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A Theory-Building Model of Prosumer Participation in Algorithmic Flexibility Markets Under Trust, Fairness, Incentives, and Grid Reliability Requirements

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Abstract

Algorithmic flexibility markets can support the energy transition by coordinating distributed prosumer resources through automated platforms. Yet participation depends not only on price signals but also on whether prosumers trust platforms, perceive compensation as fair, and believe flexibility provision will not compromise reliability. Existing work has advanced knowledge on peer-to-peer trading, demand response, virtual power plants, and automated energy coordination. However, no unified theory fully explains how trust, fairness, incentives, and grid reliability requirements jointly shape prosumer participation in algorithmic flexibility markets. This article develops a theory-building model of prosumer participation in algorithmic flexibility markets. The model links micro-level perceptions of trust, fairness, and incentives with macro-level grid reliability requirements and market design constraints. The article is conceptual and develops theory by integrating behavioural, institutional, technological, and energy-system perspectives. It defines core constructs, specifies causal relationships, and derives propositions for future empirical testing. The theory proposes that participation emerges from four interlocking mechanisms: trust in algorithmic platforms, perceived fairness of compensation and procedures, incentive salience, and perceived alignment with grid reliability needs. These mechanisms interact dynamically rather than operating as independent determinants. The model provides a foundation for future empirical research and for designing flexibility markets that are technically effective and socially acceptable. It also clarifies why participation may fail even when economic incentives appear attractive.

Keywords Prosumer participation, Algorithmic flexibility markets, Trust, Fairness, Incentives, Grid reliability

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Introduction

Prosumer flexibility has become a central resource for electricity systems seeking to integrate distributed renewable generation, storage, electric vehicles, and controllable loads. Studies of peer-to-peer energy communities show that households do not merely respond to market prices but evaluate participation through social, environmental, and strategic preferences [1]. As local electricity markets and trading platforms mature, prosumers are increasingly expected to act as active market participants rather than passive consumers [2].

Algorithmic flexibility markets intensify this shift by using automated platforms to match flexibility offers, dispatch resources, calculate compensation, and enforce market rules. Research on peer-to-peer trading indicates that such market arrangements can create new forms of value, but participation depends on whether users understand and accept

the platform's logic [3]. The model proposed in this article treats algorithmic market participation as a socio-technical decision shaped by technology, institutions, and household-level meaning.

The participation challenge is especially important because demand response and flexibility provision often require households to surrender some control over energy timing, storage, or appliance operation. Reviews of residential demand response show that engagement is influenced by motivations, enabling conditions, and barriers that extend beyond financial rationality [4]. Accordingly, the theory developed here argues that prosumers assess algorithmic flexibility markets through four mechanisms: trust, fairness, incentives, and grid reliability requirements.

This article contributes to theory by integrating behavioural and system-level explanations into a single conceptual model of participation. The model builds on evidence that prosumers' trading preferences are shaped by simplicity, social fairness, and environmental values [5], while market participation is also conditioned by institutional and technical design choices [6]. The article therefore develops a causal framework that explains when algorithmic flexibility markets become acceptable, actionable, and durable for prosumers.

Prosumer Participation Problem

Defining prosumer participation

Prosumer participation refers to the willingness and capacity of households or small-scale actors to provide flexibility, trade energy, or allow automated coordination of distributed resources. In peer-to-peer energy trading, participation includes not only the act of buying or selling electricity but also the acceptance of platform rules, trading partners, settlement procedures, and operational constraints [7]. In algorithmic flexibility markets, participation is therefore both behavioural and institutional: prosumers must decide whether to enroll, remain engaged, and comply with automated decisions.

Current market designs and participation gaps

Current flexibility market designs often assume that prosumers will respond predictably to price signals, but empirical and conceptual research suggests persistent participation gaps. The evolution of prosumer opportunities shows that new market roles are frequently constrained by unclear regulation, platform complexity, and uneven value distribution [2]. Even when local electricity markets improve technical coordination, participation may remain limited if the market feels too complex or insufficiently aligned with household priorities [6].

