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Risk sharing, cost barriers, and heterogeneous pathways to renewable energy community participation: Survey evidence from Polish prosumers

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Abstract

Renewable Energy Communities (RECs) are a key instrument of the EU's participatory energy transition, yet their uptake remains negligible in Central and Eastern Europe despite rapid prosumer growth. This study examines how Polish photovoltaic prosumers and prospective adopters (N = 969) evaluate design trade-offs embedded in alternative REC models and how these evaluations shape participation intentions. Using exploratory factor analysis, hierarchical OLS regression, and quantile regression, we identify the attitudinal structure underlying REC acceptance and capture heterogeneity across the willingness distribution. The results show that preferences for risk sharing consistently predict higher participation readiness across all motivation levels ($\beta = 0.24$, $p < .001$), while perceived financial cost acts as a strong but asymmetric barrier concentrated among less willing individuals ($\beta = -0.36$ at $\tau = 0.10$ vs. -0.10 at $\tau = 0.90$). Automation acceptance facilitates engagement primarily among hesitant citizens. REC-specific perceptions and cost concerns explain substantially more variance than demographics or personality traits, underscoring the primacy of institutional design over individual dispositions. These findings carry direct policy implications for RED II enabling frameworks: participation friction should be minimised through simplified joining procedures and standardised contracts; risk-sharing mechanisms such as collective ownership and pooled revenues should be institutionally embedded; and cost-reduction measures targeting start-up and transaction costs are essential to broaden uptake beyond early adopters. Without differentiated participation models that address heterogeneous barriers, energy communities risk remaining confined to already-motivated and financially secure households.

1. Introduction

1.1. Energy communities as a policy instrument of the EU energy transition

Despite legal mandates under the Renewable Energy Directive (European Parliament and Council, 2018) and the Internal Electricity Market Directive (European Parliament and Council, 2019) the uptake of Renewable Energy Communities (RECs) remains uneven and often limited across many EU Member States. In several countries, particularly those with historically centralised and fossil-fuel-based energy systems, the development of community-based energy initiatives has progressed more slowly than anticipated. This implementation gap highlights the challenge of translating supportive regulatory frameworks into widespread citizen participation and locally embedded energy governance.

Within EU policy, RECs are intended to serve as a key instrument for decentralised and participatory energy transition. The directives require Member States to establish enabling frameworks that allow citizens, local authorities and small businesses to collectively produce, consume, share and manage renewable energy. Through these mechanisms, RECs are expected to contribute not only to renewable energy deployment but also to system flexibility, local value creation and broader societal acceptance of decarbonisation policies (Schlindwein and Montalvo, 2023; Bauwens et al., 2024; Radtke and Renn, 2024).

The policy rationale underlying RECs assumes that embedding energy generation and decision-making within local communities enhances legitimacy, distributes economic benefits more equitably and strengthens public support for the energy transition (Sovacool et al., 2017; Heffron and Sokołowski, 2024). However, the mere existence of legal frameworks does not guarantee participation. Empirical studies increasingly show that engagement depends on citizens' perceptions of feasibility, fairness and expected benefits (Jans et al., 2024; Llewellyn et al., 2025). If participation is perceived as administratively complex, financially uncertain or socially risky, RECs may remain a marginal governance mechanism despite formal regulatory support.

1.2. Poland as a critical case

Implementation challenges are particularly salient in Central and Eastern Europe (CEE), where coal dependence, affordability concerns and institutional trust intersect. Poland represents a critical case. While still highly coal reliant, it has experienced rapid growth in residential photovoltaics, creating a prosumer paradox: strong individual engagement with distributed renewables alongside limited development of community initiatives. By the end of 2024, Poland had over 1.5 million renewable energy source (RES) micro-installations, the vast majority owned by individual prosumers, while only three installations operated by collective prosumers had been registered (Energy Regulatory Office, 2025).

Although research has examined Poland's coal transition and energy vulnerability (Sokołowski and Bouzarovski, 2022) systematic evidence on REC participation remains limited. Poland's transposition of RED II has been described as incomplete regarding energy community (Neska et al., 2025) and enabling framework design is evolving. Understanding behavioural drivers of participation can therefore inform governance and incentive design. Poland's post socialist legacy and just transition pressures also make it relevant for other coal dependent EU Member States (Heffron and Sokołowski, 2024).

1.3. Literature gaps in REC acceptance research

Despite growing empirical research on Renewable Energy Community participation (Jans et al., 2024; Concetti, 2025; De Simone et al., 2025), several gaps remain.

First, acceptance is often measured as general willingness to join, offering limited insight into how citizens evaluate specific participation conditions. Technically feasible configurations include peer to peer trading, shared installations and demand side response services (Sepehrzad et al., 2026). Governance design and financial arrangements shape participation (Jans et al., 2024; le Maitre et al., 2023), yet evidence on perceived trade-offs within REC models remains scarce.

Second, the literature is geographically imbalanced, with most empirical studies focusing on Western European contexts. Coal-dependent CEE countries remain underrepresented, despite facing distinct institutional legacies, energy security concerns and affordability constraints. In Poland in particular, systematic evidence on behavioural determinants of REC participation intentions remains limited.

Third, existing research largely relies on mean-based analytical approaches, such as linear regression or structural equation modelling, which implicitly assume homogeneous effects across the distribution of participation intentions. However, determinants of participation may differ between individuals who are strongly reluctant, moderately interested or already highly willing to engage. Evidence capturing such distributional heterogeneity remains scarce in REC research. Analytical approaches capable of identifying heterogeneous effects across different segments of the willingness distribution are therefore needed to better understand participation dynamics and design differentiated policy interventions.

