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Balancing social attitudes and ecological conservation in Taiwan's wind power development under climate change

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With the global threat posed by climate change, over 130 countries are aiming for "net-zero emissions by 2050." This study assessed the attributes of wind power development in Taiwan using a discrete choice experiment and an immersive virtual environment. We assessed the public's willingness to support ecological compensation and obtained 850 valid responses from 1,012 distributed questionnaires (valid completion percentage: 84.0%). Our analysis revealed two critical findings. First, the respondents emphasized that the spacing between turbines significantly influences their visual impact, highlighting the need to enhance the ecological compensation mechanisms for wind power development and ecosystem preservation. Second, they preferred green energy companies to incorporate conservation trust funds into site planning rather than incur additional consumer costs, underscoring the industry's growing role in environmental stewardship and shifting societal expectations. Our results contribute to sustainable wind energy development and ecological conservation in Taiwan and align with global efforts to develop environmentally responsible energy solutions.

KEYWORDS

climate change mitigation, ecologicalconservation, public attitudes, renewable energy, wind power development

1 Introduction

The Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) highlighted that a significant climate crisis is inevitable, even if global warming is limited to 1.5 °C. This climate threat poses severe ecological risks, including ice sheet loss, rising sea levels, reduced biodiversity, and disruptions to ecological chain (IPCC, 2021). To mitigate the effects of global warming, the 26th United Nations Climate Change Conference of the Parties (COP26) agreed to the objectives of the Paris Agreement, focusing on reducing carbon emissions and developing national strategies. This international mandate supports the United Nations' Sustainable Development Goal 7 (Affordable and Clean Energy), which calls for a significant reduction in fossil fuel use and a transition toward renewable energy sources (Baldwin et al., 2019; Swain and Karimu, 2020).

Consequently, wind energy, recognized for its high efficiency, low environmental impact, and mature technology, has become a foundational component of energy policies in several countries (Gielen et al., 2019; Infield and Freris, 2020; Yuping et al., 2021; Zheng et al., 2021). According to the International Renewable Energy Agency, the global renewable energy capacity increased by 260 GW in 2020, representing a 10% annual growth rate, with solar and wind energy accounting for 91% of this increase. With an energy capacity of 1.68 GW, Taiwan surpassed the global average, reflecting a growth of approximately 21%.

The GWEC (2021) reported that wind turbine installations reached 93 GW in 2020, with offshore capacities of 35.3 GW. Onshore installations grew by 13%–19%, while offshore developments surged by 18%–40%, particularly in the United Kingdom (UK), Germany, and the Netherlands (Bureau of Energy and Ministry of Economic Affairs, 2020).

The "23-Year Average Wind Speed Observation" study by 4C Offshore (2020) revealed that 16 of the top 20 offshore wind farms with the highest wind speeds are located in the Taiwan Strait, positioning Taiwan as a prime candidate for future offshore wind development. Inspired by successful European models, Taiwan has undertaken a "4-Year Plan for Wind Power Promotion (2017–2020)," which aims for an installed capacity of 6.9 GW by 2025, with a focus on energy diversification and self-sufficiency (The Executive Yuan, 2019).

However, offshore wind turbines create substantial low-frequency noise during pile-driving construction, raising acute ecological concerns, particularly for marine mammals. The Taichung Port Offshore Wind Farm near the ecologically sensitive Gaomei Wetland poses a direct threat to vulnerable coastal plant species and specific marine species, including the Indo-Pacific humpback dolphin (IPHMD). Therefore, effective noise-mitigation strategies, quantified in this study using specific decibel ranges (dB), are essential for protecting these sensitive marine ecosystems, tourism, and the community's quality of life (Shi, 2020). Consequently, governments must balance ecological, economic, and social sustainability while advancing wind energy, particularly in terms of biodiversity and climate change.

The concept of payment for ecosystem services has emerged as an economic incentive to promote conservation efforts. This approach can curb the exploitation and degradation of ecological resources by assigning tangible value to these resources within communities, aiming for a "No Net Loss" of ecosystem services (Sonter et al., 2020; Yang et al., 2020). Accurate ecosystem evaluation, often quantified using the contingent valuation method, is a crucial aspect of ecological compensation to assess consumers' willingness to pay (WTP) for environmental services (Perez-Verdin et al., 2016).

While research indicates a willingness to invest in renewable energy worldwide (Dreyer et al., 2017; Xie and Zhao, 2018; Einarsdóttir et al., 2019; Koto and Yiridoe, 2019), concerns remain regarding their localized impacts. Public engagement is critical for mitigating the effects of climate change (Keramitsoglou, 2016), and the input of key stakeholders significantly influences energy policy decisions (Omenge et al., 2019; Ediger et al., 2018; Oluoch et al., 2020).

This study is grounded in the theoretical framework of environmental justice to structure this complex interplay among WTP/investment, social acceptability (public engagement), and conservation planning. We focus on procedural, distributive, and recognitional justice (Gürtler, 2023; Hanson and Alkan Olsson, 2022). This framework identifies how the public perceives the fairness of decision-making (Procedural Justice), accepts localized burdens (Distributive Justice), and recognizes the specific needs of different stakeholders (Recognitional Justice).

This study primarily focuses on community acceptance of localized wind power impacts, measured through public WTP for necessary ecological compensation rather than broad-scale market acceptance (willingness to invest in the energy sector generally). This focus allowed us to address acute trade-offs in highly sensitive areas.

This study explicitly addresses the following key research questions:

1. How do Taiwanese residents and tourists perceive the trade-offs between critical wind power attributes (biodiversity protection, noise, visual impact, participation, and cost)?
2. What is the public's Marginal Willingness to Pay (MWTP) for implementing ecological compensation measures to mitigate the environmental damage caused by wind power development?
3. What specific policy strategies can be derived from public preferences to balance the advancement of renewable energy with ecological conservation in sensitive wetland areas?

To address these questions rigorously, this study employs a discrete choice experiment (DCE) integrated with an immersive virtual environment (IVE). This innovative methodological approach mitigates common cognitive biases by providing a realistic visual and auditory experience, offering a superior method for assessing non-market goods, such as wetland conservation, in the context of energy development. This study uses robust econometric models, including conditional logit (CL) and random parameter logit (RPL), to estimate the public WTP for ecological compensation related to Taiwan's conservation priorities. The findings of this study will inform the development of strategies and recommendations for advancing wind power initiatives.

2 Materials and methods

2.1 Theoretical framework

Determining the optimal energy choice involves a complex decision-making process influenced by the region's societal, environmental, and economic factors (Kosenius and Ollikainen, 2013). The DCE experimental method employed in this study is explicitly grounded in random utility theory (RUT). RUT posits that decision-makers (the public) select an alternative wind power development scenario that maximizes their utility. The choice experiment (CE) approach is suitable for quantifying the trade-offs associated with non-market goods and evaluating policy alternatives because utility comprises observable attributes (the systematic component) and unobservable characteristics (the random component).

CE facilitates the construction of multi-attribute utility functions for natural resources, enabling the estimation of the economic value of environmental services. Numerous studies have successfully employed CE to gauge public preferences for renewable energy sources, including wind and solar power, revealing insights into the acceptance and WTP (Kim et al., 2020; Danne et al., 2021; Oluoch et al., 2021).

