerns. Moreover, although the sample size met the threshold for a power of 0.80, it was still constrained by the inclusion of an additional predictor and by a lack of safety data for one case. This result should, therefore, be interpreted cautiously.

Overall, residents' acceptance was primarily related to factors they could directly observe, such as the site impacts they experienced and their perception of the site's fairness and the developer's transparency. Other factors important for the acceptance of mature wind energy, such as social norms emerging from public discourse and the technology's role in the energy transition, may lack sufficient tangibility or visibility for AWE at this stage. Taken together, our findings suggest that the IAM provides a useful parsimonious starting point for studying the acceptance of AWE in this early-stage phase, while also indicating that the relative importance of its categories may be stage- and context-dependent. The IAM is not explicitly intended for nascent technologies. Still, it is technology-agnostic and can be adapted to the context, for example, by specifying technology-relevant impact items (e.g., aviation lights) under the 'impacts' category or by tailoring the 'planning process' category to the local permitting situation. In this early, low-salience setting, proximal factors (i.e., experienced impacts and perceived transparency/fairness) appeared to outweigh distal factors (i.e., energy-transition attitudes; perceived social norms). It is therefore plausible that the IAM's categories are applicable to novel technologies like AWE with relative weights that may shift as technologies move from testing to commercial operation. If AWE technologies move toward commercial deployment with formal participation and grid connection, current distal factors may become increasingly important.

At the same time, the present findings may also reflect that some relevant constructs could not be tested here (e.g., nature impacts across both sites), and that additional place-based variables may be needed to fully capture acceptance processes in cross-context comparisons. Prior research shows that renewable energy projects are often evaluated through a "place lens": residents consider whether a development aligns with local landscape meanings and identity (e.g., rurality, heritage, or tranquility), and whether it compromises valued characteristics of place (Devine-Wright, 2009; Devine-Wright & Peacock, 2024; Lambert, 2022; Međugorac & Schuitema, 2023; Wheeler, 2017). Place attachment and place identity can therefore shape acceptance, and may also moderate how residents respond to perceived impacts and to procedural fairness. This is particularly relevant in cross-context studies, as in this case, where differences in planning histories and prior experiences with energy projects can shape place meanings and trust. Future studies on AWE should incorporate place-based measures (e.g., place attachment/identity) to test these mechanisms directly.

Several limitations should be considered when interpreting these results. At this stage of technology development, active AWE test sites are located in sparsely populated areas rather than near densely populated residential settlements, resulting in small sample sizes per site. To increase power in multiple regression, we pooled data from two sites. While the German-only sensitivity analysis yielded the same substantive pattern of results, it should be interpreted cautiously given the modest sample size. We therefore cannot fully rule out site-specific influences on the relationships between predictors and acceptance. Although the total sample size was sufficient to achieve a statistical power of 0.80, a larger sample would have been needed for a more robust power of 0.95. Additionally, nature impacts – moderately correlated with acceptance in the German study (Schmidt et al., 2024) – were not measured in the Irish study and thus could not be included in the regression analysis. Insights from the German study suggest that at the test-site stage, residents may find it difficult to assess nature impacts due to limited visible evidence and information, which can make such ratings less stable than more directly experienced impacts. Nonetheless, nature impacts, particularly bat and bird mortality, remain central to public debates on wind energy (Baxter et al., 2013; Brannstrom et al., 2022; Frantál et al., 2023; Nordstrand Frantzen et al., 2023; Wilson & Dyke, 2016), and while AWE may pose less risk to wildlife than traditional wind turbines, future research should explore how perceptions of environmental impacts affect acceptance of AWE (Schmidt et al., 2022). Moreover, we did not measure place attachment or place identity, which may be relevant when comparing acceptance processes across different national and planning contexts (Devine-Wright & Peacock, 2024). Finally, in assessing residents' reported annoyance with site impacts, we did not account for stress complaints, which are a more accurate indicator of stress response (Hübner et al., 2019; Pohl et al., 2018). Consequently, the study may have overestimated the effect of landscape impacts, sound emissions, and aviation lights on residents.

As AWE is still emerging, it is plausible that other factors, which are less relevant to mature wind turbine technology, are important. For example, as suggested earlier, residents' belief in AWE's potential may be more predictive than their energy transition attitudes at this stage and place-based approaches could offer additional insights. Future research should thus explore which other variables can help predict community acceptance of AWE test sites beyond resident impacts and 'fairness & transparency'. Furthermore, future studies should apply the IAM to larger samples across AWES types and in different regions to test the replicability and generalizability of these findings. If AWE technologies move closer to commercialization and begin to impact local economies and contribute to energy goals, it would be relevant to investigate whether variables such as economic impacts and energy transition attitudes become more predictive of acceptance. Given that AWE might initially especially be deployed in island nations, remote communities, and the Global South, it would be valuable to investigate if and how the IAM would have to be adapted to explain acceptance in non-Western and indigenous contexts (BVG Associates, 2022; Krupnik et al., 2022; SkySails Power, 2023b). Indigenous communities commonly oppose wind energy projects because these projects often disregard traditional beliefs and knowledge, fail to respect tribal ways of life, and threaten natives' reliance on natural resources and land for survival (Kim et al., 2018; Lakhanpal, 2019; Normann, 2021; Ulloa, 2023). As a result, wind energy development in tribal areas is associated with neocolonial and extractive practices, including land grabbing and the perpetuation of existing environmental and social injustices (Cormack & Kurewa, 2018; Normann, 2021; Ulloa, 2023; Zárate-Toledo et al., 2019).