These gaps matter because RECs are social as well as technological arrangements (Bauwens et al., 2024). Participation reflects evaluations of risk sharing, delegation, privacy and cost exposure. Designing socially viable enabling frameworks therefore requires not only identifying average drivers of participation but also understanding how these drivers operate across different levels of willingness to engage.

1.4. Research objectives and analytical approach

This study provides policy-relevant evidence on how potential participants in Poland evaluate trade-offs embedded in REC designs and how these evaluations shape participation intentions. The analysis focuses on two strategically important groups for near-term uptake: current photovoltaic prosumers and households planning photovoltaic adoption. Previous qualitative research in Poland suggests that motivations and barriers differ between these groups (Bielecki et al., 2025; Neska et al., 2025), making them analytically and policy relevant segments.

The study is guided by three research questions. First, how do potential REC participants in a mature prosumer market evaluate key trade-offs embedded in alternative REC design models? Second, which design-related preferences and individual-level factors predict intentions to participate in RECs? Third, do these predictive relationships vary across the distribution of willingness to participate, and if so, which determinants exhibit the strongest heterogeneity?

Methodologically, the paper combines exploratory factor analysis to identify the latent structure of REC design preferences, hierarchical ordinary least squares (OLS) regression to assess the relative contribution of contextual, psychological and design-related predictors, and quantile regression to capture heterogeneity across the distribution of participation intentions. While mean-based models identify average effects, quantile regression makes it possible to examine whether determinants operate differently among individuals with low, moderate and high willingness to engage. Recent behavioural applications in energy research suggest that combining mean-based and distribution-sensitive approaches can generate more nuanced insights into participation dynamics (Kim, 2020; le Maitre et al., 2023; Sovacool et al., 2017). Identifying heterogeneous effects is particularly relevant for policymakers seeking to design differentiated engagement strategies and enabling frameworks adapted to diverse segments of potential participants.

1.5. Contribution and policy relevance

This paper makes three contributions to the literature and policy debate. First, it provides the first dedicated empirical analysis of REC participation intentions and design preferences in Poland, extending the geographical scope of existing acceptance research. Second, it offers a user-centred mapping of the REC design space, identifying which operational features are most strongly associated with willingness to join and which function as barriers. This evidence is directly relevant for regulators, local authorities and developers shaping participation schemes under evolving enabling frameworks. Third, by modelling heterogeneity across levels of baseline motivation, the study demonstrates how determinants of participation differ between more reluctant and more enthusiastic citizens, thereby supporting more targeted and potentially more inclusive REC policies. This distributional approach is particularly relevant for policymakers because it reveals whether the same intervention, such as reducing cost barriers, would be equally effective for reluctant citizens and early adopters.

More broadly, the findings speak to debates on energy justice and socially robust decarbonisation. RECs are frequently framed as instruments of energy democracy and local benefit sharing (Schlindwein and Montalvo, 2023; Sovacool et al., 2017). Yet these ambitions depend on participation structures that are perceived as fair, manageable and trustworthy. In a context marked by coal transition pressures, affordability concerns and institutional sensitivities, understanding how citizens interpret risk sharing, convenience, automation and cost becomes central to designing energy community pathways that are not only technically feasible but also socially viable.

2. METHODOLOGY

2.1. Participants and Procedure

Data were collected through a Computer-Assisted Web Interview (CAWI) conducted in November 2024 using quota sampling from the Ariadna online panel. The survey targeted homeowners who either already owned photovoltaic (PV) systems or planned to install one within the following twelve months, ensuring that all respondents were situated within segments most relevant to potential REC participation. The initial dataset comprised 1,037 cases. Quality screening excluded 68 cases in two steps. First, five respondents who selected non-binary or undisclosed gender categories were excluded due to insufficient cell sizes for meaningful statistical comparison[1]. Second, 63 respondents were removed for providing completely invariant responses across the 20-item personality inventory (SD = 0 across all IPIP items), indicating careless or inattentive completion. The final analytical sample consisted of N = 969 participants. A standardized description of the REC concept, presented to all respondents prior to the attitudinal questions, is publicly available on OSF (see section III of the survey https://osf.io/ekzd6/files/z6tnc). Table 1 summarizes main sociodemographic and psychological characteristics of the sample.

Table 1
Sample Characteristics (N = 969)

Variable	*n*	%	*M*	*SD*
Demographic characteristics				
PV status				
PV users	576	59.4		
PV planners	393	40.6		
Sex				
Female	460	47.5		

[1] We acknowledge that this exclusion limits representativeness. Future research with larger and more diverse samples should examine whether gender identity influences REC participation preferences.