The preferences of Greek residents regarding wind power attributes, such as plant scale and turbine height (Dimitropoulos and Kontoleon, 2009). German residents' examination of the impact of endangered birds and proximity to residential areas (Meyerhoff et al., 2010). The preference of Korean citizens for solar energy is based on habitat loss and maintenance costs (Yang et al., 2017). Norwegian preferences emphasize installation locations and WTP estimates (Dugstad et al., 2020).

These studies, along with those detailing WTP trends in Turkey (Dogan and Muhammad, 2019; Muhammad et al., 2021), the UK (Demel et al., 2020), Myanmar (Han et al., 2020), and Nigeria (Ayodele et al., 2021), confirm robust public support for renewable energy but underscore that individual and societal factors, including demographics, income, and environmental awareness, strongly shape WTP for specific initiatives. CE is therefore critical for understanding these intricate decision-making processes and elucidating the essential trade-offs among societal, environmental, and economic dimensions.

The experimental design was further structured based on the theoretical foundations of environmental justice to ensure the relevance and ethical framing of the policy trade-offs specific to the sensitive Gaomei Wetland location. This comprehensive framework encompasses three dimensions: (1) Procedural justice necessitates fair and transparent decision-making processes (Zhang et al., 2024; Yang and Lo, 2025). (2) Distributive justice, which requires the equitable sharing of costs and benefits and is often quantified through WTP for compensation (Zepharovich et al., 2021; Strzelecka et al., 2021). (3) Recognitional justice demands acknowledgment of the distinct identities and vulnerabilities of different stakeholder groups, such as local residents *versus* tourists (Blue et al., 2021; San Martín and Wood, 2022).

The specific operationalization of these three dimensions—linking them to the attributes Biodiversity, Noise Level, Visual Impact, Public Participation, and Conservation Trust Fund—is detailed in the DEC Design (Section 2.2), where the attributes and levels are introduced.

Finally, we integrated the IVE to enhance the reliability of the DCE. Traditional DCE methods struggle to ensure that respondents adequately comprehend the measurement of abstract or numerical attributes. The integration of IVE technology addresses this issue by enhancing understanding through visualization techniques, providing a more immersive experience than traditional media, and standardizing stimulus exposure to mitigate experimental bias (Blascovich et al., 2002; Cranmer et al., 2020). Empirical evidence (Cranmer et al., 2020) suggests that immersive approaches positively influence public perceptions and improve the acceptance of renewable energy projects compared with traditional methods.

2.2 Distinct choice experiment design

In this study, a conventional fractional factor DCE design was employed to assess public preferences for wind power development and conservation policies. Participants were presented with structured trade-offs between project attributes consistent with standard choice-based conjoint methodologies. The DCE was integrated into an IVE to enhance realism and mitigate the cognitive biases associated with abstract policy options.

The IVE used 720-degree panoramic images generated from synthesized camera data (Blascovich et al., 2002; Cranmer et al., 2020), ensuring a realistic visual and auditory experience (Figure 1). The visualization was delivered using a standard head-mounted display system (e.g., Oculus Quest 2, 90 Hz refresh rate) to maximize immersion. Each participant was exposed to visual and auditory stimuli corresponding to a given choice set for a standardized duration of 45 s before selection.

The overall survey instrument was structured into three segments:

1. Environmental Awareness Assessment: This section assessed respondents' environmental awareness, knowledge of the impacts on marine fisheries, and preferences regarding wind power development.
2. Assessment Model (Choice Task): This segment established a multi-attribute assessment model for wind energy development.
3. Demographic Data Collection: The section collected essential demographic data, including age, sex, income, and education level.

2.2.1 Attribute selection and levels

The experimental design incorporated five key attributes, selected to align with the environmental justice framework, and addressed the specific policy trade-offs relevant to wind power development near the ecologically sensitive Gaomei Wetland. The attributes and their corresponding levels are listed in Table 1.

The five attributes are defined as follows:

1. Biodiversity: Defined as an indicator of ecological status and species abundance that reflects the diversity of wetland and marine species. It was operationalized as the percentage reduction in current species diversity (30% reduction, 50% reduction, and biodiversity maintenance). This attribute evaluates trade-offs concerning local fauna and flora based on the current development status, consistent with the conservation needs assessed in previous studies (Hassan et al., 2019; Owuor et al., 2019; Pieretti and Danovaro, 2020).
2. Noise Level: Noise levels of the wind turbines were set based on Taiwan's Environmental Protection Administration (2013) "Noise Control Standards," which specify various decibel ranges. The levels used in the experiment (0, 20, 40, 60, and 80 dB) also considered the auditory sensitivity range of the IPHMD (5–100 Hz), a species present near the site (Wang, 2018).
3. Visual Impact: This attribute addresses line-of-sight visual intrusion, a critical esthetic disamenity that significantly influences public attitudes toward wind power (Lee et al., 2020; Peri et al., 2020). The horizontal spacing between the turbines was used to quantify the visual impact, with levels set at 400, 600, and 800 m spacing, referencing a standard 1.65 MW wind turbine. Distance directly reflects perceived scenic intrusion affecting stakeholders.

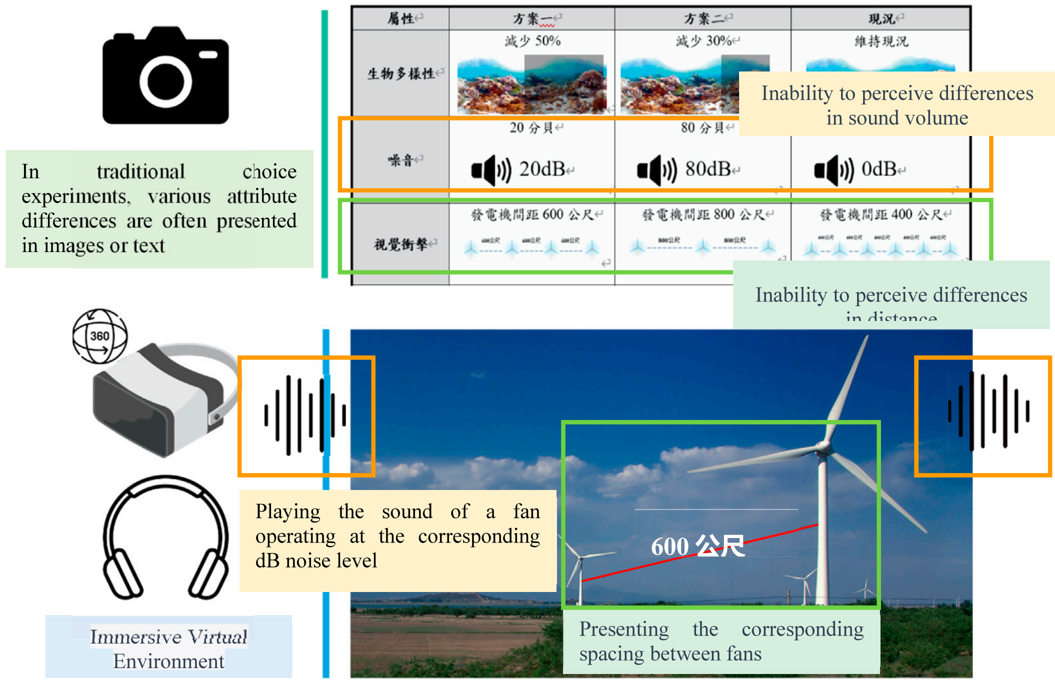


FIGURE 1
Differences between traditional choice experiments and the use of VR tools.

