

## Research article

## Community preferences and expectations for end-of-life management strategies of wind farms: A prospective study

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## ABSTRACT

In this study, we examined resident preferences for prospective end-of-life management of a coastal wind farm in Japan through a case study of an 11-turbine, 22 MW installation, based on a questionnaire survey of 218 households within a 4 km radius. Respondents were presented with four disposition options: repowering with unchanged capacity (56.9%), repowering with increased capacity (18.8%), decommissioning (15.1%), and lifespan extension (9.2%). Preferences were examined through perceptual, attitudinal, and demographic lenses, though inferential support remained limited across several predictors. Descriptively, negative impressions were concentrated among decommissioning proponents, yet inferential testing showed no significant predictive effect for visual or acoustic evaluations. Principal component analysis consolidated perceptual dimensions, and binary logistic regression indicated that disaster-risk cognition alone significantly predicted support for active reconstruction, whereas mitigation measures and noise annoyance were statistically non-significant. Analysis of variance followed by Tukey's honestly significant difference post-hoc tests revealed significant yet modest differences in expectations for post-operational attributes—such as landscape harmony, tourism attraction, information transparency, proper explanations, and blade length—across preference groups, though effect sizes remained limited. No demographic or geographic variables were significantly associated with end-of-life preferences, indicating limited explanatory power of conventional socio-spatial characteristics. These findings highlight the limited role of demographic determinants and the importance of disaster-risk cognition and procedural fairness in shaping wind farm end-of-life strategies. They also underscore the need to incorporate local perspectives into policy frameworks through transparent communication, locally adaptive mitigation, and sustained stakeholder engagement.

## 1. Introduction

Wind energy has emerged as a key renewable energy source owing to its potential to reduce carbon emissions, promote sustainable development, and mitigate the impacts of climate change (Kasner, 2022). There have been substantial global investments in wind energy projects in response to these benefits, including initiatives such as Japan's Basic Energy Plan and the Yokohama Offshore Wind Project (Boyd et al., 2022; Vetter et al., 2025). Despite its promise as a solution to climate change, the expansion of wind farms has raised environmental and social concerns, particularly regarding their impact on nearby residents' daily lives

and well-being. Notable concerns include noise pollution, visual disruptions, and shadow flicker, all of which can affect quality of life in local communities (Nishikizawa et al., 2013; Windemer, 2019). While some studies show that residents may adapt to these disturbances over time (Freiberg et al., 2019), potentially leading to improved social acceptance, effective public engagement and transparent communication remain essential for fostering community support (Vetter et al., 2025).

Current research focuses primarily on wind farms' planning, construction, and operational phases, with relatively limited attention paid to resident preferences regarding the post-operational disposition of these facilities (Agra Neto et al., 2024). As wind farms approach the end

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### Abbreviations

WT      wind turbines

of their operational lifespans or enter the decommissioning phase, decisions regarding their future, whether through decommissioning, repowering (with unchanged or increased capacity), or lifespan extension, become critical for the wind energy sector (Boyd et al., 2022; Leite et al., 2022). These decisions entail complex tradeoffs involving technical, economic, and social considerations, with substantial implications for local communities (Jadali et al., 2021a; Piel et al., 2019). Recognizing that local interests may not always align with commercial or environmental goals is essential. Although residents' sensitivity to wind farm impacts is assumed to diminish over time owing to increased familiarity (Zhang et al., 2025), this assumption overlooks the emergence of subjective preferences when confronted with alternative disposition options (Mikindani, 2024).

Motivated by this gap in the literature, we address three primary objectives in this study: (1) quantify residents' preferences regarding the future end-of-life management of wind farms: decommissioning, repowering (unchanged/increased capacity), and lifespan extension; (2) examine how residents' perceptions and affective responses to existing wind farms influence their favored end-of-life management pathways; and (3) assess how expectations for future wind farm development vary among residents with different end-of-life management preferences.

The following hypotheses guided this study.

**H1.** The valence of residents' risk- and institution-related cognitive evaluations of existing wind farms—specifically perceived disaster-risk controllability, trust in governance arrangements, and procedural legitimacy—positively predicts preference for non-decommissioning pathways (lifespan extension or repowering) over decommissioning (Agra Neto et al., 2024).

**H2.** Positive experiences, such as perceived economic and environmental benefits, are positively associated with preference for non-decommissioning pathways (lifespan extension or repowering) over decommissioning (Jadali et al., 2021a; Stetter et al., 2020).

**H3.** Residents' affective and sensory responses—particularly emotional reactions to noise annoyance, shadow-flicker disturbance, and perceived visual intrusion from existing wind farms—negatively predict preference for non-decommissioning pathways (i.e., are associated with greater decommissioning preference) (Windemer, 2019).

**H4.** Systematic differences in expectations for future wind farm development will emerge among residents with varying end-of-life management preferences (Jadali et al., 2021b).

A case study approach was adopted, focusing on a coastal wind farm in Japan that has been operational for an extended period and is nearing a decision point regarding its future. We investigate the factors shaping residents' preferences for wind farm disposition, considering both direct experiences with current wind farm impacts and broader social and environmental contexts. By examining how geographical, social, and environmental factors influence local perceptions and preferences, this study offers a nuanced understanding of the relationship between residents' lived experiences and wind energy management decisions (Mikindani, 2024; Silveira and Weschenfelder, 2021).

Ultimately, we seek to develop a comprehensive framework to guide the future disposition of wind farms by integrating technical, economic, and social factors (Stetter et al., 2020). The findings are expected to inform decision-making processes in wind energy development by aligning community preferences with commercial and environmental objectives, thereby promoting the long-term sustainable growth of the wind energy sector and ensuring positive community engagement and

coexistence.

## 2. Concept of end-of-life management strategies for onshore wind farms (including coastal cases)

### 2.1. End-of-life management strategies for onshore wind farms (including coastal contexts)

The typical operational lifespan of a wind turbine is approximately 20 years, during which time it maintains high efficiency and delivers renewable energy to regional power grids. As more turbines approach the end of their design life, effective management of wind energy facilities has become increasingly critical. Three main strategies are available at the end-of-life stage: decommissioning, lifespan extension, and repowering (Agra Neto et al., 2024).

Decommissioning involves systematically dismantling turbines and restoring sites to their original environmental conditions. This option is usually chosen when turbines are no longer economically viable or when environmental constraints prevent continued operation. Potential consequences include reduced energy supply, loss of local employment, and economic impacts on communities that depend on wind farms (Hall et al., 2020; Stripling, 2016).

Repowering with unchanged capacity replaces aged turbines with new models of similar size and output. This approach enhances operational efficiency and reduces maintenance costs without altering the overall capacity of the wind farm. Advances in turbine design and favorable cost considerations have made this an attractive option for achieving sustained performance (Mikindani, 2024). However, in practice, this approach may be constrained by the limited availability of older turbine models, which are often no longer manufactured, as well as challenges in sourcing compatible components or spare parts (Behford et al., 2015; Nguyen et al., 2013; Schouten et al., 2022).

Repowering with increased capacity replaces existing turbines with larger or more powerful units, boosting total site output. While this significantly increases energy production, it can also intensify environmental impacts, such as greater noise, altered visual landscapes, and more pronounced shadow flicker, potentially affecting community acceptance (Philpott and Windemer, 2022). In addition, the installation of larger turbines may impose higher structural loads, and existing foundations may not be adequate to support these loads, potentially requiring reinforcement or replacement and thus leading to increased capital costs (Nguyen et al., 2013; Sahyouni and Briancon, 2022).

In addition to the above approaches, repowering can also be implemented by installing larger turbines while maintaining the total installed capacity, resulting in a reduced number of turbines. This configuration may lead to different visual landscape effects due to changes in turbine density and spacing, and could also influence environmental impacts and public acceptance (Lantz et al., 2013; Meyerhoff et al., 2010; Molnarova et al., 2012).

Lifespan extension retains the original turbines but introduces enhanced maintenance protocols, technological upgrades, or component modifications to prolong their service life. Although this avoids the immediate capital costs of replacement, it entails higher ongoing maintenance expenses and may lead to a gradual decline in efficiency as equipment ages (Amiri et al., 2019).

Overall, the effective end-of-life management of onshore wind farms requires balancing technical performance, economic viability, environmental protection, and policy objectives to ensure the long-term sustainability of the wind energy infrastructure (Leite et al., 2022).

### 2.2. Determinants of residents' preferences for end-of-life management strategies for wind farms

The determinants of community preferences concerning end-of-life management strategies for wind farms encompass a broad spectrum of economic, environmental, sociopolitical, and technological factors.