Male	509	52.5		
Age (years)			45.87	13.78
Education				
Primary	6	0.6		
Vocational	53	5.5		
Secondary	271	28.0		
Post-secondary	98	10.1		
Higher	541	55.8		
Housing type				
Detached house	731	75.4		
Semi-detached house	92	9.5		
Terraced house	67	6.9		
Apartment in family-owned multi-unit building	79	8.2		
City size				
Village/rural area	397	41.0		
Small town (<50k)	124	12.8		
Mid-size city (50-200k)	216	22.3		
Large city (200-500k)	148	15.3		
Major city (>500k)	84	8.7		
Financial and household indicators				
Perceived financial situation (5-point subjective scale)			2.65	0.84
Household size (1 to 5+ household members)			3.20	1.13
Monthly electricity bill (PLN)			411.61	354.26
Technology and knowledge				
Energy knowledge (0–6)			4.19	1.52
Technical skills (self-rated, 1–5 Likert scale)			3.63	0.65
Online services use (frequency-based, 1–5 scale)			3.40	0.65
Psychological characteristics				
Neuroticism (IPIP)			2.85	0.79
Extraversion (IPIP)			3.21	0.84
Agreeableness (IPIP)			3.67	0.70

Conscientiousness (IPIP)	3.62	0.72
Openness (IPIP)	3.69	0.69
Values: Openness (vs. Conservation)	0.13	0.74
Values: Self-Transcendence (vs. Enhancement)	0.87	1.14
Pro-environmental attitude (NEP)	4.59	0.86
Political orientation (0 = Left, 10 = Right)	5.44	2.59

Note. For categorical variables used in dichotomized form in regression models (Education, Housing type, City size), detailed breakdowns with all original levels are shown. IPIP = International Personality Item Pool; NEP = New Ecological Paradigm.

2.2. Measures

The survey comprised four thematic blocks. Household and demographic characteristics are summarised in Table 1. Psychological predispositions were assessed through the 20-item IPIP-BFM personality inventory (Big Five), the New Ecological Paradigm scale (NEP), the Higher-Order Value Scale (HOVS17), and a single-item left–right political orientation measure. Technology-related variables included self-rated technical skills and frequency of digital service use. Perceived cost of REC participation was measured using a three-item scale adapted from (Irfan et al., 2021), capturing beliefs about additional financial costs associated with REC membership. Behavioural intention to join a REC was assessed with a three-item scale adapted from (Shakeel and Rahman, 2018). All TPB and cost items were adapted from their original context of individual renewable technology adoption to collective REC participation and rated on seven-point Likert scales (1 = *strongly disagree*, 7 = *strongly agree*). Full item wordings are available in the supplementary materials (Table S1).

Attitudes toward REC design were measured through nine bipolar items on seven-point semantic differential scales, each presenting a trade-off between two contrasting operational features of energy communities. The items addressed the degree of automation and algorithmic control in energy management versus direct participant oversight, the extent of data sharing required for optimisation purposes, preferences for individual versus collective models of participation and decision-making, the allocation of financial risk and infrastructure responsibility between individual members and the community, the level of initial investment and expected returns, approaches to profit distribution between individual gains and community reinvestment, infrastructure ownership arrangements and their implications for energy independence, and the preferred institutional form of REC management. Together, these items captured a range of behavioural, financial, and organisational aspects that differentiate among the main REC configurations examined in this study: peer-to-peer trading, shared installations, and demand-side response arrangements. Full item wordings are presented in Table S1.

2.3. Analytical Approach

The analysis proceeded in three steps.

First, we validated the psychometric structure of the constructs used in subsequent models. Confirmatory factor analysis (CFA; ML estimation) was applied to the TPB and perceived cost items to test whether cost represented a distinct construct and to derive a higher-order TPB factor summarising overall orientation toward REC participation. Perceptions of REC operational models were examined using exploratory factor analysis (EFA; ML extraction, oblimin rotation) to identify underlying dimensions among the design preference items. Latent factor scores were extracted using empirical Bayes modal estimation (Skrondal and Rabe-Hesketh, 2004).

Second, we estimated a series of hierarchical ordinary least squares (OLS) regression models to assess the relative contribution of four progressively expanding blocks of predictors, including: demographic and household characteristics, psychological dispositions, REC design perceptions, and perceived cost, to the explanation of general REC adoption orientation. All continuous predictors were standardised prior to model estimation to enable direct comparison of effect sizes. Heteroscedasticity-consistent standard errors (HC3; MacKinnon and White, 1985) were used throughout.

Finally, because prior research indicates that the drivers of energy-related behavioral intentions may differ for individuals with low versus high motivation (Bielecki et al., 2025; Neska et al., 2025), we complemented the OLS models with quantile regression estimated at five quantiles (τ = 0.10, 0.25, 0.50, 0.75, 0.90) using the full model specification from the final OLS step (Koenker and Bassett, 1978). Standard errors were obtained via the xy-pair bootstrap (R = 1,000 replications). Heterogeneity of individual coefficients across quantiles was assessed using Wald F tests (Koenker and Bassett, 1982), with false discovery rate correction (Benjamini and Hochberg, 1995) applied across all 24 predictors.

All analyses were conducted in R version 4.5.1(R Core Team, 2026). Raw data, analysis scripts, and supplementary materials (Tables S1–S8) are available on OSF (https://osf.io/ekzd6) for full reproducibility.

3. RESULTS

3.1. REC perception measures

We assessed REC perceptions using nine bipolar items on seven-point semantic differential scales. Factorability diagnostics for the full set confirmed suitability for factor analysis (KMO = 0.85, Bartlett's χ^2 = 1980.89, df = 36, $p < .001$). One item, governance preference (private company vs. local government management), was excluded due to negligible factor loadings (highest $|\lambda|$ = 0.24) and low communality (h^2 = 0.07), suggesting governance constitutes a distinct evaluative dimension orthogonal to operational preferences (cf. Costello and Osborne, 2005).