TABLE 1 Attributes and levels used in the choice experiment design.

Attribute	Attribute description	Number of levels	Levels for the alternatives	Status quo level
Biodiversity	Ecological health	3	30% reduction in biodiversity; 50% reduction in biodiversity	Maintaining biodiversity
Noise level	The sound	3	20 dB; 40 dB; 80 dB noise level	0 dB noise level
Visual impact	Esthetic impact determined by turbine proximity and spacing	3	400-m turbine spacing; 600-m turbine spacing; 800-m turbine spacing	400-m turbine spacing
Public participation	The level	3	No participation; information participation (via the internet/materials/TV); public hearing participation	No participation
Conservation trust fund	Annual financial contribution (NTD/year) paid	4	NTD 0/year; NTD 500/year; NTD 1,000/year; NTD 1,500/year	NTD 500/year

4. Public Participation: Public involvement in decision-making is critical for acceptance. The levels included "no participation," "information participation (via internet/materials/TV)," and "public hearing participation."
5. Conservation Trust Fund (WTP): This monetary attribute serves as a cost attribute in the DCE. This represents the respondent/public's annual financial contribution (NTD/year) to fund the ecological compensation measures required by the ecological resources of the Gaomei Wetland. The attribute levels tested were NTD 0/year, NTD 500/year, and NTD 1,000 and 1,500 per year.

2.2.2 Experimental design and choice task

The combination of the five attributes (three, three, three, three, three, and four levels) resulted in a full factorial of 324 possible unique scenarios (3 × 3 × 3 × 3 × 4 = 324 scenarios). An orthogonal design based on the FFM was used to select a balanced subset of attribute level combinations to achieve efficiency and minimize respondent burden, resulting in 16 core experimental alternatives (scenarios). The design optimization capabilities within NGEN software were used to ensure that the design maintained D-efficiency relative to the full factorial design.

These 16 alternatives were combined with a fixed *status quo* scenario. The *status quo* reflected the current policy and environmental baseline: maintaining biodiversity, 0 dB noise level, 400-m turbine spacing, and no public participation. Crucially, the cost level for the *status quo* was fixed at a non-zero NTD 500/year as an existing Conservation Trust Fund contribution.

After excluding three impractical attribute combinations, 66 choice sets were generated through permutation procedures. Each respondent was presented with three choice sets for evaluation.

The choice question was designed as a ternary choice (three options), requiring the respondent to select the single most preferred option among the two hypothetical alternatives (Schemes 1, 2) and the fixed *status quo* option (Table 2).

The exact question was as follows:

> "Considering the ecological, social, and financial implications of each scheme, which of the three options (Schemes 1, 2, or the Status Quo) do you prefer?"

Respondents indicated their choice by selecting one box: "Scheme selection (choose one from the three) Schemes 1, 2 Status Quo."

A comprehensive *status quo* option (fixed at the current policy/environmental baseline) served as a robust anchor. This mechanism enables respondents to reject both hypothetical schemes if they are deemed unacceptable, thus functioning as a rejection option.

2.3 Model selection and analysis

The choice data were analyzed using the CL and RPL models, both of which were grounded in RUT. The DCE is an established approach for assessing the MWTP for various attributes, reflecting public preferences for ecological compensation (Shoyama et al., 2013; Lyu, 2017).

2.3.1 CL and RPL

The CL model serves as the baseline, assuming that the error terms are independently and identically Gumbel-distributed, which enforces the independence of irrelevant alternatives (IIA) as a restrictive assumption.

Subsequently, the RPL model was employed to overcome the IIA assumption and to capture heterogeneity in respondents' preferences regarding attributes such as biodiversity and visual impact. This model captures variations in preferences among individuals with diverse backgrounds by interpreting the coefficients as the means of the assumed random parameter distributions.

Random parameters were defined for key nonmonetary attributes (BD_1, BD_2, NL_1, NL_2, VI_1, VI_2, PP_1, and PP_2) and the cost attribute (FUND) to account for observed taste variation in how individuals value changes in biodiversity, noise level, and visual impact. Following the standard practice in choice modeling, all nonmonetary parameters were assumed to follow a normal distribution, while the monetary (cost) parameter (β_{cost}, FUND) was fixed to be lognormally distributed to ensure negative signs in utility, consistent with economic theory.

2.3.2 Model fit and convergence criteria

The model estimation relied on standard maximum likelihood estimation procedures. The models achieved statistical convergence, demonstrating significant predictive power compared with the intercept-only null model. Specifically, the likelihood ratio test confirmed that the estimated parameters were highly significant for both groups (Tourists: $p < 0.001$; Local Residents: $p < 0.001$). For tourists, the log-likelihood (LL) shifted from −1937.906 (CL) to −1923.188 (RPL). For local residents, the LL shifted from −758.888 (CL) to −745.501 (RPL).

This improvement, along with the statistical significance of the coefficients (as detailed in Table 6), confirms that compared with the null model, the estimated parameters significantly improve predictive power, justifying their use for subsequent analysis.

2.3.3 Latent class model

The LCM was combined with RPL analysis to explore the distinct groupings of preferences that may exist within the population segments. The LCM assumes that preference heterogeneity can be modeled by segmenting the population into a finite number of distinct classes.

The selection of the two-class solution for tourists and residents was based on optimizing the model fit. This determination used the Bayesian information criterion (BIC), specifically when the BIC value reached its minimum, thereby ensuring the most parsimonious balance between the model complexity and explanatory power. This selection process involved testing models from one to five classes. The two-class solution was chosen to minimize the BIC while maintaining theoretical relevance. The calculated BIC values supporting this segmentation were as follows: Tourists: BIC = 2.1590; and Residents: BIC = 2.1994.

To ensure full transparency regarding the choice sets used, we clarify that the values in Table 6 (choice sets) reflect the total possible observations generated by the experimental design (5,490 tourists, 2,160 residents), while the N. obs. reported in Table 7 reflect the total number of choices made by the respondents (1,830 tourists, 720 residents based on three choice tasks per respondent).

2.3.4 Estimation of marginal willingness to pay

The MWTP estimates (Table 8) for each nonmonetary attribute were derived from the ratio of the respective non-cost attribute coefficient (β_{attribute}) to the negative cost coefficient (β_{cost}), where the cost coefficient is derived from the FUND attribute. The MWTP reflects the annual implicit price that respondents are willing to pay to improve a specific attribute level, such as enhanced turbine spacing or reduced noise. Therefore, the Conservation Trust Fund attribute functions explicitly as a WTP cost metric.

2.4 Data collection and statistical analysis

2.4.1 Data collection and ethical procedures

This study targeted two distinct and relevant groups: tourists visiting the Taichung Wind Power Station area and residents living nearby. This geographical focus was employed to evaluate public preferences and perceptions regarding ecological conservation and wind power development near the ecologically sensitive Gaomei Wetland.

The data collection methods were standardized and accessible to all participants. Two complementary methods were used: one-on-one interviews and online questionnaires. Online access was provided via QR codes placed at public points of interests to mitigate potential contact risks and offer flexible participation options. Before engaging the participants, the interviewers provided a standardized briefing that covered the study's

TABLE 2 Questionnaire design example.