Economic considerations are particularly significant in regions where local economies rely heavily on wind energy projects. Wind farms create substantial employment, enhance tax revenues, and stimulate regional economic growth. Conversely, the decommissioning of these installations often results in job losses and diminished fiscal support for local governments, which may incentivize communities to favor continued operation (Agra Neto et al., 2024). Moreover, the lifecycle costs of wind farms, including decommissioning, recycling, and environmental remediation, play a pivotal role in local decision-making. When both immediate and long-term economic benefits are evaluated, community attitudes may shift toward favoring lifespan extension or selective repowering (Stetter et al., 2020).

Environmental factors are key determinants (Nishikizawa et al., 2013). Concerns regarding the degradation of bird habitats, disruption of local biodiversity, and adverse impacts on terrestrial ecosystems often motivate preferences for decommissioning (Hall et al., 2020). Regions that prioritize climate change mitigation incorporate a sustainability framework into their evaluations, recognizing long-term environmental benefits that may offset localized ecological disturbances (Kasner, 2022). The adoption of site optimization and wildlife mitigation measures, such as bird-friendly turbine designs, has been shown to enhance community support for continued wind energy operations.

Sociopolitical factors further complicate community decision-making. Robust local government support, inclusive policy frameworks, and active public participation in decision processes correlate with greater acceptance of ongoing wind energy development (Windemer, 2019). Regions characterized by proactive political engagement and strong social identity tend to favor strategies that extend operational life or enable repowering, whereas areas with limited government backing are more likely to support decommissioning.

Technological advancements have reshaped discussions around end-of-life strategies. Innovations that enhance turbine efficiency, reduce maintenance costs, and support predictive maintenance can strengthen the economic feasibility of lifespan extension. Retrofit solutions such as blade optimization and digital monitoring systems have been successfully applied to prolong turbine service life and reduce the urgency of decommissioning (Amiri et al., 2019). Thus, technological progress and

rigorous cost-benefit assessments are increasingly considered critical factors in community evaluations of end-of-life options.

Despite substantial research on wind energy's economic, environmental, sociopolitical, and technological aspects, a gap remains in exploring residents' preferences for end-of-life management strategies. Most studies have focused on the general acceptance of wind energy rather than on the nuanced, resident-centered evaluation of decommissioning, repowering, or lifespan extension (Agra Neto et al., 2024). This study was designed to systematically assess the factors influencing community preferences in the context of a Japanese coastal wind farm, where long-term interactions with the wind energy infrastructure provide a unique empirical setting for understanding these dynamics.

### 3. Methodology

#### 3.1. Study areas

This study was conducted at Wind Farm A (Fig. 1), operated by Company B and located in City A. The wind farm comprises 11 turbines with a total installed capacity of 22 MW. The first three turbines were commissioned in 2010, followed by an additional eight turbines in 2011. The turbines were SUBARU80/2.0, each with a rated capacity of 2 MW, hub height of 80 m, and rotor diameter of 80 m. As part of Japan's broader renewable energy strategy, Wind Farm A plays a significant role in supporting the region's clean energy production (Topham et al., 2019).

#### 3.2. Survey and questionnaire description

One thousand questionnaires were distributed to households within a 4 km radius of a wind farm, yielding 218 responses (response rate 21.8%). The questionnaires were distributed between December 2 and 4, 2024. Data collection, including response submission and retrieval, was completed within three weeks following the distribution period. Households were selected based on residential zoning information provided by Zenrin maps. The study area was divided into multiple zones according to the Zenrin residential map classification, and the

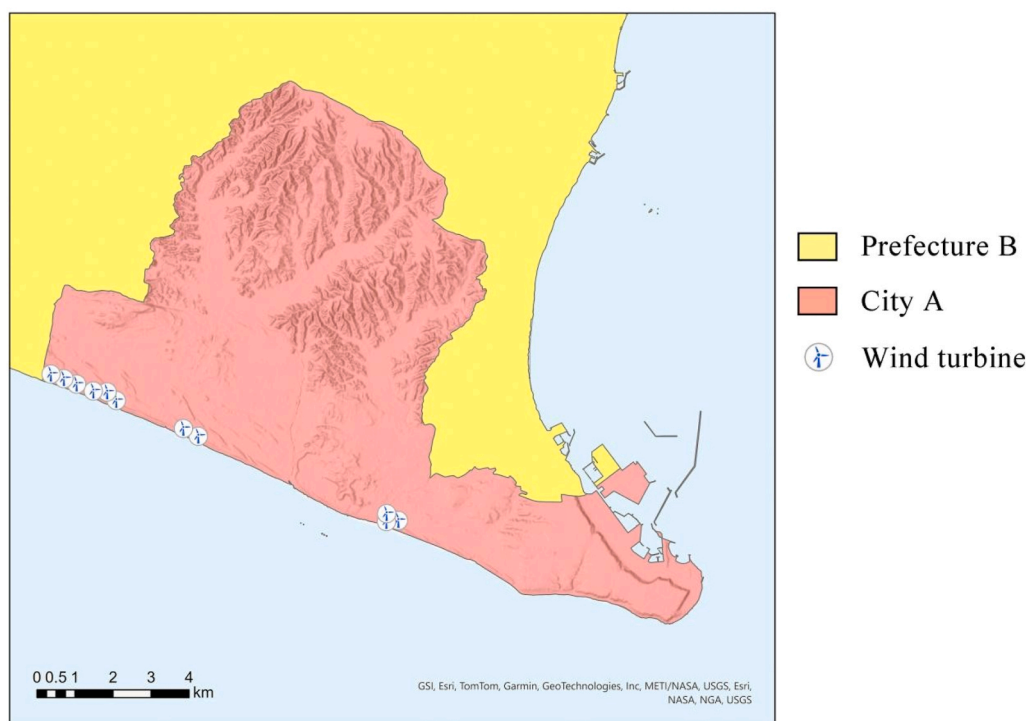


Fig. 1. Location map of Wind Farm A in Japan.

number of questionnaires distributed in each zone was proportionally allocated based on the number of households within each zone, in order to ensure spatial representativeness. Within each zone, households were randomly selected for questionnaire distribution. During distribution, GPS coordinates were recorded for all households, and the corresponding altitudes were obtained using the Google Maps API. The overall survey period therefore covered both the distribution phase and the subsequent response collection period. The coordinates of the wind turbines were sourced from official websites and Google Maps. Euclidean distances between households and the nearest wind turbines within a 4 km radius were computed using the proximity tool in ArcGIS Pro 3.0.1 (ESRI). All geospatial operations and analyses were conducted using ArcGIS Pro 3.3.0, a desktop software package (Haac et al., 2022; Voicescu et al., 2016). Although the total population size of the study area was not explicitly determined, the sampling design was intended to reflect the spatial distribution of households within the 4 km radius. Given the site-specific nature of the study, the sample size and spatial concentration are considered appropriate for analyzing local perceptions, although they may limit the generalizability of the findings.

As outlined in Table 1, the questionnaire was designed to gather comprehensive data on public perceptions of and attitudes toward wind farms. It was structured into several thematic categories: visibility and sighting of wind farms, perceptions of current wind farm attributes, attitudes toward wind farms, preferences for future wind farm characteristics, concerns related to climate change and energy preferences, and demographic information. These categories address various factors influencing the acceptance and impact of wind energy projects, drawing on the existing literature on social acceptance and community perceptions of renewable energy infrastructure (Westerlund, 2020).

The “visibility and sighting” section investigated how the visual presence of wind farms influences local perceptions. Questions in this section focused on whether respondents could see wind turbines from their homes, how frequently they observed them, and the temporal context of their first and most recent sightings. Existing research has highlighted the impact of visual exposure in shaping public attitudes toward renewable energy infrastructure, particularly wind farms (Haac et al., 2022; Cranmer et al., 2023; Schäffer et al., 2019).

The “perceptions of current wind farm attributes” section assessed views on the broader environmental, economic, and social impacts of wind farms. This section explored perceptions regarding the effectiveness of wind farms in mitigating greenhouse gas emissions, enhancing local energy self-sufficiency, and stimulating regional economic development. The impact of wind farms on local communities, including their effects on tourism, economic activity, and potential concerns such as noise and shadow flickering, has been an essential focus of recent research (Bošnjaković et al., 2024; Müller et al., 2023; Peri et al., 2020).

The “attitudes toward wind farms” section gauged the level of support or opposition toward wind farms, which is a key indicator of public acceptance. Extensive studies have documented the relationship between public attitudes and support for wind energy projects. Research has consistently shown that individuals residing closer to wind farms are more likely to express frequent opposition because of concerns about the visual impacts, noise, and perceived environmental consequences (Voicescu et al., 2016; le Maitre et al., 2024; Pouta et al., 2024).