For the remaining eight items (KMO = 0.85, Bartlett's χ^2 = 1919.68, df = 28, $p < .001$), parallel analysis suggested three factors. Comparing one- through four-factor solutions, the three-factor model demonstrated superior fit (RMSEA = 0.037, TLI = 0.980, BIC = −31.9) and yielded three interpretable dimensions (Table 2):

- **Automation Acceptance** (Factor 1; items r3, r4, r5; α = 0.74): willingness to delegate energy management to algorithms and apps rather than exercising direct personal control.
- **Risk Sharing** (Factor 2; items r6, r8; α = 0.68): preference for group-based models that reduce personal risk and time commitment, even at the cost of lower individual returns.
- **Minimal Investment Preference** (Factor 3; items r2, r7, r9; α = 0.56): preference for low-barrier entry with minimal upfront cost, community profit reinvestment, and shared infrastructure responsibility.

Despite acceptable statistical fit, Factor 3 exhibited two critical limitations: (a) insufficient internal consistency (α = 0.56 < .70 threshold), and (b) high correlation with Factor 1 (r = 0.65), indicating poor discriminant validity. Factors 1 and 2 showed moderate intercorrelation (r = 0.48), suggesting adequate distinctiveness for separate analysis. Hence, only Factors 1 and 2 were used in further analyses.

Factor scores were extracted from the EFA model and standardised (M = 0, SD = 1). These correlated highly with simple mean scores (r > .93 for both retained factors).

Table 2

Factor Loadings from Exploratory Factor Analysis of REC Operational Preference Items

Item Content[a]	**Factor 1**	**Factor 2**	**Factor 3**	***h²***
Home energy decisions: manual control by residents vs. automated decisions by app	**.82**	-.09	.05	.67
Data management: complete privacy with manual savings vs. app optimization with data sharing	**.56**	.29	-.07	.48
Energy transaction control: manual by community members vs. algorithmic management	**.48**	.17	.10	.42
Infrastructure responsibility: individual liability vs. shared group responsibility	-.01	**.86**	.01	.75
Participation model: individual (higher profit, more time) vs. group (lower profit, less time)	.11	**.44**	.21	.41
Initial investment: higher upfront for greater REC returns vs. lower with reduced profits	-.03	.03	**.60**	.35
Profit distribution: individual financial gains vs. reinvestment in local community projects	.26	.02	**.38**	.36
Infrastructure ownership: REC-owned for independence (with costs) vs. external ownership (no liability)	.06	.07	**.41**	.24
REC management: private company vs. local government[b]	-	-	-	-
Factor Statistics				
Eigenvalue	1.53	1.24	0.92	
% of Variance	19.1	15.4	11.5	
Cumulative %	19.1	34.5	46.0	

Note. N = 969. Extraction method: Maximum likelihood. Rotation: Oblimin. Factor loadings > |.30| are boldfaced. h^2 = communality. F1 = Automation Acceptance; F2 = Collective Participation; F3 = Minimal Investment. Items are presented in order of primary loading magnitude within each factor. Interfactor correlations (Phi matrix): $r_{F1\text{-}F2}$ = .48, $r_{F1\text{-}F3}$ = .65, $r_{F2\text{-}F3}$ = .43.

[a]Full wording of all the items is presented in Table S1 of supplementary materials.

[b]Item excluded from factor analysis due to negligible factor loadings (highest |λ| = .24) and low communality (h^2 = .07).

3.2. TPB and cost structure

The 15 TPB and cost items (Table S1) were subjected to confirmatory factor analysis to establish the measurement structure used in subsequent regression models. Full model comparisons are reported in Table S4. To determine whether perceived cost (ω = .86) represents an independent construct, we compared a single-factor model (CFI = .858, RMSEA = .138) with a two-factor CFA separating cost from the 12 TPB items. The two-factor solution demonstrated substantially better fit (CFI = .966, RMSEA = .068), confirming the distinctiveness of cost perceptions. A five-factor CFA (four TPB dimensions plus cost) exhibited excellent fit (CFI = .983, RMSEA = .050; ωs = .74–.93). However, latent correlations among the four TPB dimensions ranged from r = .86 to .98, with all HTMT ratios exceeding the .85 discriminant validity threshold (Henseler et al., 2015). In contrast, correlations between cost and TPB dimensions were uniformly weak (r = −.18 to −.28). Respondents thus did not meaningfully differentiate among the four TPB components, treating them as facets of a unitary evaluative orientation toward REC participation.

We therefore specified a hierarchical CFA in which the four first-order factors loaded onto a single higher-order TPB construct. This model achieved equivalent fit (CFI = .983, RMSEA = .060), with first-order loadings of λ = .89–.99 and composite reliability ω = .98. The higher-order factor score served as the dependent variable in subsequent regression analyses.

3.3. Hierarchical OLS Regression Analysis

Table 3 reports the results of four nested OLS models. Each successive block of predictors yielded a statistically significant improvement in explained variance (all ΔR^2 ps < .001). The sequential addition of demographics and technology (R^2 = .106), psychological dispositions (ΔR^2 = .081), REC design perceptions (ΔR^2 = .109), and perceived cost (ΔR^2 = .027) produced a final R^2 of .323.

Several demographic and household variables, sex, education, housing type, financial situation, household size, and energy knowledge, showed no significant associations in any model specification. Among contextual predictors, urban residence emerged as the most robust effect (β = 0.18–0.20, p = .002 across all models), while online services use remained significant throughout (β = 0.12–0.18, $p \leq .001$).