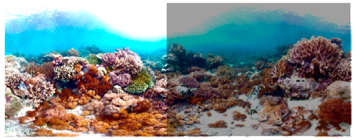
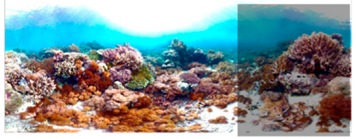
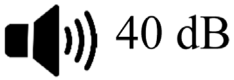
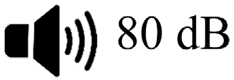
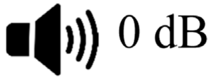
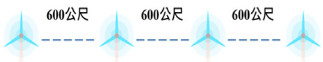
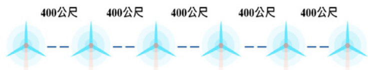
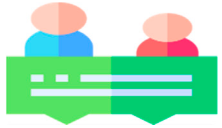
Attribute	Scheme 1	Scheme 2	Status Quo
Biodiversity Noise level	50% reduction 	30% reduction 	Maintaining biodiversity 
Visual impact	40 dB 	80 dB 	0 dB 
Public participation	600 m turbine spacing 	800-m turbine spacing 	400-m turbine spacing 
Conservation trust fund (CTF)	No participation 	Information participation (internet, reading materials, or TV programs) 	Participation in public hearings 
	NTD 1,500/year	NTD 1,000/year	NTD 500/year
Scheme selection (choose one from three)	□	□	□

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TABLE 3 Demographic information.

Variable	Item	Tourists (N = 610)		Local residents (N = 240)	
		N	%	N	%
Gender	Male	298	48.9%	114	47.5%
	Female	312	51.1%	126	52.5%
Age (years)	Under 25	60	9.8%	10	4.2%
	26–35	181	29.7%	47	19.6%
	36–45	145	23.8%	59	24.6%
	46–55	130	21.3%	81	33.8%
	56–64	69	11.3%	30	12.5%
	65 above	25	4.1%	13	5.4%
Education level	Junior high schooling under	28	4.6%	3	1.3%
	Senior high school or vocational school	35	5.7%	37	15.4%
	Junior college	143	23.4%	58	24.2%
	Bachelor's degree	295	48.4%	119	49.6%
	Master's degree	95	15.6%	19	7.9%
	Doctor's degree and above	14	2.3%	4	1.7%
Average monthly personal income	NTD 30,000 and below	119	19.5%	19	7.9%
	NTD 30,001–50,000	211	34.6%	100	41.7%
	NTD 50,001–70,000	160	26.2%	78	32.5%
	NTD 70,001–90,000	92	15.1%	32	13.3%
	NTD 90,001 and above	28	4.6%	11	4.6%
Participation in environmental groups	Yes	66	10.8%	11	4.6%
	No	544	89.2%	229	95.4%
Preference for ecocompensation	Ecological remediation	427	70.0%	187	77.9%
	Ecosystem creation	183	30.0%	53	22.1%

background, research objectives, and explanations of the survey attributes.

Ethical Review and Consent: This study did not require formal ethics committee review and approval in accordance with the host institution guidelines and local legislation. The study was classified as minimal risk because it did not involve vulnerable populations, sensitive personal information, or any interventions beyond the voluntary completion of the questionnaire. The survey questions solely addressed the participants' opinions and attitudes toward environmental conservation and renewable energy projects. Under these conditions, implied informed consent was inferred through the voluntary completion and submission of the questionnaire was deemed sufficient.

All respondents were informed of the study's purpose, scope, and anonymity safeguards, both verbally and in writing, and were advised that participation was entirely voluntary. Data collected via the online questionnaire were secured using industry-standard encryption protocols and stored on secure servers to ensure participant anonymity and data confidentiality.

2.4.2 Sample size and descriptive statistics

A total of 1,012 questionnaires were distributed to participants. Of these, 850 were deemed valid, yielding a valid completion rate of 84.0%. The final valid respondent pool comprised 610 tourists and 240 residents. The integration of online data collection methods, which were employed in part, is supported in the literature as a way to improve efficiency and enhance data quality in survey-based research (Alalwan, 2020).

Table 3 summarizes the respondents' demographic characteristics, including sex, age, education level, monthly household income, and participation in environmental groups. Notably, the sample consisted of slightly more females than males across both groups, and the largest age group for tourists was 26–35 years (29.7%), whereas it was 46–55 years (33.8%) for residents.

TABLE 4 Ecological knowledge and ecological compensation.

Item	Options	Tourists		Local residents	
		N	%	N	%
1. Do you believe that "wind power generation" harms the environment?	Yes	489	80.2%	204	85.1%
	No	89	14.6%	27	11.2%
	No idea	32	5.2%	9	3.7%
2. Have you heard that the government plans to develop "wind power generation" in the Taichung Gaomei wetland?	Yes	484	79.4%	209	87.1%
	No	126	20.6%	31	12.9%
3. Do you believe that wind power facility construction will influence the surrounding ecosystem?	Yes	492	80.7%	199	83.3%
	No	77	12.6%	35	14.4%
	No idea	41	6.7%	6	2.3%
4. Do you agree with the prevention or mitigation of hazards to the Ecosystem via "ecocompensation"?	Yes	434	71.2%	176	73.4%
	No	97	15.9%	27	11.2%
	No idea	79	12.9%	37	15.4%
		Average value	Standard deviation	Average value	Standard deviation
5. How well do you know about "wind power generation?"		5.08	0.96	5.38	0.88
6. How well do you know about "ecocompensation?"		5.16	0.87	5.20	0.73

3 Results

3.1 Ecological awareness and preferences

Table 4 summarizes the descriptive statistics for the respondents' ecological knowledge and preferences for ecosystem protection. Participants rated their agreement with statements regarding wind power development and ecological compensation using a seven-point Likert scale ranging from 1 ("strongly disagree") to 7 ("strongly agree").

The results indicated that tourists and residents had an intermediate self-reported knowledge level concerning "wind power generation" (Tourists: 5.08, SD 0.96; Residents: 5.38, SD 0.88) and "ecocompensation" (Tourists: 5.16, SD 0.87; Residents: 5.20, SD 0.73). In general, local residents demonstrated a slightly greater awareness of wind power generation than tourists. This finding suggests that authorities such as the Tourism Bureau and the Agricultural Committee should consider intensifying promotional efforts through campaigns, video guides, and guided tours to bridge the remaining knowledge gaps regarding wind power development and ecological compensation issues.

Table 4 also demonstrate a strong awareness of the local context and potential environmental impact. Approximately 80% of tourists (79.4%) and 87.1% of residents reported hearing about the government's plan to develop wind power generation in the Gaomei Wetland area. Furthermore, a significant majority of respondents acknowledged the potential harms of development: 80.2% of tourists and 85.1% of local residents believed that wind power generation harmed the environment, and a similar proportion (80.7% of tourists; 83.3% of residents) agreed that the construction of facilities would influence the surrounding ecosystem. Approximately 70% of both groups agreed with "ecocompensation" to prevent or mitigate hazards (Tourists: 71.2%; Residents: 73.4%). Additionally, the majority of respondents favored ecological remediation over ecosystem creation (Tourists: 70.0%; Residents: 77.9%).

3.2 Preferred combination of attributes

Table 5 presents the respondents' choices across the predefined attribute combinations in the experiment. The analysis focused on identifying the policy scenarios (alternatives) that were most and least frequently selected among the 16 core alternatives and the *status quo* option.