The “preferences for future wind farm characteristics” section focused on the factors prioritized by respondents when considering future wind farm projects. This section explored the importance of various factors such as noise impact, shadow flicker, bird collisions, and landscape integration. Research has emphasized that the design and siting of wind turbines, including their size, proximity to residential areas, and potential effects on local wildlife, are critical factors shaping public attitudes toward future wind energy development (Schäffer et al., 2019; Ata Teneler and Hassoy, 2024; Brudermann et al., 2019; van Kamp and van den Berg, 2018).

The “end-of-life management options” section addressed concerns about the future of wind farms once they reach the end of their

**Table 1**

All questions and options from the questionnaire.

| Category                                    | Questions (key words)        | Coding                                                                                                                  |
|---------------------------------------------|------------------------------|-------------------------------------------------------------------------------------------------------------------------|
| Visibility and sighting                     | Visibility of wind farms     | 1: No; 2: Yes                                                                                                           |
|                                             | Visibility from home         | 1: No; 2: Yes                                                                                                           |
|                                             | Frequency of visibility      | 1: Other<br>2: At least once per year<br>3: At least once per month<br>4: At least once per week<br>5: Almost every day |
|                                             | First sighting               | 1: <1 year ago; 2: 1–4 years ago;<br>3: 5–9 years ago; 4: 11–14 years ago; 5: >15 years ago                             |
|                                             | Initial landscape perception | 1: Negative; 2: Somewhat negative;<br>3: Neutral; 4: Somewhat positive; 5: Positive                                     |
|                                             | Most recent sighting         | 1: <1 week; 2: 1 week to 1 month;<br>3: 1 month to 6 months; 4: 6 months to 1 year; 5: Other                            |
| Perceptions of current wind farm attributes | Recent landscape perception  | 1: Negative; 2: Somewhat negative;<br>3: Neutral; 4: Somewhat positive; 5: Positive                                     |
|                                             | Greenhouse gas reduction     | 1: Not at all<br>2: Hardly<br>3: Neutral<br>4: Somewhat<br>5: Very much                                                 |
|                                             | Energy self-sufficiency      |                                                                                                                         |
|                                             | Tourism increase             |                                                                                                                         |
|                                             | City symbol                  |                                                                                                                         |
|                                             | Economic activation          |                                                                                                                         |
|                                             | Noise perception             |                                                                                                                         |
|                                             | Noise annoyance              |                                                                                                                         |
|                                             | Shadow flicker perception    |                                                                                                                         |
|                                             | Shadow flicker annoyance     |                                                                                                                         |
|                                             | Bird collision concern       |                                                                                                                         |
|                                             | Bird collision problem       |                                                                                                                         |
|                                             | Disaster damage concern      |                                                                                                                         |
|                                             | Disaster safety              |                                                                                                                         |
|                                             | Mitigation measures          |                                                                                                                         |
|                                             | Consultation opportunity     |                                                                                                                         |
|                                             | Trust relationship           |                                                                                                                         |
|                                             | Community contribution       |                                                                                                                         |
|                                             | Attitude toward wind farms   | 1: Do not support<br>2: Hardly support<br>3: Neutral<br>4: Support somewhat<br>5: Support                               |
| Attitude                                    |                              |                                                                                                                         |
| Expectations of future wind farms           | Noise impact                 | 1: Not important<br>2: Hardly important<br>3: Neutral<br>4: Somewhat important<br>5: Important                          |
|                                             | Shadow flicker impact        |                                                                                                                         |
|                                             | Bird collision               |                                                                                                                         |
|                                             | Landscape harmony            |                                                                                                                         |
|                                             | Greenhouse gas reduction     |                                                                                                                         |
|                                             | Economic development         |                                                                                                                         |
|                                             | Tourism attraction           |                                                                                                                         |
|                                             | Local financial support      |                                                                                                                         |
|                                             | Information transparency     |                                                                                                                         |
|                                             | Proper explanations          |                                                                                                                         |
|                                             | Resident feedback            |                                                                                                                         |
|                                             | Turbine quantity             |                                                                                                                         |

(continued on next page)

**Table 1** (continued)

| Category          | Questions (key words)                                                                 | Coding                                                                                                                                       |
|-------------------|---------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| Preference option | Turbine height<br>Blade length<br>Distance from home<br>End-of-life management option | 1: Lifespan extension (unchanged capacity)<br>2: Repowering (unchanged capacity)<br>3: Repowering (increased capacity)<br>4: Decommissioning |
| Demographics      | Gender                                                                                | 1: Man; 2: Woman; 3: Other                                                                                                                   |
|                   | Age                                                                                   | 1: 10s; 2: 20s; 3: 30s; 4: 40s; 5: 50s; 6: 60s; 7: Above 70                                                                                  |
|                   | Occupation                                                                            | 1: Agriculture; 2: Fisheries; 3: Electric power; 4: Unemployed; 5: Other                                                                     |
|                   | Residence duration                                                                    | 1: <1 year; 2: 1–5 years; 3: 5–10 years; 4: 10–15 years; 5: >15 years                                                                        |
|                   | Elevation                                                                             | 1: 0–10m; 2: 10–20m; 3: 20–30m; 4: 30–40m; 5: 40–50m; 6: 50–60m                                                                              |
|                   | Distance to turbine                                                                   | 1: 0–500m; 2: 500–1000m; 3: 1000–1500m; 4: 1500–2000m; 5: 2000–2500m; 6: 2500–3000m; 7: 3000–3500m; 8: 3500–4000m                            |

operational lifespan. We examined the attitudes toward strategies such as lifespan extension, repowering, and decommissioning. The management of wind farm decommissioning and repowering processes is an increasingly salient topic in renewable energy studies, with a growing emphasis on sustainable and socially acceptable approaches to wind farm end-of-life management (Windemer, 2023). The implications of decommissioning and the potential for repowering with increased capacity are key issues in maintaining the long-term viability and public acceptance of wind farms (Fois et al., 2022).

Demographic information provided key background data on the respondents, including gender, age, occupation, and distance from wind turbines. These demographic factors are essential for understanding the variations in public attitudes toward wind farms. Numerous studies have shown that factors such as age, occupation, and proximity to wind farms can significantly influence individuals' perception and acceptance of wind energy projects (Ki et al., 2022; Vasudevan et al., 2023).

In summary, the questionnaire integrated insights from a broad body of research on the factors influencing public perception of wind farms. By incorporating questions on visibility, perceived benefits and drawbacks, and demographic data, this study offers a comprehensive approach to understanding the social acceptance of wind energy (Devine-Wright, 2009; Langer et al., 2017; Wolsink, 2018). This study also reflects the growing emphasis on climate change concerns and the participatory governance of renewable energy projects (Firestone et al., 2018; Gross, 2007).

### 3.3. Data analysis methods and process

We employed a comprehensive multistage analytical framework (Fig. 2) to investigate the relationships between wind farm visibility, public perceptions, and preferences for future wind farm options. First, descriptive statistics were employed to compare the distribution of “preference option” across the various “visibility and sighting” categories, revealing meaningful variations that suggest a potential association between the two variables. Next, we conducted PCA with Varimax rotation to extract factors from items measuring the “Perception of Current Wind Farm,” followed by binary logistic regression to assess how these factors influenced preferences for decommissioning/lifespan extension versus repowering. In parallel, a multivariate analysis of variance (MANOVA) was conducted to compare the multivariate

distribution of expectation-related responses across different preference-option groups. Finally, a separate binary logistic regression analysis was conducted to quantify the influence of key demographic factors on preference options for alternative schemes. All data processing and statistical analyses were performed in SPSS 27 (IBM Corp., Armonk, NY, USA) to ensure robustness and reproducibility. This integrated approach provides nuanced insights into the cognitive, emotional, and demographic drivers that underlie wind farm preferences, with direct implications for the planning of future development and end-of-life management strategies such as decommissioning, lifespan extension, or repowering. (Leite et al., 2022).

To maintain conceptual and analytical coherence, predictor variables were systematically grouped according to the formulated hypotheses within their respective analytical frameworks. In the binary logistic regression, environmental and socio-economic benefit perceptions (greenhouse gas reduction, energy self-sufficiency, tourism increase, city symbolism, and economic activation) were treated as indicators of positive instrumental experiences (H2); disaster-risk cognition and institutional-trust dimensions (disaster damage concern, disaster safety, consultation opportunity, trust relationship, mitigation measures, and community contribution) were classified as risk- and institution-related cognitive evaluations (H1); and experiential and sensory burdens (noise perception, noise annoyance, and shadow flicker) were operationalized as affective responses (H3). Concurrently, H4 was examined through a separate one-way ANOVA framework, wherein residents' end-of-life management preferences (lifespan extension, repowering with unchanged or increased capacity, and decommissioning) served as the independent grouping variable, and expectations for future wind farm development (landscape harmony, tourism attraction, information transparency, proper explanations, and blade length) served as the dependent variables. This structured classification ensures that each hypothesis corresponds to a mutually exclusive set of variables and analytical procedures, permitting direct and unambiguous empirical testing within the regression and ANOVA frameworks, respectively.