The addition of psychological predictors (Model 2) revealed agreeableness (β = 0.17–0.21, p < .001) and pro-environmental attitude (β = 0.13–0.19, p < .001) as the strongest individual-level correlates, both remaining significant across all subsequent models. Other Big Five dimensions, Schwartz value contrasts, and political orientation showed no significant effects in Models 2 and 3. Notably, age and PV planner status, significant in Model 1, were no longer significant once psychological dispositions were controlled.

REC design perceptions contributed the largest incremental variance (ΔR^2 = .109). Risk sharing showed the strongest positive association (β = 0.24, p < .001 in Model 4), followed by automation acceptance (β = 0.12, p = .004). Perceived cost emerged as a distinct barrier (β = −0.18, p < .001), and its inclusion had a notable suppression effect: political orientation became significant (β = 0.08, p = .027), suggesting that right-leaning respondents show higher REC orientation once cost perceptions are accounted for. This finding warrants cautious interpretation and further investigation.

3.4. Quantile regression

Quantile regression applied to the full model specification (Table S8) revealed that the majority of predictors operated homogeneously across the willingness distribution. Of 24 predictors tested, only four exhibited statistically significant coefficient heterogeneity after FDR correction (Figure 1).

In particular, risk sharing preferences maintained stable and strong positive effects across all quantiles (β range: 0.23–0.31, all p < .01), as did agreeableness (β range: 0.11–0.21, all p < .05), confirming that these mechanisms operate as universal facilitators regardless of baseline motivation. Pro-environmental attitude, online services use, and urban residence similarly showed no significant distributional variation.

Among the four heterogeneous predictors, perceived cost showed a strongly diminishing negative effect from lower to upper quantiles (τ = 0.10: β = −0.36, p < .001; τ = 0.90: β = −0.10, p < .05; Wald F = 15.41, p < .001). Notably, even the OLS estimate (β = −0.18) underestimates the barrier effect at the lower tail, where cost sensitivity is twice as strong. Automation acceptance displayed a complementary pattern (Wald F = 7.79, p < .001), with positive effects concentrated at lower quantiles ($\tau = 0.10$: $\beta = 0.22$, $p < .01$) but becoming negligible at higher quantiles ($\tau = 0.90$: $\beta = -0.02$, n.s.). PV planner status showed significant heterogeneity (Wald $F = 4.54$, $p = .009$), with positive effects at lower quantiles ($\tau = 0.10$: $\beta = 0.26$, $p < .01$; $\tau = 0.25$: $\beta = 0.14$, $p < .05$) diminishing to near-zero above the median. Electricity bill displayed a less pronounced but significant pattern (Wald $F = 3.99$, $p = .019$), with a positive effect at the median ($\tau = 0.50$: $\beta = 0.10$, $p < .01$) but non-significant effects at the tails.

Together, these results indicate that the core psychological and design-related mechanisms underlying REC acceptance operate largely uniformly across the willingness distribution, while cost sensitivity, automation acceptance, and PV planning status function as segment-specific drivers concentrated among less willing individuals.

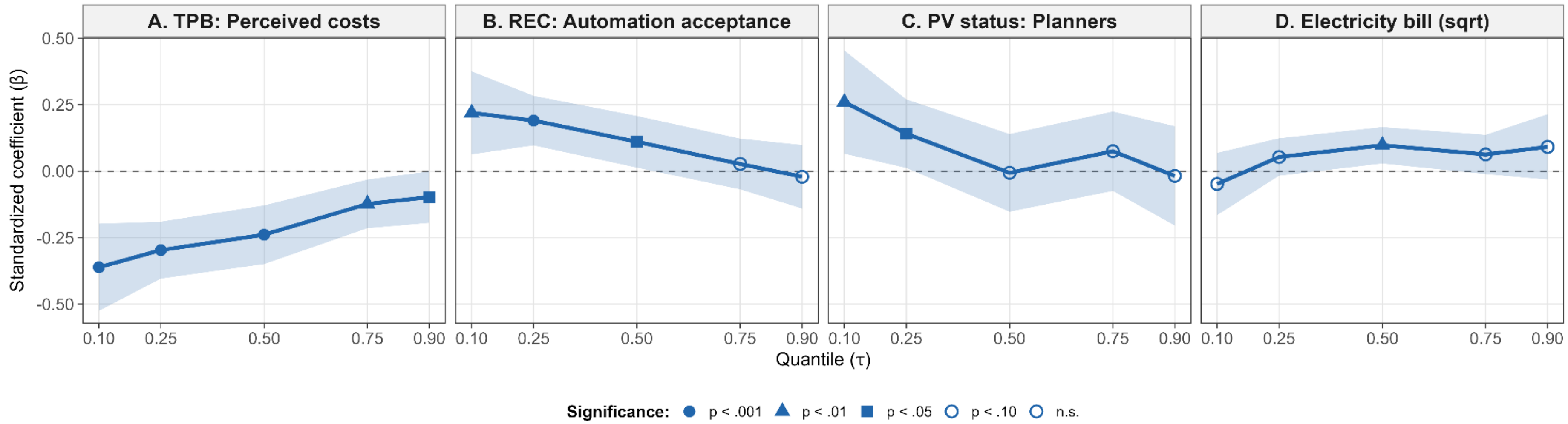
Table 3.