Most Preferred Combination: Both tourists and local residents selected alternative no. 1 as their single most preferred scenario, demonstrating a consensus on minimizing immediate financial commitment. A total of 8.9% of tourists (n = 163) and 15.1% of local residents (n = 109) selected Alternative 1. This highly favored combination included attribute levels reflecting low perceived financial costs, specifically an NTD 0/year Conservation Trust Fund contribution, along with information participation, a 20-dB noise level, 400-m turbine spacing, and acceptance of a 30% biodiversity reduction.

Least preferred combination and *status quo*: The least preferred choice differed between the groups. Based on the overall selection frequency, the *status quo* scenario was the least preferred option for local residents, which was chosen by only 1.7% of the residents (n = 12). Notably, the *status quo* reflected biodiversity maintenance, a 0-dB noise level, 400-m turbine spacing, and no public participation, but it required an

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TABLE 5 Combination of the respondents' preferences.

No.	Biodiversity	Noise level	Visual impact	Public participation	Conservation trust fund (CTF)	Tourists		Local residents	
						N	%	N	%
1	30% reduction	20 dB noise level	400-m turbine spacing	Information participation	NTD 0/year	163	8.9%	109	15.1%
2	30% reduction	0 dB noise level	800-m turbine spacing	No participation	NTD 1,000/year	158	8.6%	94	13.1%
3	Maintaining the number of species	20 dB noise level	800-m turbine spacing	No participation	NTD 500/year	131	7.2%	82	11.4%
4	50% reduction	80 dB noise level	800-m turbine spacing	Participation in public hearings	NTD 0/year	141	7.7%	68	9.4%
6	Maintaining the number of species	0 dB noise level	600 m turbine spacing	Participation in public hearings	NTD 1,500/year	129	7.0%	50	6.9%
7	50% reduction	0 dB noise level	600 m turbine spacing	No participation	NTD 1,000/year	141	7.7%	48	6.7%
8	Maintaining the number of species	80 dB noise level	400-m turbine spacing	Information participation	NTD 1,000/year	143	7.8%	57	7.9%
9	Maintaining the number of species	80 dB noise level	600 m turbine spacing	No participation	NTD 500/year	139	7.6%	41	5.7%
11	50% reduction	0 dB noise level	400-m turbine spacing	Information participation	NTD 500/year	132	7.2%	40	5.6%
12	30% reduction	0 dB noise level	400-m turbine spacing	Participation in public hearings	NTD 500/year	124	6.8%	29	4.0%
13	Maintaining the number of species	0 dB noise level	800-m turbine spacing	Information participation	NTD 1,500/year	148	8.1%	50	6.9%
16	Maintaining the number of species	20 dB noise level	400-m turbine spacing	Participation in public hearings	NTD 1,000/year	156	8.5%	40	5.6%
Status quo	Maintaining the *status quo*	0 dB noise level	400-m turbine spacing	No participation	NTD 0/year	125	6.8%	12	1.7%

existing NTD 500/year Conservation Trust Fund contribution. The scenario with the lowest selection frequency for tourists was Alternative No. 12 (6.8%, n = 124). This option included a 30% reduction in biodiversity, 0-dB noise level, 400-m turbine spacing, public hearing participation, and an NTD 500/year Conservation Trust Fund contribution.

These descriptive findings indicate that respondents generally preferred scenarios that minimized immediate financial commitment (NTD 0/year) and noise levels (20 dB) but were willing to accept minimal biodiversity reduction (30%).

3.3 Results of the model analysis

The choice data were analyzed using the CL and RPL models, supplemented by an LCM, to segment and explore public preferences and estimate the MWTP for wind power attributes.

3.3.1 CL and RPL coefficients

Table 6 presents the CL and RPL estimation results for both tourists and residents. The RPL model, employed to capture preference heterogeneity, confirmed significant taste variations, as evidenced by the significance of biodiversity, noise level, and visual impact.

CL Model Interpretation: Analysis using the CL model showed that tourists exhibited significantly positive utility for aesthetics and conservation attributes. Specifically, they favored a 50% reduction in biodiversity mitigation (BD_2) (coefficient = 0.1182, t-value = 1.697*) and the widest turbine spacing (VI_2: 800 m) (coefficient 0.1933, t-value = 3.926***). Tourists also favored PP1 (coefficient = 0.1657, t-value = 3.280). In contrast, local residents demonstrated strong positive coefficients, primarily for minimizing localized nuisances. Residents significantly preferred a 20-dB noise level (NL_1; coefficient = 0.2532; t-value = 2.264*) and 800-m turbine spacing (VI_2; coefficient = 0.2969; t-value = 3.770***).

The RPL results, which account for the preference heterogeneity, confirm a general preference for specific mitigation measures. Overall, tourists expressed preferences for six improved attributes (BD_2, NL_1, NL_2, VI_1, VI_2, and PP_2), whereas residents demonstrated significant preferences for four attributes (BD_2, NL_1, NL_2, and VI_2).

3.3.2 Heterogeneity of the LCM preference

The LCM analysis revealed the existence of two distinct latent groups for both tourists and residents, a finding statistically supported by the optimization of model fit using the Bayesian information criterion (BIC). Table 7 lists the segmentation results obtained using the proposed model.

For the tourist segment (N. obs. = 1,830), Group 1 (Biodiversity/Visual Priority) demonstrated a strong positive preference for significant mitigation measures, specifically favoring 800-m turbine spacing (VI_2) (coefficient = 1.5803***) and a 50% reduction in biodiversity (BD_2) (coefficient = 0.5961**). Interestingly, membership in this group was significantly and negatively influenced by age (AGE: −0.9797*), suggesting that younger tourists may place a higher premium on specific ecological and aesthetic protections. Conversely, Tourist Group 2 (Noise/Participation Priority) exhibited a different set of priorities, showing a strong preference for a 30% reduction in biodiversity (BD_1) (coefficient = 1.8920***) and accepting a higher noise level of 80 dB (NL_2) (coefficient = 1.5277***).

Among the local residents (N. obs. = 720), segmentation likewise identified two groups with divergent concerns. Resident Group 1 (Immediate Impact Priority) prioritized the minimization of localized nuisances, as evidenced by strong positive preferences for a 20 dB noise level (NL_1) (coefficient = 0.4853***) and the widest 800-m turbine spacing (VI_2) (coefficient = 0.5597***). The analysis indicates that membership in this group is significantly influenced by both sex (coefficient = 0.4610*) and age (coefficient = −0.8725*), highlighting that these demographic factors are critical drivers of how residents perceive the daily quality-of-life impact of wind farms. In contrast, Resident Group 2 exhibited non-significant positive coefficients across the tested attributes, indicating a segment of the population with less-defined or statistically detectable preference patterns.

Collectively, the LCM analysis highlights that preference heterogeneity is not random but is strongly shaped by socioeconomic factors, emphasizing the need for renewable energy policies that recognize the distinct vulnerabilities and expectations of different stakeholder groups.

3.3.3 Marginal willingness to pay (MWTP)

Table 8 presents the estimated MWTP for each attribute level, reflecting the annual implicit price that respondents are willing to pay for policy improvements.

Resident and Tourist Valuation Priorities: Local residents demonstrated the highest valuation for mitigating localized visual impact, valuing the 800-m turbine spacing (VI_2) the highest at NTD = 1,222.39. Residents also placed substantial value on ecological compensation and noise mitigation, with the MWTP for a 50% reduction in biodiversity mitigation (BD_2) reaching NTD = 817.71 and the 20 dB noise level (NL_1) valued at NTD = 800.14.