In summary, while resident impacts and 'fairness & transparency' emerged as significant predictors of local acceptance, additional research is needed to identify other relevant factors, especially as AWE evolves and scales up.

5. Conclusions and policy implications

To date, AWE suppliers have predominantly concentrated on the technical, economic, and policy dimensions of technology development and deployment, which is understandable given the industry's race toward commercialization. Suppliers are pressured to address remaining technological challenges, secure necessary investments, and navigate the regulatory void, particularly regarding airspace regulations (BVG Associates, 2022; Salma & Schmehl, 2023). However, assuming that community acceptance of AWE sites will naturally follow once these technical and policy hurdles are overcome may be misguided.

Our findings indicate that residents who experience greater negative impacts from AWE test sites and are dissatisfied with the developer's transparency and fairness of site operations tend to be less accepting of the sites. These results are consistent with established research on other renewable energy technologies, such as wind farms, where project impacts and procedural justice aspects have been shown to play a crucial role in local acceptance. Conceptually, our results tentatively suggest that the IAM can be applied to emergent technologies, and are consistent with a possible stage-dependent pattern in which more proximal factors are more salient than more distal ones in early-stage contexts. At the same time, these findings should be interpreted with caution, given the small sample size and the omission of potentially relevant variables (e.g., place attachment), which may also shape acceptance.

Addressing social considerations is vital to AWE's long-term success. Social science insights can contribute to designing and implementing AWE in ways that are both technically viable and socially acceptable. Specifically, AWE developers could leverage R&D projects to conduct interdisciplinary studies exploring residents' perceptions of various impacts, the factors driving annoyance, and potential prevention and mitigation measures (for an interdisciplinary study on wind turbines, see Gaβner et al., 2022; Müller et al., 2023). The evolution of wind energy has demonstrated the importance of early-stage research into the social and environmental impacts, leading to more effective mitigation strategies and regulations (Bulling et al., 2015; Pohl et al., 1999, 2012, 2018).

In line with this, the AWE sector should adopt empirically derived and standardized measures of annoyance from social science to achieve three key outcomes: (1) ensuring consistency across studies (e.g., the acceptance stress scale by Pohl et al., 2018), (2) facilitating the implementation of regulations, for example, for sound emissions, that extend beyond a purely technical fix and address the social dynamics of AWE deployment (Kirkegaard et al., 2023), and (3) improving the monitoring of regulatory compliance in AWE projects.

Beyond mitigating or compensating for impacts on residents, our findings emphasize the importance of establishing socially responsible deployment practices. AWE developers should draw from best-practice guidelines in the wind energy sector to make their planning processes more inclusive, transparent, and open, particularly if there are no formal public engagement requirements for test sites. Additionally, emerging social science research can help identify specific characteristics of AWE, such as airspace conflicts, that may require special attention in community engagement efforts.

Given the established links between distributive and procedural justice and acceptance of renewable energy projects, AWE developers should consider implementing ownership and benefit-sharing schemes to support a fair distribution of project profits. The industry association Airborne Wind Europe could advocate for broader regulatory guidance, at least at the European level, and encourage developers to voluntarily offer financial benefits. For example, by establishing a quality mark for especially fair developers, as is done for wind energy in some regions (Thüringer Energie- und GreenTechAgentur, n.d.). However, financial compensation alone is unlikely to be sufficient; its effectiveness depends on aligning the options offered with the community's specific needs (e.g., level of financial risk), resources (e.g., financial strength), and perceptions of fairness and trust in the developer (Knauf & le Maitre, 2023).

In conclusion, if AWE technologies advance toward commercialization, regulatory bodies should consider implementing evidence-based, AWE-specific regulations to support socially responsible and minimally intrusive deployment. Addressing both the technical and social dimensions of AWE increases the likelihood of achieving broader acceptance while safeguarding the well-being and interests of local communities.

CRediT authorship contribution statement

Helena Schmidt: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Florian J.Y. Müller:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Valentin Leschinger:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Gerdien de Vries:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Roland Schmehl:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Reint Jan Renes:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Gundula Hübner:** Writing – review & editing, Supervision, Resources, Methodology, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this article, the authors used Grammarly and ChatGPT to improve its readability and fluency. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships, which may be considered potential competing interests: Roland Schmehl reports a relationship with the Dutch airborne wind energy developer Kitepower B.V., including board membership and equity or stock ownership.

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Appendix A

Table A.1
Sensitivity analysis predicting the acceptance of local AWE sites with the IAM in the German sample (n = 43; $R^2_{adj} = 0.76$)

Effect	Beta	*Robust SE*	95% CI *LL*	95% CI *UL*	*p*
Intercept	2.088	0.386	1.305	2.870	<0.001
Impacts on residents	−0.691	0.134	−0.962	−0.420	<0.001
Fairness & transparency	0.270	0.129	0.008	0.531	0.044
Economic impacts	0.203	0.246	−0.295	0.701	0.414
Social norms	0.072	0.081	−0.092	0.236	0.379
Attitudes toward the energy transition	0.023	0.093	−0.166	0.211	0.808

Note. SE = standard error; CI = confidence interval; *LL* = lower limit; *UL* = upper limit.

Data availability

The datasets underlying the manuscript can be found online at https://doi.org/10.4121/fc1e49ca-08b6-435d-9888-a73f334edd92 (Study 1) and https://doi.org/10.4121/0025d61e-f405-4747-96a7-ff49a3ce7ddf (Study 2).

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