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Users trade frictions, not only kilowatt-hours: Rethinking the foundations of peer-to-peer energy market model

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Dear Editor,

To examine the behavioural foundations of peer-to-peer (P2P) energy trading, we conducted a structured survey in January 2026 across 13 Chinese provinces and municipalities, including Beijing, Shanghai, Jiangsu, and Zhejiang. The questionnaire was distributed online through the Wenjuanxing platform without monetary incentives.[1] After quality screening, 350 valid responses were retained. The sample was 52% male and 48% female, with 68% holding a bachelor's degree or higher. Approximately 42% were prosumers, although most had no prior experience with P2P energy trading. The questionnaire covered demographics, social influence, risk attitude, willingness to adopt distributed resources, P2P participation intention, and scenario-based choice experiments involving price spreads (0.2-0.8 CNY/kWh), generation intervals, seller reputation, cognitive burden, and settlement uncertainty. All responses were anonymised with informed consent. We define behavioural frictions as cognitive burden, interaction complexity, and settlement uncertainty that reduce participation beyond economic incentives. Cognitive burden refers to the mental effort required for trading decisions, while settlement uncertainty reflects perceived unpredictability of final outcomes caused by market-clearing dynamics.[2]

The survey reveals five major findings. (i) Cognitive burden dominates participation decisions, with perceived complexity exceeding 0.78 on a normalized scale. (ii) Economic incentives have limited influence. (iii) Settlement uncertainty reduces trading willingness by more than 40%. (iv) Respondents are more responsive to reductions in cognitive burden than to increases in economic gain. (v) Automation preference is prevalent, with more than 62% of users favouring automated decision-making even at the expense of lower expected savings.

DATA COLLECTION, STATISTICAL ANALYSIS, AND LIMITATIONS

The survey was conducted in January 2026 across 13 Chinese provinces and municipalities using the Wenjuanxing platform. After quality screening, 350 valid responses were retained. The questionnaire covered demographics, prosumer status, social influence, risk attitude, automation preference, and scenario-based experiments involving price spreads, cognitive burden, and settlement uncertainty.

The analysis used descriptive statistics, normalized indicators, Pearson correlation, and scenario comparisons to evaluate the effects of economic incentives, cognitive burden, and uncertainty on participation willingness.

This study has several limitations. The sample was limited to China, and most respondents lacked real-world P2P trading experience, meaning the results reflect stated rather than revealed behavior. In addition, cognitive burden, uncertainty, and automation preference were measured through scenario-based proxies instead of standardized psychometric scales. Future work should include field experiments, cross-cultural validation, and standardized measurement methods.

RETHINKING THE BEHAVIORAL FOUNDATIONS OF DECENTRALIZED ENERGY MARKETS

P2P energy markets are often modeled as systems where prosumers optimize trading based on dynamic price signals. However, the limited success of real-world deployments raises doubts about these behavioral assumptions. This survey provides new evidence of such barriers.

Analysis of 350 responses shows that demographic characteristics (gender, age, household size) were only weakly correlated with participation intention ($|r| < 0.10$), while prosumer status showed a modest positive association ($r \approx 0.24$). By contrast, cognitive burden was high, averaging 0.78 out of 1, whereas price sensitivity remained low at 0.07. These findings reveal a structural mismatch between theoretical market designs and actual user behavior. Energy trading is perceived not only as an economic activity but also as a cognitive one, with users seeking to minimize mental effort alongside maximizing financial benefit.

This behavioral pattern is consistent with Prospect Theory, which suggests that people evaluate decisions based on perceived gains and losses rather than expected utility alone. In P2P energy trading, cognitive effort, settlement uncertainty, and the risk of suboptimal decisions are often perceived as losses. Users are more sensitive to reductions in complexity and uncertainty than to equivalent increases in financial gain. These findings also support prior studies showing that P2P market performance depends not only on pricing and clearing mechanisms, but also on human behavioral characteristics.

THE DOMINANCE OF COGNITIVE AND INTERACTIONAL FRICTIONS

The survey results reveal a clear behavioral pattern. Increasing the price spread from 0.2 to 0.8 CNY/kWh produced only limited changes in user preference for green electricity. Raising the premium from 0.2 to 0.4 CNY/kWh shifted only 5.2% of respondents toward renewables, while further increases had no significant additional effect. In contrast, over 72% of users reduced trading willingness when tasks required extra information processing or parameter configuration.