Conversely, tourists expressed the highest WTP for mitigating ecological damage, valuing a 50% reduction in biodiversity (BD_2) at NTD = 1,175.84. This was followed by a noise level of 80 dB (NL_2) (NTD = 1,002.53) and a turbine spacing of 800 m (VI_2) (NTD = 987.16).

Key Analytical Findings: The MWTP results highlighted several critical trends. Both stakeholder groups expressed a high WTP for the widest turbine spacing (VI_2:800 m), confirming that visual mitigation was a major driver of the public's acceptance. Crucially, the analysis revealed a paradoxical biodiversity valuation: both tourists and residents expressed a significantly positive WTP for mitigation associated with a 50% reduction in biodiversity (BD_2) but exhibited a substantial negative WTP for a 30% reduction (BD_1) (Tourists: NTD = −1,009.74; Residents: NTD = −883.82). This outcome suggests that respondents perceived ecological damage as inevitable in this context and were only willing to pay for compensatory measures that addressed substantial and acknowledged impacts. Finally, both tourist and resident groups exhibited a negative MWTP for all public participation attributes (PP_1 and PP_2), consistent with the utility analysis.

TABLE 6 Multinomial logit empirical estimation results.

Variable designation	Tourists						Local residents					
	CL		RPL				CL		RPL			
	Coefficient	*t*-value	Coefficient	*t*-value	Standard error	*t*-value	Coefficient	*t*-value	Coefficient	*t*-value	Standard error	*t*-value
BD_1	−0.1115	−1.599	−1.9185	−0.371	7.6896	0.377	−0.7331	−0.660	−2.4747	−0.298	11.9981	0.305
BD_2	0.1182	1.697*	2.2341	0.380	4.5847	0.371	0.1302	1.158	2.2896	0.301	2.2992	0.273
NL_1	0.0573	0.819	0.8936	0.370	9.1087	0.377	0.2532	2.264*	2.2404	0.307	1.7556	0.253
NL_2	0.1120	1.603	1.9048	0.374	0.1997	0.070	−0.0126	−0.111	0.6081	0.266	0.3248	0.080
VI_1	0.0413	0.837	0.7492	0.370	0.0603	0.022	−0.0210	−0.265	−0.7629	−0.303	3.3055	0.285
VI_2	0.1933	3.926***	1.8756	0.377	8.8056	0.377	0.2969	3.770***	3.4227	0.308	2.5813	0.280
PP_1	0.1657	3.280***	−1.2825	−0.375	2.4351	0.347	−0.1096	−1.367	−0.7539	−0.317	0.2206	0.049
PP_2	0.0723	1,455	0.4068	0.335	5.5394	0373	0.0475	0.592	−0.3401	−0.227	5.3685	0.297
FUND	−0.0001	−0.652	−0.0019	0.105			−0.5905	−0.220	−0.0028	−0.154		
Choice sets	5,490		5,490				2,160		2,160			
Log-likelihood ratio	−1937.906		−1923.188				−758.888		−745.501			

*** and * are significant at 1% and 10%, respectively.

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TABLE 7 LCM results.

Attributes and variables	Tourists				Local residents			
	Group 1		Group 2		Group 1		Group 2	
	Coef	Std. Err	Coef	Std. Err	Coef	Std. Err	Coef	Std. Err
BD_1	−0.6422***	0.5896	1.8920***	0.1241	−0.2561	0.1599	5.8407	0.1810
BD_2	0.5961**	0.2510	0.0024	0.1019	0.3741*	0.1664	4.5228	0.1748
NL_1	−0.1190	0.3173	0.0793	0.1018	0.4853***	0.1644	−0.4400	0.1004
NL_2	−0.1612**	0.6906	1.5277***	0.1235	−0.1226	0.1699	1.9989	0.0882
VI_1	−0.3815	0.2481	0.4164***	0.0785	0.0288	0.1121	−0.6348	0.0508
VI_2	1.5803***	0.3395	−0.4909***	0.0816	0.5597***	0.1232	−0.6890	0.1301
PP_1	−0.3740***	0.3574	0.2195**	0.0734	−0.1417	0.1149	0.2286	0.1004
PP_2	0.7536**	0.2579	0.0819	0.0777	−0.0591	0.1251	1.8801	0.0882
FUND	−0.0052***	0.0013	−0.0028***	0.0002	−0.0004	0.0004	0.2894	0.0523
Membership variables								
SEX	0.0083	0.1379			0.4610*	0.2487		
AGE	−0.9797*	0.4579			−0.8725**	0.4182		
EDU	−0.0695	0.1858			−0.0804	0.3448		
MARRY	−0.1185	0.1437			0.3113	0.2773		
INCOME	0.0146	0.1409			−0.0558	0.2894		
Log-likelihood	−937.906				−58.888			
AIC	2.1289				2.1358			
BIC	2.1590				2.1994			
N. obs	1,830				720			

** and * are significant at 1%, 5%, and 10%, respectively.

TABLE 8 MWTP for each attribute.

Attributes and variables	Variable designation	MWTP (NTD)—Tourist	MWTP (NTD)—Local residents
BD_1	30% reduction in the biodiversity	NTD −1,009.74	NTD −883.82
BD_2	A 50% reduction in biodiversity	NTD 1,175.84	NTD 817.71
NL_1	20 dB of noise level	NTD 470.32	NTD 800.14
NL_2	80 dB of noise level	NTD 1,002.53	NTD 217.18
VI_1	600 m between the turbines	NTD 394.32	NTD −272.46
VI_2	800 m between the turbines	NTD 987.16	NTD 1,222.39
PP_1	Information participation	NTD −675.00	NTD −269.25
PP_2	Participation in public hearings	NTD 214.11	NTD −121.46

4 Discussion

This study utilized a CE integrated with an IVE to conduct a comprehensive multi-attribute preference analysis of wind power development, wetland ecosystem conservation, and compensation preferences among tourists and residents near the Taichung Wind Power Plant and Gaomei Wetland. The RPL model's estimation of the MWTP yielded significant insights that must be interpreted in light of existing empirical evidence and the theoretical framework of environmental justice. Crucially, these findings reflect respondents' stated preferences and MWTP rather than observed behavior or actual market dynamics.

Although wind power infrastructure imposes localized externalities that theoretically invoke a willingness to accept (WTA) compensation for environmental degradation, this study uses WTP as the primary metric. This methodological choice is justified because our primary research objective is to quantify the public's WTP for environmental mitigation and policy improvement (ecological compensation), which falls within the WTP framework. We assessed the public's WTP for implementing ecological compensation measures to mitigate environmental damage induced by wind power development. Therefore, the MWTP functions as an economic measure of the required level of societal resource allocation needed to achieve a socially acceptable outcome (mitigated noise, improved spacing, and effective compensation) relative to the baseline (Status Quo).

The MWTP for mitigating burdens such as visual impact (NTD = 1,222.39 for residents for 800-m spacing) quantifies the value of avoiding or compensating for acute localized nonmonetary costs within the context of DJ. These high positive MWTP values establish the necessary economic thresholds for a fair impact distribution.

Furthermore, the negative MWTP observed for attributes such as inadequate biodiversity compensation (30% reduction, e.g., tourists: NTD = −1,009.74) and public participation (e.g., tourists: NTD = −675.00) is critical. These negative valuations serve as an effective proxy for the WTA, indicating that the public requires a negative price (i.e., compensation or policy removal/reform) to accept these inadequate attributes. Thus, the observed positive MWTP values quantify the cost of improvement, whereas the negative MWTP values define the threshold of unacceptability (WTA threshold), providing a comprehensive picture of community acceptance within the framework of environmental justice.