## 4. Results and discussion

To link the theoretical framework with empirical analysis, each hypothesis was evaluated against the statistical results. H1, concerning risk- and institution-related cognitive evaluations, is partially supported, as disaster-risk cognition exerts a statistically significant positive effect in the binary logistic regression (Table 5), whereas institutional-trust dimensions including mitigation measures do not reach significance, indicating that perceived technological safety rather than generalized governance trust guides preference selection. H2, relating to positive instrumental experiences such as economic and environmental benefits, is not supported, with eco-sustainability and socio-economic expectations showing no significant effects, suggesting that abstract benefit perceptions exert limited influence on end-of-life management preferences in mature wind-energy landscapes. H3, addressing affective and sensory responses, is not supported, as neither noise annoyance nor shadow flicker significantly shapes preferences, demonstrating that emotional and sensory reactions do not operate independently in this context. H4, concerning expectation differentiation, is weakly supported, as one-way analysis of variance (Table 6) identifies significant yet modest differences among preference groups in landscape harmony, tourism attraction, information transparency, proper explanations, and blade length, though end-of-life options explain less than four percent of variance in future expectations. Collectively, these results indicate that residents' preferences are predominantly driven by disaster-risk cognition rather than abstract benefit perceptions or affective mechanisms, emphasizing the central role of perceived technological resilience and safety governance in shaping acceptance of wind farm end-of-life strategies.

Figs. 3 and 4 illustrate the geographical distribution of attitudes

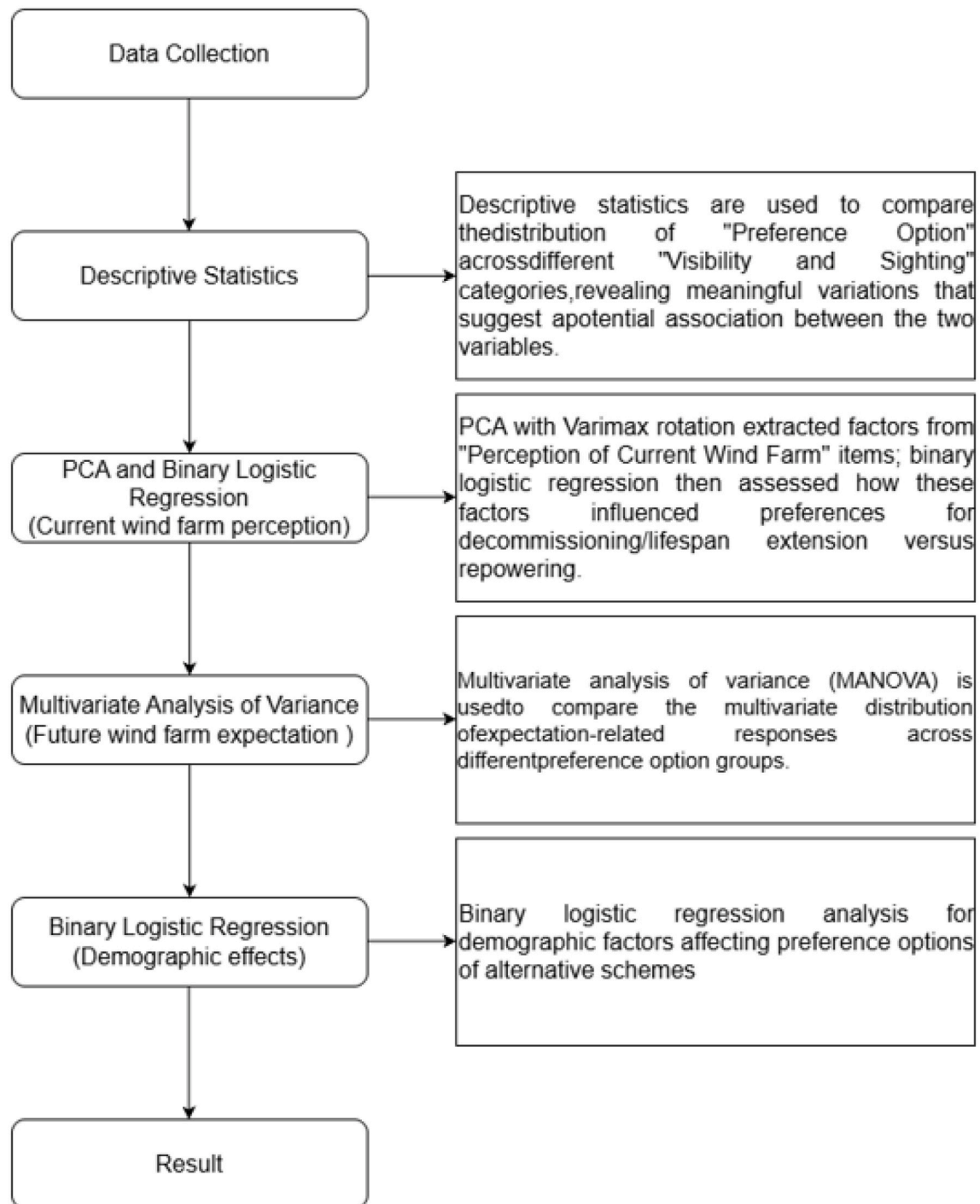


Fig. 2. Data analysis methods and process.

toward wind farms and preferences for wind farm end-of-life management options, respectively. Table 2 shows the distribution of 218 respondents' preferred end-of-life management options for existing wind farms: lifespan extension (9.2%), repowering with unchanged capacity (56.9%), repowering with increased capacity (18.8 %), and decommissioning (15.1%). A pronounced majority (56.9%) opted for repowering with unchanged capacity, reflecting a broad inclination toward technological renewal that maintains existing landscape footprints, consistent with findings that communities prioritize continuity of service and minimal visual disruption over capacity gains (Windemer, 2023). The comparatively lower support for repowering with increased capacity suggests reservations about intensified turbine

density and potential escalation of perceived nuisance effects, aligning with evidence that amplified turbine numbers can exacerbate community apprehension regarding noise and shadow flicker (Bezbradica et al., 2016). Lifespan extension, though the least favored, nonetheless garnered support primarily among neutral to supportive residents, indicating that inertia and cost-efficiency arguments retain some traction absent significant capacity incentives. Decommissioning remained a minority preference, concentrated among those expressing outright opposition to wind installations, underscoring that dismantlement is viewed as a last resort when all mitigation and upgrade pathways are untenable (Agra Neto et al., 2024). These patterns reveal that, within mature wind energy landscapes, repowering—particularly at constant

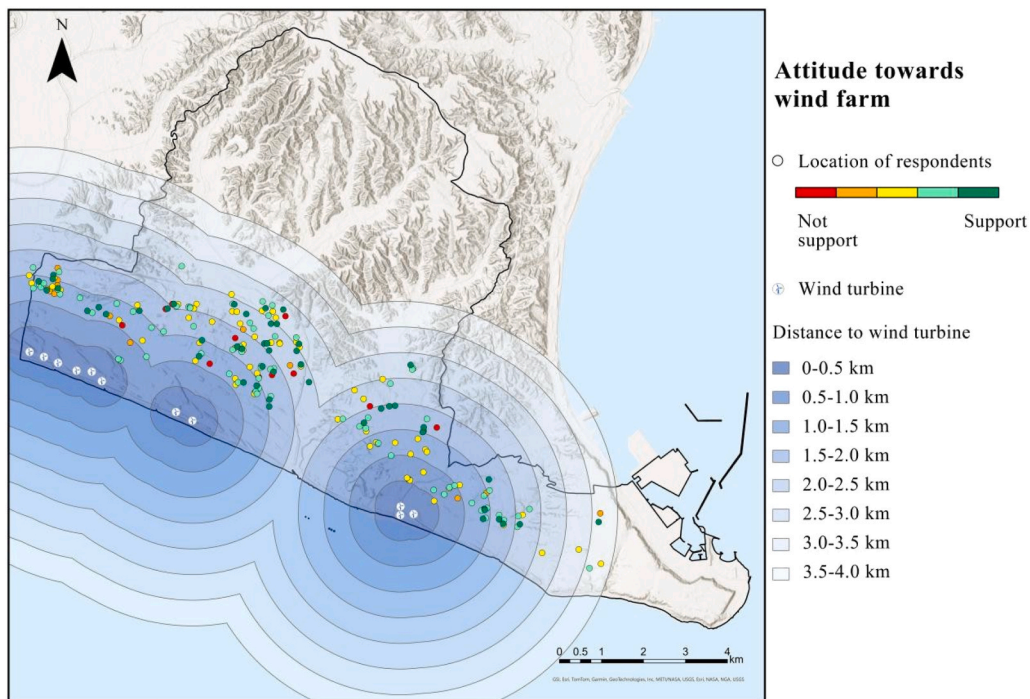


Fig. 3. Geographical distribution of attitudes towards wind farms.