Cognitive complexity therefore showed a stronger association with participation willingness than monetary incentives.[3] Even among respondents with engineering backgrounds and high energy literacy, 61% identified pricing interfaces and settlement rules as the main participation barrier. Uncertainty had a similarly strong effect: participation willingness fell by 43% when settlement outcomes depended on market-clearing dynamics, compared with only 8% in deterministic scenarios.

Overall, users appeared far more sensitive to cognitive effort and uncertainty than to incremental financial gains, suggesting that psychological costs outweighed economic incentives in shaping participation behavior.

The current models overestimate the market responsiveness

Existing P2P market architectures assume users respond strongly to marginal incentives and can actively process bids, prices, and counterparties.[4,5] However, the survey results suggest otherwise.

The attention bandwidth is sharply limited. Respondents strongly preferred "set-and-forget" interaction styles (0.76) overactive market monitoring (0.19). Most users disliked frequent interactions and showed aversion to even small cognitive burdens, indicating that limited attention constrains participation.

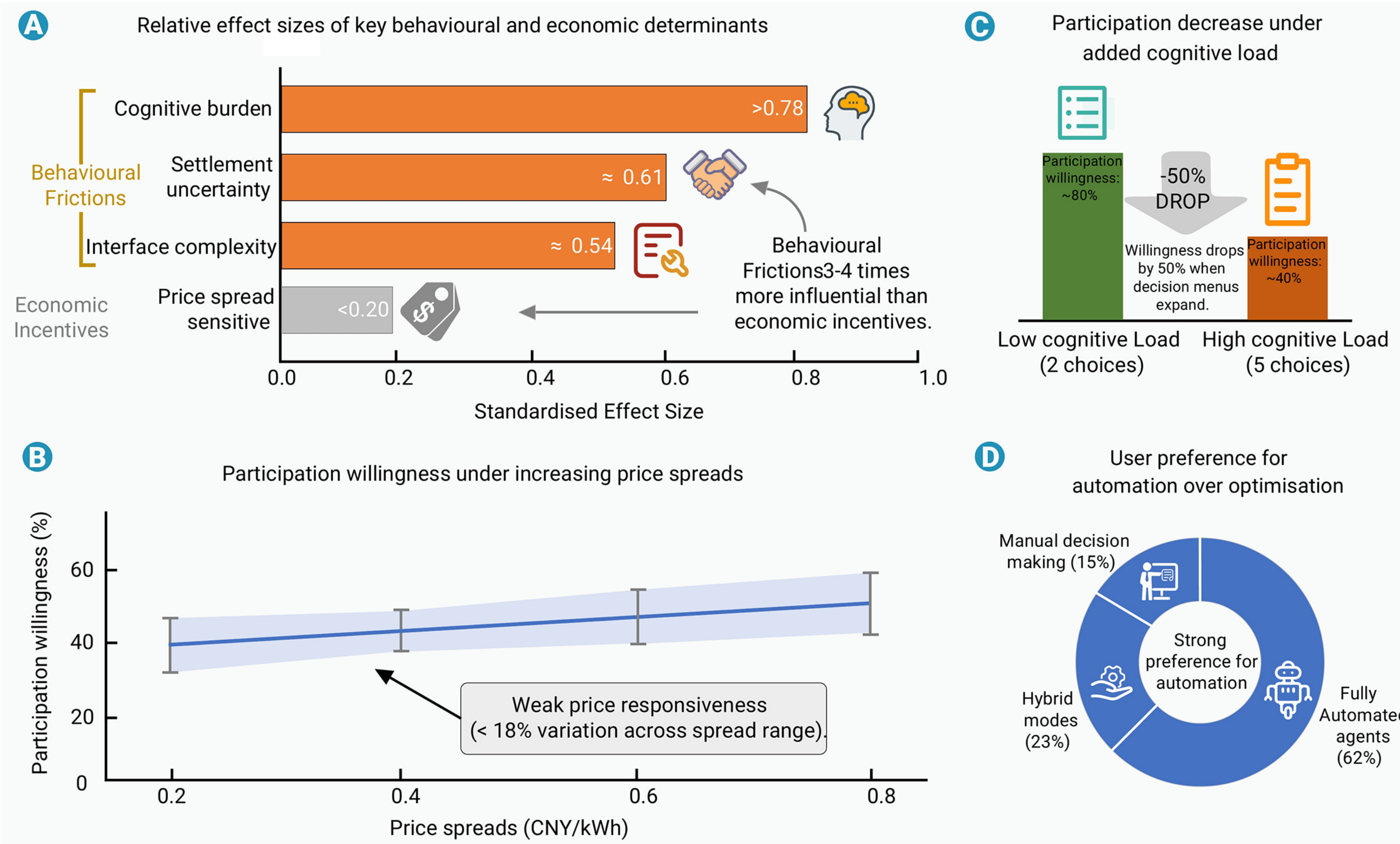

Figure 1. Behavioral determinants of participation in peer-to-peer energy market (A) Relative effects of behavioural and economic factors. (B) Participation willingness increases only slightly as the price spread rises from 0.2 to 0.8 CNY/kWh. (C) Participation willingness declines sharply from ~80% to ~40% as choice options expand from two to five. (D) User preference for automation over manual optimisation.

The tolerance for uncertainty is low. Additional settlement uncertainty reduced participation more than modest price incentives could offset. Users treated uncertainty as a psychological cost and preferred predictable, though suboptimal, outcomes over volatile optimized ones.

The complexity is treated by users as a direct disutility. Expanding decision menus from two to five options reduced participation willingness by nearly 50%, despite greater optimization potential. Complexity therefore acts as friction, with cognitive economy outweighing economic benefit.

These misalignments have profound implications. A market predicated solely on optimization could underperform in settings with high user cognitive load, though optimization-based designs remain effective in fully automated or industrial contexts.[6]

A new design paradigm for human-centered energy markets

The survey evidence suggests that future P2P market design cannot rely solely on improved pricing algorithms but instead requires human-in-the-loop automation and cognitively minimal trading structures.[7] Automation should assist rather than replace users: participants define preferences, risk limits, and trading rules, while automated agents handle routine optimization. We argue for three shifts:

The markets should minimize user decision points. Automated agents, default contracts, and context-driven nudges can reduce the cognitive burden of interpreting complex price and settlement mechanisms while preserving user oversight and opt-out flexibility. Actionable deliverable: user-initiated actions ≤1 per week; default strategies cover ≥80% of scenarios; settlement outcomes remain deterministic, explainable, and bounded by explicit loss caps. When pricing mechanisms become overly complex, simplified contracts or limited barter-like exchanges may provide practical alternatives while maintaining user control and transparency.

The trading interfaces should be redesigned to reduce cognitive burden. This requires clearer visual and conceptual presentation so users can understand participation without interpreting technical parameters. Actionable deliverable: ≥90% of users correctly understand outcomes after first interaction; average task completion time reduced by ≥30%; key concepts expressed in goal-oriented rather than technical language.

The behavioral metrics should be integrated into market performance evaluation. Cognitive burden, trust, and user comprehension should be treated as equally important as economic efficiency and grid welfare. Actionable deliverable: standardized behavioral metrics (e.g., NASA Task Load Index) incorporated into system KPIs and reported alongside economic and reliability indicators in simulations and field deployments.

TOWARDS A NEW UNDERSTANDING OF DECENTRALIZED ENERGY PARTICIPATION

This survey provides empirical evidence that behavioral frictions may matter more than insufficient economic incentives in decentralized trading adoption. Within the surveyed sample, these behavioral frictions appeared more strongly associated with participation intention than demographic characteristics and marginal price-spread variations. They are not stochastic noise but structural determinants of market outcomes.

The implications extend beyond P2P trading. As distributed renewable energy expands, participant behavior will become central to market performance.[8] Markets that ignore behavioral boundaries may underperform, while those adapted to human decision-making could achieve higher participation.

Recognizing that households trade frictions, not only kilowatt-hours, reframes future energy market design. Future P2P systems may need to prioritize simplicity, automation, and reduced cognitive burden alongside economic optimization.

Although the sample was geographically limited to China, the observed patterns, such as aversion to cognitive load and preference for automation, are broadly consistent with prior studies.[9,10] Cross-cultural validation is still needed and remains an important direction for future work.

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DECLARATION OF INTERESTS

The authors declare no competing interests.