4.1 Localized impacts, visual esthetics, and distributive justice

Interpreting public preferences through the lens of Distributive Justice reveals that local stakeholders demand MWTP proportionate to the localized nonmonetary burdens imposed by the wind power infrastructure. The public views this compensation as essential for balancing the regional benefits of clean energy with the acute local costs incurred by the community, such as visual disamenities and noise.

Our results strongly align with those of prior research, demonstrating that visual impact substantially affects public opposition to wind turbine construction (Peri et al., 2020). Tourists and residents consistently assigned the wider turbine spacing (800 m) a high positive utility and substantial MWTP. Minimizing visual blight was the most highly valued compensatory mechanism for local residents, as the 800-m turbine spacing (VI_2) commanded the highest MWTP (NTD = 1,222.39). This substantial valuation indicates that visual blight associated with proximity is not merely an esthetic preference but also a critical local burden that infringes on community wellbeing. This finding underscores that achieving fair cost distribution requires adherence to established recommendations to maintain significant distances (800–1,300 m) from ecologically sensitive areas and habitats (Li et al., 2020; Vuichard et al., 2022).

Furthermore, the high valuation placed on noise mitigation emphasizes these localized impacts. Residents directly affected by daily operations and proximity effects prioritize lower noise levels (20 dB) and exhibit a substantial MWTP (NTD 800.14). This preference confirms previous findings that individuals residing near wind turbines are more sensitive to operational noise, which adversely affects their QoL (Arezes et al., 2014). Therefore, the positive MWTP for noise mitigation among local residents serves as direct economic evidence of the necessity of DJ by compensating for the unavoidable impacts on their immediate environment and wellbeing.

Although the cost coefficient for the Conservation Trust Fund (β_{cost}, FUND) was statistically insignificant in the RPL model estimations for both tourists and residents (Table 6), the derived MWTP estimates remain robust for policy analysis. This nonsignificance is interpreted as empirical evidence of the public's rejection of additional consumer costs (NTD 0/year preference). Furthermore, the high statistical significance of the nonmonetary attributes (e.g., VI_2, NL_1, BD_2) and the overall predictive power of the RPL models (LL shift confirmed as highly significant $p < 0.001$) justify the use of these MWTP estimates as economic indicators of the relative value placed on specific mitigation attributes required for social acceptance, consistent with the requirements of DJ.

4.2 Ecological compensation and corporate stewardship

The analysis of the MWTP for the Conservation Trust Fund provides critical insights into public expectations regarding environmental mitigation and corporate responsibility. Tourists and residents provided robust support for the general concept of ecological compensation, which aligns with the findings of Gao et al. (2023) and Liu et al. (2023), confirming its role in balancing green energy development and ecosystem preservation.

Crucially, respondents revealed a strong preference regarding the source of this compensation, indicating that green energy companies should incorporate conservation trust funds into site planning, rather than passing additional financial costs directly to consumers. The most preferred scenario (Alternative 1) for both tourists and local residents included an NTD 0/year Conservation Trust Fund contribution, directly demonstrating the rejection of additional consumer costs. This preference underscores the evolving societal expectations regarding the industry's role in environmental stewardship. The public perception is that operators should undertake comprehensive resource planning and financing before constructing wind turbines. This finding supports the assertion that GEOs must actively implement compensation measures to balance their ecological and economic requirements (Cheng et al., 2022).

The paradoxical MWTP valuation of biodiversity was a notable finding. Respondents exhibited a negative WTP for a minor trade-off, specifically a 30% reduction in biodiversity (BD_1) (e.g., residents: NTD = −883.82; tourists: NTD = −1,009.74), but demonstrated a significant positive WTP for mitigation measures associated with a substantial 50% reduction in biodiversity (BD_2) (e.g., residents: NTD = 817.71; tourists: NTD = 1,175.84).

This paradox demonstrates the sophistication of public judgment rooted in the effectiveness of perceived policies. The negative valuation for minor damage (BD_1) implies that stakeholders view token conservation efforts as ineffective or inadequate, given the context of sensitive wetland area development. They are unwilling to financially support conservation commitments that they believe will ultimately fail to achieve their goals. Conversely, the positive WTP for mitigating the substantial 50% reduction (BD_2) signals that stakeholders value the compensation mechanism itself—the assurance that substantive steps will be taken to address major impacts—over a minimal conservation commitment. This finding implies that policy design in sensitive regions must acknowledge the perception of inevitable ecological loss and direct resources toward demonstrably robust compensatory actions rather than relying on minimal "No Net Loss" assumptions.

4.3 Preference heterogeneity and procedural justice

The application of the LCM allowed for the segmentation of the surveyed population, addressing the requirements of RJ by acknowledging the specific, distinct preferences of the affected stakeholder groups.

4.3.1 Recognition of justice and heterogeneity among stakeholders

To prevent the dilution of the acute concerns of local residents, who represent a smaller but disproportionately affected segment of the population, this study intentionally analyzed tourists and residents as distinct stakeholder groups. This separation reveals critical divergences in valuation that are essential for Recognitional Justice. Local residents prioritized the minimization of immediate localized nuisances that affect their daily quality of life, assigning their highest valuations to 800-m turbine spacing (VI_2) (NTD = 1,222.39) and a 20 dB noise level (NL_1) (NTD 800.14). In contrast, while tourists also placed significant value on visual esthetics (VI_2 MWTP: NTD 987.16), their preferences were more complex, characterized by a dominant willingness to pay to mitigate substantial ecological damage (BD_2 MWTP: NTD = 1,175.84).

The LCM analysis confirmed that socioeconomic factors strongly drive preference heterogeneity. Age significantly influenced attitudes toward wind power attributes for tourists and residents. Membership in Resident Group 1 (Immediate Impact Priority), which strongly preferred noise and visual mitigation (NL_1 and VI_2), was also significantly influenced by sex. These findings underscore the need for developmental planning that actively incorporates the perspectives of diverse age and gender groups to achieve a broad consensus.

4.3.2 Procedural justice and public participation

Procedural justice necessitates fair and transparent decision-making processes that are typically evaluated through public engagement and participation. However, our findings reveal a significant challenge in achieving effective PJ in the study area.

Tourists and local residents exhibited a negative MWTP for public participation (PP_1 and PP_2). Tourists showed a negative MWTP of NTD −675.00 for information participation, and residents showed a negative MWTP of NTD −269.25. This negative economic valuation leads to the hypothesis that the public perceives the current mechanisms of PJ as ineffective or hindered by political factors in the Taiwanese institutional context. This finding contradicts research in other contexts, which generally highlights a positive correlation between public engagement and acceptance (Sadik-Zada and Gatto, 2023).

This outcome is a critical indicator that the public perceives the current mechanisms of PJ in the Taiwanese institutional context as ineffective, symbolic, or hindered by political factors, leading to skepticism or indifference. The negative MWTP demonstrates that participating in current processes (such as public hearings) imposes a perceived cost on the public without delivering a meaningful influence or benefit. Therefore, while the attribute was included to quantify PJ, its low economic valuation demonstrates a fundamental institutional challenge, necessitating a critical re-evaluation of how engagement is structured to ensure that it is perceived as genuine and effective.