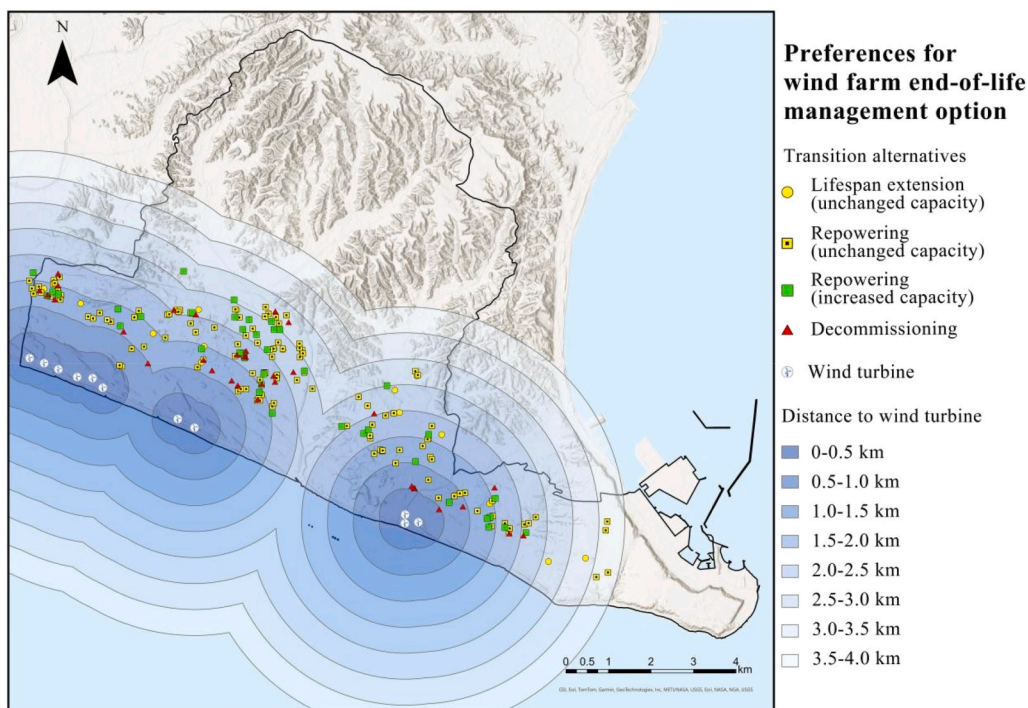


Fig. 4. Geographical distribution of preferences for wind end-of-life management options.

capacity—is perceived as the optimal tradeoff between sustainability, social license, and infrastructural pragmatism (Kasner, 2022), a conclusion that carries implications for policy frameworks aiming to harmonize technical upgrades with community acceptance (Boyd et al., 2022).

Table 3 presents the descriptive associations between turbine visibility, landscape perception, and preferred end-of-life management pathways, while simultaneously indicating the substantial imbalance in subgroup sample sizes that constrains inferential interpretation.

Preferences for repowering—particularly repowering at unchanged capacity—were consistently observed across most visibility and perception categories, suggesting that familiarity with existing wind energy infrastructure may contribute to greater tolerance toward technological continuity rather than complete removal. However, caution is warranted because several subgroup distributions were derived from extremely limited observations, especially among respondents without direct wind-farm visibility, rendering strong comparative conclusions

**Table 2**

Results of attitudes toward wind farms and end-of-life management options.

| Variable                   | Category         | Lifespan extension (unchanged capacity) | Repowering (unchanged capacity) | Repowering (increased capacity) | Decommissioning | Total |
|----------------------------|------------------|-----------------------------------------|---------------------------------|---------------------------------|-----------------|-------|
| Attitude toward wind farms | Do not support   | 1                                       | 3                               | 0                               | 8               | 12    |
|                            | Hardly support   | 0                                       | 8                               | 0                               | 8               | 16    |
|                            | Neutral          | 6                                       | 39                              | 10                              | 10              | 65    |
|                            | Support          | 7                                       | 48                              | 13                              | 6               | 74    |
|                            | somewhat Support | 6                                       | 26                              | 18                              | 1               | 51    |
| Total                      |                  | 20                                      | 124                             | 41                              | 33              | 218   |

**Table 3**

Association between visibility, perceptions, and end-of-life management: Descriptive statistics.

| Variable                     | Category                    | Lifespan Extension (unchanged capacity) | Repowering (unchanged capacity) | Repowering (increased capacity) | Decommissioning |
|------------------------------|-----------------------------|-----------------------------------------|---------------------------------|---------------------------------|-----------------|
| Visibility of Wind Farms     | No                          | 1                                       | 5                               | 2                               | 0               |
|                              | Yes                         | 19                                      | 119                             | 39                              | 33              |
| Visibility from Home         | No                          | 12                                      | 75                              | 28                              | 17              |
|                              | Yes                         | 7                                       | 44                              | 11                              | 16              |
| Frequency of Visibility      | Other                       | 1                                       | 5                               | 2                               | 0               |
|                              | At least once per year      | 0                                       | 5                               | 1                               | 1               |
|                              | At least once per week      | 10                                      | 51                              | 20                              | 9               |
|                              | Almost every day            | 8                                       | 58                              | 16                              | 23              |
| First Sighting               | <1 year ago                 | 0                                       | 4                               | 0                               | 0               |
|                              | 1 - 4 years ago             | 0                                       | 1                               | 1                               | 1               |
|                              | 5 - 9 years ago             | 0                                       | 20                              | 3                               | 3               |
|                              | 11 - 14 years ago           | 7                                       | 28                              | 14                              | 10              |
|                              | >15 years ago               | 12                                      | 66                              | 21                              | 19              |
| Initial Landscape Impression | Negative                    | 1                                       | 3                               | 0                               | 10              |
|                              | Somewhat negative           | 0                                       | 10                              | 3                               | 7               |
|                              | Neutral                     | 11                                      | 61                              | 15                              | 13              |
|                              | Somewhat positive           | 0                                       | 23                              | 13                              | 1               |
|                              | Positive                    | 5                                       | 22                              | 8                               | 2               |
| Recent Sighting              | <1 week                     | 0                                       | 8                               | 3                               | 5               |
|                              | 1 week - 1 month            | 0                                       | 6                               | 1                               | 0               |
|                              | 1 month - 6 months          | 0                                       | 9                               | 3                               | 1               |
|                              | Between 6 months and 1 year | 1                                       | 13                              | 6                               | 4               |
|                              | Other                       | 18                                      | 83                              | 26                              | 23              |
| Recent Landscape Impression  | Negative                    | 1                                       | 5                               | 0                               | 12              |
|                              | Somewhat negative           | 2                                       | 11                              | 4                               | 5               |
|                              | Neutral                     | 10                                      | 72                              | 22                              | 14              |
|                              | Somewhat positive           | 1                                       | 14                              | 5                               | 1               |
|                              | Positive                    | 5                                       | 17                              | 8                               | 1               |

statistically unreliable. Consequently, the results are more appropriately interpreted as indicative patterns rather than robust population-level tendencies. Within the larger visibility-exposed groups, more frequent and longer-term visual exposure appeared to coincide with comparatively stronger acceptance of repowering scenarios, whereas decommissioning preferences were more commonly associated with persistently negative landscape impressions. This pattern aligns with recent evidence indicating that social acceptance of renewable energy infrastructure is shaped less by visibility alone than by the interaction between visual familiarity, perceived landscape fit, procedural legitimacy, and distributive fairness (Batel et al., 2013; Fast et al., 2016). In particular, longitudinal exposure to turbines has been shown to attenuate initial aesthetic resistance through processes of normalization and place adaptation, especially where projects are perceived as locally beneficial or environmentally justified (Devine-Wright et al., 2021; Xie et al., 2022). Conversely, negative visual appraisal has repeatedly been identified as a principal predictor of opposition to continued wind-energy deployment and end-of-life redevelopment, reflecting the enduring influence of affective landscape evaluation on infrastructure legitimacy (Wolsink, 2007; Ladenburg et al.). The distribution observed for recent turbine sightings further suggests that short-term salience effects may temporarily intensify decommissioning preferences, a phenomenon consistent with cognitive availability mechanisms reported in

environmental risk perception research (Perlaviciute and Steg, 2014). Importantly, the present descriptive findings should not be interpreted as causal relationships, given the absence of statistical testing and the uneven category representation across several variables. Rather, the table provides exploratory evidence that visual exposure and perceptual orientation may condition end-of-life preferences in nuanced ways, thereby reinforcing emerging calls for more socially adaptive and perception-sensitive approaches to renewable energy repowering and retirement governance (Firestone et al., 2018; Bolinger et al., 2022).