Hierarchical OLS Regression Models Predicting TPB General Orientation

Predictors	Model 1: Demographics + Tech				Model 2: + Psychology				Model 3: + REC				Model 4: + Cost			
	β	SE	t	p	β	SE	t	p	β	SE	t	p	β	SE	t	p
Intercept	**-0.239**	**0.098**	**-2.46**	**0.014**	**-0.233**	**0.097**	**-2.41**	**0.016**	**-0.256**	**0.092**	**-2.80**	**0.005**	**-0.231**	**0.093**	**-2.48**	**0.013**
Group: PV planners	**0.139**	**0.063**	**2.19**	**0.029**	0.109	0.062	1.75	0.081	0.108	0.058	1.86	0.063	0.101	0.058	1.75	0.080
Sex: Male	0.054	0.063	0.86	0.393	0.109	0.064	1.70	0.089	0.068	0.061	1.13	0.261	0.061	0.060	1.02	0.309
Education: Higher	0.037	0.065	0.56	0.576	0.054	0.064	0.85	0.393	0.068	0.059	1.15	0.250	0.055	0.058	0.94	0.350
Age	**0.103**	**0.032**	**3.22**	**0.001**	0.041	0.034	1.21	0.227	0.018	0.031	0.57	0.566	0.004	0.031	0.14	0.887
Housing Type: Independent	0.054	0.073	0.74	0.457	0.031	0.072	0.43	0.670	0.073	0.068	1.071	0.286	0.061	0.068	0.89	0.376
City size: Mid-size or large city	**0.203**	**0.064**	**3.19**	**0.002**	**0.169**	**0.062**	**2.75**	**0.006**	**0.182**	**0.057**	**3.17**	**0.002**	**0.177**	**0.057**	**3.13**	**0.002**
Financial situation	-0.027	0.034	-0.79	0.432	-0.003	0.033	-0.08	0.939	-0.013	0.032	-0.40	0.690	-0.010	0.033	-0.31	0.755
Household size	-0.025	0.035	-0.73	0.468	-0.022	0.034	-0.64	0.520	-0.018	0.031	-0.58	0.559	-0.011	0.030	-0.36	0.721
Electricity bill (sqrt)	0.070	0.036	1.95	0.051	**0.080**	**0.035**	**2.27**	**0.024**	**0.066**	**0.033**	**2.02**	**0.044**	0.058	0.033	1.77	0.078
Energy knowledge	0.033	0.034	0.963	0.336	0.019	0.034	0.55	0.583	0.035	0.032	1.09	0.277	0.018	0.034	0.53	0.596
Tech skills	**0.132**	**0.038**	**3.53**	**<0.001**	0.070	0.038	1.85	0.065	0.093	0.035	2.64	**0.009**	**0.076**	**0.036**	**2.12**	**0.034**
Online services use	**0.183**	**0.034**	**4.86**	**<0.001**	**0.168**	**0.037**	**4.52**	**<0.001**	**0.123**	**0.037**	**3.37**	**<0.001**	**0.131**	**0.037**	**3.51**	**0.001**
IPIP: Neuroticism					-0.031	0.039	-0.81	0.420	-0.043	0.035	-1.24	0.217	-0.025	0.035	-0.72	0.470
IPIP: Extraversion					0.050	0.045	1.11	0.268	0.004	0.042	0.10	0.922	0.007	0.042	0.16	0.877
IPIP: Agreeableness					**0.209**	**0.042**	**4.92**	**<0.001**	**0.196**	**0.040**	**4.87**	**<0.001**	**0.172**	**0.039**	**4.39**	**<0.001**
IPIP: Conscientiousness					0.002	0.034	0.06	0.956	0.020	0.032	0.61	0.542	0.022	0.032	0.70	0.488
IPIP: Openness					0.014	0.048	0.30	0.765	0.042	0.044	0.95	0.342	0.042	0.043	0.96	0.339
Values: Openness vs Conservation					-0.055	0.033	-1.64	0.102	-0.049	0.031	-1.60	0.111	-0.046	0.029	-1.61	0.109
Values:Self-Transcendence vs Enhancement					-0.079	0.042	-1.88	0.061	-0.061	0.038	-1.61	0.109	-0.069	0.036	-1.89	0.059
Pro-environmental attitude					**0.188**	**0.040**	**4.68**	**<0.001**	**0.158**	**0.037**	**4.30**	**<0.001**	**0.133**	**0.036**	**3.67**	**<0.001**
Political orientation (L-R)					0.057	0.037	1.56	0.120	0.055	0.035	1.59	0.111	**0.076**	**0.034**	**2.21**	**0.027**
REC: Automation acceptance									**0.109**	**0.044**	**2.50**	**0.013**	**0.124**	**0.043**	**2.86**	**0.004**
REC: Risk sharing									**0.265**	**0.042**	**6.36**	**<0.001**	**0.240**	**0.040**	**6.01**	**<0.001**
Perceived cost of joining REC													**-0.183**	**0.045**	**-4.11**	**<0.001**
R^2	0.106				0.187				0.296				0.323			
Adjusted R^2	0.095				0.169				0.279				0.306			
Model comparison					$\Delta R^2 = .081$, $F(9, 947) = 10.44$, $p < .001$				$\Delta R^2 = .109$, $F(2, 945) = 73.08$, $p < .001$				$\Delta R^2 = .027$, $F(1, 944) = 37.72$, $p < .001$			

Note: All continuous predictors and dependent variable are standardized. All nominal predictors are dummy coded. Robust (HC3) standard errors used throughout.