4.4 Policy implications

To ensure sustainable wind energy development near ecologically sensitive areas, such as the Gaomei Wetland, policies must mandate specific spatial planning requirements that mitigate localized burdens on adjacent communities. Grounded in the framework of distributive justice, which requires the equitable sharing of costs and benefits, this approach addresses the acute non-monetary costs residents experience, such as visual disamenities and noise pollution. Empirical evidence from this study supports such a mandate, as local residents placed their highest Marginal Willingness to Pay (MWTP) of NTD 1,222.39 on the widest turbine spacing (VI_2: 800 m) to avoid visual blight, and assigned a substantial MWTP of NTD 800.14 for a 20 dB noise level (NL_1). To achieve a fair distribution of impacts and protect the quality of life of those in close proximity, significant setback distances of 800–1,300 m from residential and ecologically sensitive zones should be enforced alongside stringent operational noise ceilings (20 dB).

Furthermore, government agencies should shift the responsibility for financing environmental mitigation to developers by aligning compensation models with the public's expectations of corporate stewardship. These industry-led schemes must be structured to address substantive ecological damage, rather than passing additional financial costs directly to consumers. The study reveals a clear public preference for financing models in which green energy companies incorporate conservation trust funds directly into site planning, as evidenced by the widespread preference for an NTD 0/year additional consumer contribution.

A notable paradox in biodiversity valuation further suggests that resources should be directed toward robust and effective mitigation of major impacts. While respondents showed a negative WTP for minor 30% biodiversity reductions (BD_1) (e.g., residents: NTD = −883.82), they demonstrated a significant positive WTP (e.g., NTD 817.71 for residents) for mitigating a substantial 50% reduction (BD_2). This implies that policy design should focus on demonstrably effective compensatory actions that assure stakeholders that substantive steps are being taken, rather than relying on minimal or potentially ineffective conservation efforts.

Finally, government bodies must fundamentally reevaluate current mechanisms of public participation to achieve genuine procedural and recognitional justice. As procedural justice necessitates fair and transparent decision-making, the current negative valuation of participation attributes indicates that the public perceives existing structures, such as formal public hearings, as symbolic or hindered by political factors. The results show a negative MWTP for participation (PP_1 and PP_2) across both groups, with tourists and residents valuing these processes at NTD −675.00 and NTD −269.25, respectively. To address this skepticism and restore trust, policies should prioritize transparent, streamlined communication over complex formal processes. Furthermore, adhering to recognitional justice requires utilizing Latent Class Model insights regarding age and gender to implement targeted outreach. By addressing the specific concerns of segmented groups, such as noise sensitivity among residents or visual impact concerns among tourists, authorities can foster greater community consensus and long-term project acceptance.

5 Conclusion

5.1 Research conclusions

This study used a DCE integrated with an IVE to analyze complex public preferences and trade-offs concerning wind power development attributes near the ecologically sensitive Gaomei Wetland. The analysis, which obtained 850 valid responses from tourists and local residents, provides three definitive and critical conclusions regarding the strategic adoption of an EJ framework to balance sustainable energy goals and environmental protection.

First, the results unequivocally establish that the primary determinants of public acceptance are localized burdens, particularly the visual impact associated with turbine spacing. The high MWTP expressed for increased turbine spacing (e.g., NTD = 1,222.39 for local residents for 800-m spacing) and noise mitigation (e.g., NTD = 800.14 for 20 dB noise level) demonstrates that stakeholders demand strict adherence to DJ. This requires financial compensation that is proportionate to the infrastructure's acute nonmonetary costs.

Second, the findings indicate that unambiguous industry accountability is required for effective ecological compensation mechanisms. The public's overwhelming preference for financing models that ensure green energy companies incorporate conservation trust funds directly into strategic site planning signals a mandatory societal expectation of increased industry-led environmental stewardship. Furthermore, WTP for mitigating substantial ecological damage (BD_2) but not for minor damage (BD_1) implies that resources for compensation must be directed toward demonstrably robust and effective measures.

Finally, the study concludes that the institutional failure of current procedural justice mechanisms requires reform. Preference heterogeneity, confirmed by the Latent Class Model (LCM), mandates Recognitional Justice via targeted planning based on age and gender factors. Crucially, the empirical evidence of a negative MWTP for public participation (e.g., tourists: NTD = −675.00) constitutes a severe indictment of the current institutional structures. This finding warrants immediate and fundamental reforms of participatory mechanisms to restore public trust.

In conclusion, sustainable wind power development in Taiwan requires strict adherence to environmental justice and a shift from descriptive planning to mandating quantifiable, spatially conscious compensation facilitated by trustworthy engagement mechanisms.

5.2 Limitations and future research directions

Although this research provides a comprehensive multi-attribute analysis of preferences regarding wind power development and ecological conservation, several limitations must be considered when interpreting the results and applying policy implications.

One primary limitation concerns the study's geographic and population specificity; specifically, this study focused exclusively on tourists and local residents near the Taichung Wind Power Station and Gaomei Wetlands. Consequently, the derived WTP and preference profiles may not be generalizable to the wider Taiwanese population or to wind power projects in different ecological or social environments. The results were site-specific, and while the sample was explicitly segmented to ensure the accurate measurement of local community priorities for distributive justice, the high proportion of tourist respondents (72%) relative to local residents (28%) limits the generalizability of certain preference profiles to the entire local population. However, this structure allows for robust comparisons between distinct stakeholder groups.

Temporal constraints regarding the development timeline also warrant consideration. The survey was conducted after the Taichung Wind Power Plant became operational; therefore, the assessed preferences reflect attitudes toward mitigating existing or perceived inevitable future impacts rather than initial pre-construction acceptance. This context is linked to the notable finding that respondents expressed a WTP for measures mitigating a 50% reduction in biodiversity (BD_2) but exhibited a negative WTP for a minor 30% reduction in biodiversity (BD_1). This suggests that the public perceives unavoidable ecological damage as requiring substantial compensation.

Regarding institutional factors, the finding that both tourist and resident groups exhibited a negative MWTP for public and hearing participation suggests that the public in Taiwan perceives political factors and procedural structures as hindering meaningful public engagement. This necessitates cautious interpretation of policy recommendations that rely solely on implementing formal participation mechanisms. Additionally, in terms of experimental scope, while the selected attributes were grounded in the literature, they may not encompass every factor influencing local policy planning. Furthermore, the study utilized a *status quo* option with a fixed non-zero Conservation Trust Fund contribution as the sole rejection mechanism; future designs might benefit from allowing a "no-buy" option that does not incur existing costs to better capture opt-out preferences.

Based on these findings and limitations, future research should pursue several strategies. Given that the Taichung Wind Power Plant is currently operational, subsequent studies should focus on monitoring and improving the environmental conditions after construction. Research should also expand to investigate offshore wind power development, as this context may present different ecological and social trade-offs than nearshore wetland areas. Methodologically, future research should incorporate interactive technologies, such as virtual reality (VR), augmented reality (AR), and mixed reality (MR), to deepen the understanding of potential wind power impacts and enhance the accuracy of preference elicitation. To conclude, further studies are needed to explore the additional social, political, and economic factors that may influence local policymaking and public acceptance.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the (patients/ participants OR patients/participants legal guardian/next of kin) was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

H-SC: Formal Analysis, Writing – original draft, Software, Methodology, Data curation, Validation, Conceptualization, Writing – review and editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that generative AI was not used in the creation of this manuscript.

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