Table 4 presents the principal component structure underlying residents' cognition and perception of existing wind farms, revealing a highly coherent multidimensional framework encompassing environmental sustainability, socio-economic valuation, operational disturbance, ecological risk, disaster cognition, and institutional trust. The extracted components demonstrated strong internal consistency and convergent validity, indicating that the latent constructs captured relatively stable and interpretable perceptual dimensions of wind-energy acceptance. In particular, sustainability-oriented beliefs and socio-economic evaluations emerged as the most structurally consolidated dimensions, suggesting that contemporary perceptions of wind-energy infrastructure are increasingly embedded within broader narratives of climate mitigation, regional development, and energy-transition legitimacy rather than being determined solely by localized visual or

**Table 4**

Principal component analysis (PCA) for cognition and perception of current wind farms.

| Description                         | Eco-Sustainability | Socio-Economics | Noise | Shadow Flicker | Bird Risk Perception | Disaster Risk Cognition | Community Trust & Participation | Communalities |
|-------------------------------------|--------------------|-----------------|-------|----------------|----------------------|-------------------------|---------------------------------|---------------|
| Greenhouse Gas Reduction            | 0.940              |                 |       |                |                      |                         |                                 | 0.884         |
| Energy Self-Sufficiency             | 0.940              |                 |       |                |                      |                         |                                 | 0.884         |
| Tourism Increase                    |                    | 0.892           |       |                |                      |                         |                                 | 0.795         |
| City Symbol                         |                    | 0.906           |       |                |                      |                         |                                 | 0.82          |
| Economic Activation                 |                    | 0.841           |       |                |                      |                         |                                 | 0.707         |
| Noise Perception                    |                    |                 | 0.896 |                |                      |                         |                                 | 0.802         |
| Noise Annoyance                     |                    |                 | 0.896 |                |                      |                         |                                 | 0.802         |
| Shadow Flicker Perception           |                    |                 |       | 0.903          |                      |                         |                                 | 0.815         |
| Shadow Flicker Annoyance            |                    |                 |       | 0.903          |                      |                         |                                 | 0.815         |
| Bird Collision Concern              |                    |                 |       |                | 0.906                |                         |                                 | 0.822         |
| Bird Collision Problem              |                    |                 |       |                | 0.906                |                         |                                 | 0.822         |
| Disaster Damage Concern             |                    |                 |       |                |                      | 0.719                   |                                 | 0.518         |
| Disaster Safety                     |                    |                 |       |                |                      | 0.719                   |                                 | 0.518         |
| Mitigation Measures                 |                    |                 |       |                |                      |                         | 0.761                           | 0.579         |
| Consultation Opportunity            |                    |                 |       |                |                      |                         | 0.893                           | 0.797         |
| Trust Relationship                  |                    |                 |       |                |                      |                         | 0.875                           | 0.765         |
| Community Contribution              |                    |                 |       |                |                      |                         | 0.782                           | 0.611         |
| Variance Explained by Component (%) | 88.38              | 77.39           | 80.23 | 81.54          | 82.16                | 51.76                   | 68.82                           | -             |
| Average Variance Extracted (AVE)    | 0.884              | 0.774           | 0.802 | 0.815          | 0.822                | 0.518                   | 0.688                           | -             |
| Cronbach's Alpha ( $\alpha$ )       | 0.895              | 0.786           | 0.798 | 0.765          | 0.843                | 0.789                   | 0.821                           | -             |
| Composite Reliability (CR)          | 0.941              | 0.879           | 0.892 | 0.873          | 0.9                  | 0.789                   | 0.887                           | -             |
| Sample Size (N)                     | 218                | 218             | 208   | 199            | 198                  | 218                     | 218                             | -             |

operational impacts. Such findings are consistent with recent transition-governance literature demonstrating that support for renewable energy infrastructures is strongly mediated by perceived collective benefits, procedural fairness, and alignment with decarbonization objectives (Perlaviciute and Steg, 2014; Sovacool et al., 2018). By contrast, perceptual dimensions associated with noise, shadow flicker, and avian collision concerns formed comparatively independent psychological domains, implying that operational externalities remain cognitively differentiated from broader evaluations of energy-transition necessity. Notably, the comparatively weaker variance structure associated with disaster-risk cognition suggests that perceptions of technological safety may remain more heterogeneous and context-dependent than other attitudinal dimensions, particularly in mature wind-energy regions where normalization processes have attenuated generalized infrastructural anxiety (Batel et al., 2013). The prominence of the “Community Trust & Participation” component further reinforces growing evidence that institutional credibility and participatory legitimacy represent critical determinants of renewable-energy acceptance, particularly during repowering and end-of-life transition phases where local procedural inclusion becomes increasingly salient (Fast et al., 2016; Garcia et al., 2016).

Table 5 presents the binary logistic regression results examining the association between the extracted perceptual dimensions and preferences for active reconstruction pathways versus restrained end-of-life strategies. The overall model achieved statistical significance, indicating that perceptual structures contributed meaningfully to the differentiation of management preferences; however, the explanatory capacity and discriminative performance remained limited. Among the evaluated dimensions, only disaster-risk cognition exhibited a statistically significant association with support for repowering-oriented pathways, suggesting that perceptions of technological safety and risk controllability may exert a more direct influence on redevelopment acceptance than environmental, socio-economic, or operational evaluations alone. This observation accords with recent studies demonstrating that perceived infrastructural resilience and confidence in risk governance increasingly shape public support for renewable-energy continuity under conditions of energy-system uncertainty and climate adaptation pressure (Ellis et al., 2023; Walker et al., 2014). In contrast, environmental sustainability perceptions and socio-economic

**Table 5**

Binary logistic regression analysis for perceptions of current wind farms on end-of-life management option (Decommissioning + lifespan extension VS. Repowering (unchanged/increased capacity)).

| Predictor                       | B (SE)         | Wald $\chi^2$ | df | OR      | 95% CI for OR  |
|---------------------------------|----------------|---------------|----|---------|----------------|
| Eco-Sustainability              | 0.321 (0.190)  | 2.843         | 1  | 1.379   | [0.949, 2.002] |
| Socio-Economics                 | 0.256 (0.202)  | 1.605         | 1  | 1.292   | [0.869, 1.921] |
| Noise                           | -0.193 (0.208) | 0.856         | 1  | 0.825   | [0.549, 1.239] |
| Shadow Flicker                  | -0.034 (0.215) | 0.025         | 1  | 0.967   | [0.634, 1.473] |
| Bird Risk Perception            | -0.169 (0.184) | 0.841         | 1  | 0.845   | [0.589, 1.213] |
| Disaster Risk Cognition         | 0.374 (0.184)  | 4.113         | 1  | 1.453*  | [1.012, 2.087] |
| Community Trust & Participation | -0.139 (0.188) | 0.547         | 1  | 0.87    | [0.602, 1.257] |
| Constant                        | 1.194 (0.182)  | 43.05         | 1  | 3.301** | [2.311, 4.715] |

Model fit: -2 Log likelihood = 196.037; Cox & Snell  $R^2$  = 0.086; Nagelkerke  $R^2$  = 0.127; Omnibus  $\chi^2(7)$  = 17.111,  $p$  = 0.017; overall correct classification = 79.1% (sensitivity = 98.6%, specificity = 19.1%) using cutoff 0.50. Sample:  $N$  = 191 after listwise deletion of 27 missing cases (initial  $N$  = 218).

Note: \* $p$  < 0.05; \*\* $p$  < 0.001. No predictor reached  $p$  < 0.01. All predictors entered simultaneously (enter method). Dependent variable coding: 0 = restrained (lifespan extension + decommissioning), 1 = active reconstruction (repowering (unchanged capacity) + repowering (increased capacity)). Predictor variables are factor scores from principal component analysis. OR = odds ratio. CI = profile likelihood-based 95% confidence interval.

expectations, although positively associated with reconstruction-oriented preferences, did not reach stronger inferential significance, implying that generalized support for renewable energy does not necessarily translate into unconditional acceptance of specific repowering interventions. Similarly, operational disturbance perceptions, including noise and shadow flicker, displayed comparatively weak explanatory effects, supporting recent arguments that social acceptance

is less strongly driven by isolated nuisance perceptions than by broader institutional and governance contexts (Devine-Wright et al., 2021). Nevertheless, despite the effectiveness of dimensionality reduction and category consolidation in improving model robustness, the model exhibited relatively low discriminatory capacity and limited predictive differentiation between preference groups. Accordingly, the present findings should be interpreted as exploratory rather than deterministic evidence, and no causal inference should be established regarding the relationship between perceptual constructs and end-of-life management preferences. Such caution is particularly important given the moderate explanatory power, the imbalance in classification sensitivity and specificity, and the increasingly recognized complexity of socio-technical acceptance processes within renewable-energy transition systems (Bolinger et al., 2022; Lundheim et al., 2022).