Figure 1. Heterogeneity in quantile regression coefficients for REC adoption intentions. Each of the four panels displays the trajectory of standardized coefficients across quantiles (τ = 0.10 to 0.90) for a predictor showing significant heterogeneity. Points indicate coefficient estimates with shapes representing statistical significance. Shaded ribbons represent 95% confidence intervals. The dashed horizontal line at zero indicates no effect.



4. Discussion

This study examined how Polish current and prospective photovoltaic prosumers evaluate key trade-offs embedded in REC participation and how these evaluations relate to intentions to join. The results provide evidence that REC readiness is shaped primarily by perceptions of participation conditions rather than by demographic characteristics alone. Preferences for risk sharing and low burden participation emerge as the most robust predictors of willingness to join, while perceived financial cost acts as a distinct barrier. Automation acceptance and digital engagement further differentiate participation intentions, especially among less motivated individuals. These findings are relevant for the design of enabling frameworks because they identify which features of REC arrangements are most likely to increase uptake among both early adopters and more reluctant citizens.

A first central finding concerns the importance of risk sharing oriented participation preferences. Respondents who favour shared responsibility and reduced personal exposure to operational and financial risks show substantially higher readiness to join across all model specifications. This pattern remains stable in quantile regression, indicating that risk sharing functions as a broadly applicable driver rather than a feature relevant only to a specific segment. From a behavioural perspective, this suggests that RECs are evaluated as institutional arrangements that reorganise responsibility rather than as purely technological innovations. This aligns with prior research showing that perceptions of fairness, shared benefit, and collective governance shape energy community acceptance (De Simone et al., 2025; Jans et al., 2024).

Our findings also speak directly to the experimental evidence reported by Jans et al. (2024), who demonstrate that governance arrangements influence citizens' willingness to participate in energy communities. While their study focuses on the distinction between top-down and bottom-up governance models, our results suggest that the more granular dimension of personal risk exposure may be the operative behavioural mechanism underlying these effects. In other words, governance structures may matter for participation primarily insofar as they redistribute operational and financial responsibilities among participants. This interpretation extends existing findings by highlighting the role of perceived responsibility allocation as a central design parameter shaping REC attractiveness.

A second key finding is that low effort of participation and convenience are central to readiness to join. Although the operational preference battery does not directly measure time costs as a standalone factor, the risk sharing dimension and the conceptual interpretation of low burden participation converge on the same policy relevant mechanism. Potential participants appear to value participation models that shift complexity away from the household and toward collective arrangements, professional intermediaries, or digital tools. This is particularly important in mature prosumer markets, where households already manage investment decisions, technology maintenance, billing, and regulatory changes. In such contexts, additional cognitive and administrative burdens may be perceived as a cost that discourages collective participation even when general support for RECs is present.

The role of perceived financial cost introduces an additional layer of differentiation. Cost emerges as a distinct barrier rather than a component of TPB constructs, and its negative impact is particularly pronounced among individuals with initially low motivation to join RECs. Those with strong baseline motivation appear comparatively fewer cost sensitive. These findings resonate with the Theory of Planned Behaviour framework applied to REC participation in Flanders by Conradie et al. (2021), who showed that attitudes toward participation play a key role in shaping intentions to join energy communities. Our results extend this perspective in two ways. First, they indicate that perceived financial exposure constitutes an additional behavioural constraint that operates alongside attitudinal factors. Second, the quantile regression analysis demonstrates that these relationships are heterogeneous across the distribution of willingness, suggesting that determinants of participation differ between hesitant individuals and already motivated participants.

Correlation patterns suggest two psychologically meaningful subgroups: individuals high in convenience and shared-risk preferences, who combine strong acceptance with low-cost concern, and individuals attracted to low-investment, community-oriented models, who display elevated cost sensitivity despite prosocial predispositions. These patterns should be interpreted cautiously, as the present analysis does not employ formal clustering or segmentation techniques. They are therefore indicative rather than definitive and would benefit from confirmation through dedicated segmentation approaches such as latent profile analysis or cluster modelling in future research.

The quantile regression results reinforce the policy relevance of these distinctions. Cost sensitivity, automation acceptance, and PV planning status primarily influence individuals located at the lower end of the willingness distribution, whereas core drivers such as risk-sharing preferences and pro-environmental attitudes operate more uniformly across segments. From a policy perspective, this suggests that broad communication strategies may be effective for already motivated participants, while targeted interventions addressing cost exposure and participation complexity are likely to be more effective in engaging hesitant households.

Together with the hierarchical regression results, this evidence reinforces the multidimensional nature of REC acceptance. REC-specific perceptions and cost concerns emerge as the strongest proximal predictors, explaining substantially more variance than demographic characteristics. Among psychological factors, agreeableness and environmental concern (NEP) contribute meaningfully, whereas Schwartz value dimensions showed no significant effects once NEP was included, suggesting that pro-environmental attitude captured the relevant motivational variance. Contextual factors such as urban residence remain robust predictors, and perceived cost of REC participation emerges as a distinct barrier, pointing to the continued relevance of opportunity structures and economic considerations.

These findings also help explain the prosumer paradox identified in Section 1.2. Although Polish households have enthusiastically adopted individual photovoltaic systems, the transition toward collective energy arrangements remains limited. The results suggest that this gap is not primarily driven by a lack of interest in renewable energy but by concerns related to cost exposure, responsibility allocation and administrative complexity. Individual prosumer frameworks allow households to retain control over their installations and financial risks, whereas participation in RECs may be perceived as introducing additional uncertainty and coordination burdens. Addressing these perceived barriers therefore appears central to unlocking the collective dimension of distributed energy systems.