Table 6 presents the results of the one-way analysis of variance examining how end-of-life management options—lifespan extension, repowering with unchanged or increased capacity, and decommissioning—influence expectations of future wind farms. Statistically significant but generally modest effects were observed for landscape harmony, tourism attraction, information transparency, proper explanations, and blade length, suggesting that expectations regarding these dimensions may vary across end-of-life management pathways (Philpott and Windemer, 2022; Windemer, 2023). By contrast, noise impact, shadow flicker, bird collision risk, greenhouse gas reduction, economic development potential, local financial support, resident feedback, turbine quantity, turbine height, and proximity to dwellings showed non-significant effects, indicating limited differences across treatment groups within the present sample. Importantly, the adjusted  $R^2$  values remained low across most models, indicating that end-of-life management strategy explains only a limited proportion of variation in stakeholder expectations. Accordingly, the statistically significant findings should be interpreted cautiously and understood primarily as indicative tendencies rather than strong predictive relationships. These findings are consistent with previous research suggesting that public acceptance of renewable energy infrastructure is shaped by multiple interacting social, contextual, and experiential factors (Agra Neto et al., 2024; Mikindani, 2024).

Table 7 reports Tukey's HSD post-hoc comparisons among the four end-of-life management treatments. Several pairwise differences reached statistical significance, although the magnitude of these differences was generally limited. Lifespan extension and repowering with unchanged capacity were associated with higher expectations regarding tourism attraction compared with decommissioning. In addition, expectations concerning information transparency were significantly higher under lifespan extension than under repowering with unchanged

**Table 7**

Post-hoc comparisons (Tukey's HSD) of expectations of future wind farms by end-of-life management option.

| Variable                 | LE-RU | LE-RI | LE-DC | RU-RI  | RU-DC  | RI-DC  |
|--------------------------|-------|-------|-------|--------|--------|--------|
| Noise impact             | 0.07  | 0.1   | -0.04 | 0.03   | -0.11  | -0.14  |
| Shadow flicker impact    | -0.10 | 0.19  | -0.22 | 0.29   | -0.11  | -0.41  |
| Bird collision           | -0.09 | 0.13  | -0.35 | 0.22   | -0.26  | -0.48  |
| Landscape harmony        | 0.24  | 0.49  | -0.17 | 0.25   | -0.41  | -0.66* |
| Greenhouse gas reduction | 0.42  | 0.11  | 0.39  | -0.31  | -0.03  | -0.28  |
| Economic development     | 0.14  | -0.08 | 0.59  | -0.22  | 0.45   | 0.67   |
| Tourism attraction       | 0.37  | 0.5   | 1.05* | 0.12   | 0.67*  | 0.55   |
| Local financial support  | -0.09 | -0.23 | 0     | -0.14  | 0.09   | 0.24   |
| Information transparency | 0.49* | 0.17  | 0.3   | -0.32  | -0.18  | -0.14  |
| Proper explanations      | 0.4   | -0.01 | 0.14  | -0.40* | -0.25  | -0.15  |
| Resident feedback        | 0.33  | -0.01 | 0.07  | -0.34  | -0.25  | -0.08  |
| Turbine quantity         | 0.25  | 0.12  | -0.23 | -0.12  | -0.48  | -0.36  |
| Turbine height           | 0.17  | 0.2   | -0.31 | 0.03   | -0.48  | -0.51  |
| Blade length             | 0.17  | 0.34  | -0.35 | 0.17   | -0.52* | -0.69* |
| Distance from home       | 0.21  | 0.02  | -0.09 | -0.19  | -0.30  | -0.10  |

Note: Mean differences = (first group – second group); \* $p < 0.05$ ; Positive values indicate higher perceived impact in the first group of each comparison; HSD = honestly significant difference; LE = lifespan extension (unchanged capacity); RU = repowering (unchanged capacity); RI = repowering (increased capacity); DC = decommissioning.

capacity. Conversely, repowering with increased capacity was associated with lower expectations of landscape harmony relative to decommissioning. Similarly, both repowering scenarios showed lower perceived suitability regarding blade length compared with decommissioning. Expectations concerning proper explanations were also lower under repowering with unchanged capacity relative to repowering with increased capacity. Overall, these results suggest that perceptions related to visual integration, communication processes, and tourism potential may vary across end-of-life pathways. However, the relatively low explained variance and modest effect sizes indicate that these differences should be interpreted cautiously, and are better understood as exploratory patterns rather than strong attitudinal divisions (Mikindani, 2024; Philpott and Windemer, 2022).

Integrating these findings, the results tentatively suggest that lifespan extension and repowering with unchanged capacity may be associated with comparatively more favorable expectations regarding tourism potential and procedural transparency, whereas decommissioning appears to be associated with comparatively more favorable expectations concerning landscape harmony and blade-length suitability relative to more intensive repowering scenarios. However, these differences should not be interpreted as large or deterministic effects given the limited explanatory power of the statistical models. Taken together, the findings may indicate a potential tradeoff between maximizing technical efficiency and maintaining perceived aesthetic and recreational values within host communities (Jadali et al., 2021a). In particular, more intensive repowering strategies involving larger turbine dimensions may generate greater concerns regarding visual integration, even where perceived economic or environmental benefits remain relatively stable. At the same time, the results suggest that procedural dimensions—including transparent communication and adequate explanations—may influence stakeholder expectations under different end-of-life management scenarios. Because the observed effects were generally modest, these findings should be understood primarily as exploratory indications of possible perceptual tendencies rather than

**Table 6**

Results of multivariate analysis of variance for effects of end-of-life management on expectations of future wind farms.

| Variable                 | SS     | df | MS    | F      | Adjusted $R^2$ |
|--------------------------|--------|----|-------|--------|----------------|
| Noise impact             | 0.497  | 3  | 0.166 | 0.159  | -0.012         |
| Shadow flicker impact    | 3.704  | 3  | 1.235 | 1.1    | 0.001          |
| Bird collision           | 4.395  | 3  | 1.465 | 1.26   | 0.004          |
| Landscape harmony        | 8.915  | 3  | 2.972 | 2.762* | 0.024          |
| Greenhouse gas reduction | 5.275  | 3  | 1.758 | 2.258  | 0.017          |
| Economic development     | 9.026  | 3  | 3.009 | 2.444  | 0.02           |
| Tourism attraction       | 16.564 | 3  | 5.521 | 3.5*   | 0.033          |
| Local financial support  | 1.266  | 3  | 0.422 | 0.336  | -0.009         |
| Information transparency | 6.216  | 3  | 2.072 | 3.626* | 0.035          |
| Proper explanations      | 6.919  | 3  | 2.306 | 3.93** | 0.039          |
| Resident feedback        | 5.114  | 3  | 1.705 | 2.626  | 0.022          |
| Turbine quantity         | 6.339  | 3  | 2.113 | 2.005  | 0.014          |
| Turbine height           | 6.813  | 3  | 2.271 | 2.349  | 0.018          |
| Blade length             | 9.9    | 3  | 3.3   | 3.228* | 0.03           |
| Distance from home       | 3.08   | 3  | 1.027 | 2.163  | 0.016          |

Note: \* $p < 0.05$ , \*\* $p < 0.01$ ; Adjusted  $R^2$  may be negative if model fit is poorer than the null model; SS stands for Sum of Squares.

conclusive evidence of causal social responses(Boyd et al., 2022).