From a policy and design perspective, these findings suggest that successful REC deployment requires more than appealing to environmental concern or collective ideals. Reducing administrative, cognitive, and time burdens appears equally crucial. Cooperative participation structures that distribute risk and responsibility can substantially enhance adoption, while automation functionality framed as supportive rather than controlling may be particularly effective for individuals with low motivation or limited technical confidence. Designing differentiated participation models tailored to convenience-oriented, automation-oriented, and cost-sensitive user segments may therefore improve both the inclusivity and scalability of REC initiatives.

Taken together, these results suggest that enabling frameworks will be effective only if they align institutional design with the behavioural expectations of potential participants. The following section therefore translates these insights into concrete policy implications for REC implementation.

5. Conclusion and policy implications

5.1. Main findings and policy relevance

This study provides empirical evidence on the determinants of willingness to participate in Renewable Energy Communities in Poland. Readiness to join is shaped primarily by preferences for shared risk and low burden participation, supported by environmental concern and cooperative predispositions, and constrained by perceived financial cost. Digital engagement and automation acceptance play a secondary but policy relevant role, particularly among less motivated individuals.

Quantile regression shows that these determinants are not uniform across the willingness distribution. Risk sharing arrangements are broadly relevant across all segments, whereas cost sensitivity and automation acceptance primarily influence individuals with low baseline readiness. This heterogeneity implies that uniform participation models are unlikely to generate inclusive uptake.

For enabling frameworks under RED II Article 22 (European Parliament and Council, 2018) and the Internal Electricity Market Directive (European Parliament and Council, 2019) several policy implications follow. First, enabling frameworks should establish standardised REC participation contracts with pre-defined terms for liability allocation, exit procedures, and revenue distribution, reducing the informational and legal complexity that our results identify as barriers even for technologically engaged prosumers. Such standardisation can lower participation friction by making participation conditions transparent and predictable for potential members.

Second, risk sharing should be embedded institutionally through collective ownership options, pooled revenues, shared maintenance responsibilities, and clearly specified liability. Since preferences for reduced personal exposure to operational and financial risks consistently predict participation readiness across the willingness distribution, governance arrangements that distribute responsibility collectively appear central to REC attractiveness.

Third, cost exposure must be addressed through targeted measures rather than uniform financial support. Given that cost sensitivity is concentrated among individuals with low baseline motivation ($\tau = 0.10$: $\beta = -0.36$ vs. $\tau = 0.90$: $\beta = -0.10$), targeted subsidies for REC start-up costs or transaction-cost-reducing intermediary services may be more efficient than universal subsidies. Such instruments could also mitigate the equity risk that energy community initiatives disproportionately attract already motivated and financially secure households while bypassing less engaged but potentially willing participants.

Fourth, digitalisation and automation tools should be integrated into REC participation models as mechanisms that reduce perceived complexity rather than increase perceived control. Our quantile regression results show that automation acceptance effects are concentrated in lower quantiles of willingness, suggesting that user-friendly digital interfaces and automated energy management systems could serve as an entry point for hesitant citizens. When framed as supportive infrastructure that simplifies participation rather than as intrusive monitoring technologies, such tools may lower barriers for segments that REC initiatives currently struggle to reach.

Engagement strategies should therefore prioritise clarity about practical participation conditions rather than abstract narratives alone. Environmental framing remains important, but credible communication about obligations, safeguards, and shared responsibility is central to building trust in community-based energy arrangements.

5.2. Broader implications

Although focused on Poland, the findings are relevant for other coal dependent and late transposing EU Member States. Effective implementation depends not only on formal legal compliance with EU directives, but on whether enabling frameworks translate rights into participation conditions perceived as manageable, low risk, and financially credible. In contexts marked by affordability concerns and institutional sensitivities, the design of participation structures becomes central to achieving socially robust decarbonisation.

More broadly, the results contribute to ongoing debates on energy justice and energy democracy by demonstrating that participation in energy community initiatives is conditioned by perceived risk allocation, burden distribution, and economic exposure. RECs will scale not where it is merely legally permitted, but where institutional design aligns with the behavioural expectations and constraints of potential participants.

5.3. Limitations and future research

Several limitations should be acknowledged. First, the study relies on stated preferences and intentions rather than observed behavior, which may limit direct inference about actual REC participation. Second, the cross-sectional design does not allow causal conclusions or analysis of how attitudes evolve as RECs become more widespread and tangible. Third, the findings are specific to the Polish context and to homeowners with current or planned PV installations, which may constrain generalizability to other institutional settings or population groups.

Future research should therefore pursue longitudinal designs to examine how intentions translate into participation once REC opportunities materialize, and experimental approaches to test how alternative REC framings and design features influence different user segments. Further work could also explore governance preferences in greater depth, using dedicated trust and institutional legitimacy measures, as well as extend the analysis to renters and less technologically engaged households.

Overall, the results suggest that accelerating REC uptake requires aligning institutional and technological solutions with the psychological realities of potential participants. By recognizing heterogeneity in motivations and lowering participation barriers across multiple dimensions, policymakers and practitioners can design more adaptive, resilient, and socially inclusive energy community models that support the broader goals of the energy transition.

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

During the preparation of this work the authors used GPT 5.2 in order to improve the clarity and language quality of the manuscript, and Claude (Anthropic) in order to assist with writing and refining R code. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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