Table 8 presents the binary logistic regression analysis examining the extent to which sociodemographic and geographic characteristics were associated with preferences for active reconstruction pathways versus restrained end-of-life management strategies for wind turbines. The overall model demonstrated limited explanatory capacity and failed to achieve statistical significance, indicating that demographic attributes and locational conditions alone were insufficient to meaningfully differentiate residents' end-of-life management preferences. Neither gender, age, occupation, residence duration, elevation, nor distance to turbines exhibited statistically robust associations with support for repowering-oriented pathways, suggesting that individual socio-spatial characteristics may play a comparatively secondary role relative to perceptual, institutional, and attitudinal dimensions. This finding aligns with recent renewable-energy acceptance research showing that opposition or support toward wind-energy redevelopment is increasingly shaped less by static demographic profiles and more by socially constructed factors such as trust, procedural fairness, perceived legitimacy, and local benefit distribution(Batel, 2020; Fan et al., 2021). The absence of significant distance effects is particularly noteworthy, as it contrasts with earlier proximity-based acceptance models and instead supports emerging evidence that visual or geographic exposure alone provides limited explanatory power once broader social and governance variables are considered(Batel, 2020; Fan et al., 2021; Haggett, 2011; Wolsink, 2012). Similarly, the weak contribution of residence duration suggests that long-term place attachment does not necessarily translate into either resistance or support for repowering, reinforcing contemporary arguments that energy-transition attitudes are highly context-dependent and mediated by institutional trust and perceived procedural inclusion rather than by temporal embeddedness alone (Fast et al., 2016). The model's low discriminative performance and inability to adequately distinguish between preference groups further indicate that end-of-life management attitudes are likely governed by multidimensional socio-psychological processes not fully captured through conventional demographic indicators. Accordingly, the present results should be interpreted as exploratory rather than predictive or causal evidence, particularly given the low model fit and highly imbalanced classification performance. These findings collectively support recent calls for

renewable-energy governance frameworks that move beyond demographic determinism toward more relational and perception-sensitive approaches to understanding public responses to repowering and infrastructure transition processes(Firestone et al., 2018; Jalali et al., 2016).

## 5. Conclusion and policy implications

In this study, residents living within a 4 km radius of the coastal wind farm exhibited differentiated end-of-life management preferences, with 56.9% favoring repowering (unchanged capacity), 18.8% repowering (increased capacity), 15.1% decommissioning, and 9.2% lifespan extension. Descriptive statistics suggested that visual exposure may be associated with these preferences; however, several subgroup distributions involved limited observations, particularly among respondents without direct turbine visibility, thereby constraining robust inferential interpretation. Because these descriptive distributions were not evaluated using formal inferential testing and several subgroup counts remained limited, the observed patterns should be interpreted cautiously as exploratory descriptive tendencies rather than statistically robust population-level relationships. Principal component analysis was first conducted to consolidate perceptual variables into coherent dimensions. Subsequently, binary logistic regression with consolidated outcome categories indicated that disaster-risk cognition emerged as the only perceptual dimension significantly associated with support for active reconstruction pathways, whereas environmental sustainability, socio-economic expectations, and operational disturbance perceptions did not demonstrate stronger inferential significance. One-way analysis of variance with Tukey's HSD post-hoc tests identified statistically significant but generally modest differences among management-option groups in expectations regarding landscape harmony, tourism attraction, information transparency, proper explanations, and blade length. However, the relatively low adjusted  $R^2$  values and limited number of significant pairwise contrasts indicate that these differences should be interpreted cautiously as exploratory perceptual tendencies rather than strong attitudinal divisions. Finally, binary logistic regression incorporating demographic covariates indicated that no sociodemographic or geographic variable—including gender, age, occupation, residence duration, elevation, or distance to turbines—exhibited statistically significant associations with end-of-life management preferences, suggesting that socio-spatial characteristics alone are insufficient to differentiate preference groups. Taken together, the findings provide exploratory evidence that end-of-life preferences may be associated with multiple interacting perceptual and attitudinal factors; however, given the modest explanatory power and subgroup imbalance within portions of the dataset, the present results should be interpreted as exploratory rather than definitive evidence of causal preference formation.

In light of the differentiated preferences observed for end-of-life management pathways—particularly the comparatively higher support for repowering at unchanged capacity—policy frameworks may benefit from balancing technical, environmental, and social considerations during wind-farm transition planning. In particular, repowering strategies that maintain existing spatial footprints while improving technological efficiency may be comparatively more socially acceptable within the present case-study context. Conversely, more intensive repowering scenarios involving larger turbine dimensions may generate comparatively lower expectations regarding landscape harmony and visual integration. The results further suggest that procedural dimensions, including information transparency and adequate explanation processes, may influence stakeholder expectations under different end-of-life management scenarios. Accordingly, continued stakeholder consultation, transparent environmental communication, and locally adaptive mitigation strategies may contribute to improving procedural legitimacy during repowering or decommissioning processes. However, because the observed effects were generally modest and several subgroup comparisons involved limited observations, these implications

**Table 8**

Binary logistic regression analysis for sociodemographic and geographic factors affecting wind turbine end-of-life management option (Decommissioning + lifespan extension VS. Repowering (unchanged/increased capacity)).

| Predictor              | B (SE)         | Wald<br>$\chi^2$ | df | OR    | 95% CI for OR      |
|------------------------|----------------|------------------|----|-------|--------------------|
| Gender                 | 0.584 (0.361)  | 2.62             | 1  | 1.794 | [0.884, 3.642]     |
| Age                    | 0.001 (0.154)  | 0                | 1  | 1.001 | [0.740, 1.354]     |
| Occupation             | 0.132 (0.149)  | 0.783            | 1  | 1.141 | [0.852, 1.528]     |
| Residence<br>Duration  | -0.065 (0.249) | 0.067            | 1  | 0.937 | [0.575, 1.527]     |
| Elevation              | 0.171 (0.194)  | 0.775            | 1  | 1.186 | [0.811, 1.736]     |
| Distance to<br>Turbine | 0.074 (0.145)  | 0.262            | 1  | 1.077 | [0.810, 1.432]     |
| Constant               | -0.667 (1.664) | 0.161            | 1  | 0.513 | [0.020,<br>13.393] |

Model fit:  $-2 \text{ Log likelihood} = 234.839$ ; Cox & Snell  $R^2 = 0.032$ ; Nagelkerke  $R^2 = 0.047$ ; Omnibus  $\chi^2(6) = 6.988$ ,  $p = 0.322$ ; overall correct classification = 75.7% (sensitivity = 100.0%, specificity = 0.0%) using cutoff 0.50.

Sample:  $N = 218$  (complete case analysis, no missing data).

Note: \* $p < 0.05$ ; \*\* $p < 0.001$ . No predictor was statistically significant at  $\alpha = 0.05$ . The constant was also non-significant ( $p = 0.689$ ). All predictors entered simultaneously (enter method). Dependent variable coding: 0 = restrained (lifespan extension + decommissioning), 1 = active reconstruction (repowering (unchanged capacity) + repowering (increased capacity)). Predictor variables include gender, age, occupation, residence duration, elevation, and distance to turbine. OR = odds ratio. CI = profile likelihood-based 95% confidence interval (calculated from  $B \pm 1.96 \times SE$ ).

should be interpreted cautiously and not as universally transferable policy prescriptions.

Despite the multivariate analytical framework and empirical scope of this study, several limitations should be acknowledged. First, the cross-sectional design precludes assessment of temporal changes in resident perceptions following actual implementation of repowering, lifespan extension, or decommissioning activities. Second, the study was limited to a single coastal wind farm, restricting generalizability to other geographical and sociotechnical contexts. Third, although key perceptual constructs—including noise perception, shadow flicker, consultation opportunity, and trust relationship—were incorporated into the analytical framework, additional psychosocial variables may also contribute substantially to end-of-life management preferences. Fourth, portions of the descriptive and subgroup analyses involved uneven category distributions and limited effective observations, thereby reducing statistical power and constraining robust inferential interpretation. Accordingly, non-significant findings should not be interpreted as evidence of equivalence between end-of-life management options, particularly where subgroup sample sizes remained limited. Fifth, this study mainly focuses on unchanged-capacity and increased-capacity repowering scenarios but does not fully discuss the alternative repowering strategy that adopts larger turbines while maintaining the total installed wind farm capacity. Such a scheme reduces the total number of turbines, which may generate distinct visual landscape effects and varied environmental impacts. Moreover, large-scale turbine replacement may exceed the bearing capacity of original foundations, requiring foundation reinforcement or reconstruction and bringing additional economic costs, which are not systematically analyzed in the current research. Finally, the reliance on stated-preference survey responses without complementary behavioral indicators limits the ability to infer actual community responses or participation patterns. Accordingly, future studies incorporating longitudinal designs, larger and more balanced samples, and additional psychosocial and behavioral variables would help further clarify the social dynamics underlying wind-farm end-of-life management preferences.

#### CRedit authorship contribution statement

**Wei Zhang:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft. **Shigeo Nishikizawa:** Data curation, Funding acquisition, Investigation, Methodology, Supervision, Writing – review & editing. **Takehiko Murayama:** Writing – review & editing. **Kultrip Suwanteep:** Writing – review & editing. **Shota Yokoyama:** Investigation. **Kaiqi Liu:** Investigation, Visualization. **Qiao Yu:** Investigation. **Kiyoshi Takejima:** Funding acquisition, Writing – review & editing.

#### 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.

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#### Data availability

Data will be made available on request.

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