Beyond pure economic rationality

A theory of prosumer participation must move beyond pure economic rationality because households interpret flexibility through convenience, control, identity, social norms, and perceived legitimacy. Evidence from demand response research shows that participation is shaped by motivation, ability, and opportunity rather than incentives alone [8]. The model therefore assumes boundedly rational prosumers who evaluate algorithmic flexibility markets through perceived trustworthiness, fairness, reward value, and reliability implications.

Theoretical Foundations

Trust theories

Trust theories distinguish confidence in actors, institutions, and systems, which is directly relevant to automated energy markets where decisions are delegated to digital platforms. Research on artificial intelligence shows that trust in automated decision-making depends on perceived competence, transparency, accountability, and contextual

appropriateness [9]. In algorithmic flexibility markets, trust is therefore defined as the prosumer’s belief that the platform will make reliable, understandable, and non-exploitative decisions when coordinating flexibility.

Fairness theories

Fairness theories highlight distributive, procedural, and interactional dimensions of justice, all of which shape acceptance of market outcomes. In local energy systems, fairness concerns arise when benefits, costs, responsibilities, and risks are distributed across heterogeneous participants [10]. For prosumers, distributive fairness concerns compensation, procedural fairness concerns market rules and algorithmic allocation, and interactional fairness concerns communication, explanation, and respectful treatment.

Incentive theories

Incentive theories explain how monetary and non-monetary rewards influence participation, but they also show that rewards are interpreted through salience, framing, and perceived legitimacy. Game-theoretic studies of peer-to-peer energy trading demonstrate that incentives can sustain participation when trading rules align individual gains with collective market performance [11]. The model therefore treats incentives not as isolated price signals but as interpreted rewards whose effectiveness depends on trust and fairness.

Grid reliability as a macro-level constraint

Grid reliability theory positions flexibility not only as a household opportunity but also as a system requirement that translates network constraints into market rules. Market-based frameworks for demand-side flexibility show that scheduling and dispatch must satisfy operational needs while coordinating distributed resources [12]. In the proposed model, reliability requirements shape participation indirectly by affecting algorithmic control intensity, dispatch obligations, compensation structures, and the perceived legitimacy of flexibility requests.

Table 1 synthesizes key behavioral and system-level theories to explain how trust, fairness, incentives, and reliability jointly shape prosumer engagement and sustained participation in algorithm-driven flexibility markets.

Table 1. Summary of Theoretical Lenses and Their Relevance to Prosumer Flexibility Markets

Theoretical lens	Core conceptual concern	Relevance to algorithmic flexibility markets	Expected participation implication
Trust theory	Confidence in actors, institutions, systems, and automated decisions	Explains whether prosumers accept algorithmic dispatch, settlement, and data use	Higher trust strengthens enrollment, compliance, and continued engagement
Fairness theory	Distributive, procedural, and interactional justice	Explains how prosumers judge compensation, rule design, access, and explanations	Higher perceived fairness strengthens legitimacy and long-term participation
Incentive theory	Monetary rewards, non-monetary benefits, framing, and motivation	Explains how price signals, contracts, convenience, and environmental framing influence choices	Incentives increase participation when salient, credible, and aligned with values
Reliability theory	System adequacy, operational constraints, resilience, and grid needs	Explains why flexibility requests become more binding during network stress	Reliability needs increase participation when translated into legitimate and understandable signals

Trust Mechanism

Dimensions of trust in algorithmic platforms

Trust in algorithmic flexibility markets has several dimensions: trust in the technical system, trust in the market operator, trust in the algorithmic decision process, and trust in data governance. Studies of virtual power plants show that householders may support automation only under conditions that protect autonomy, transparency, and perceived household interests [13]. The model proposes that these trust dimensions jointly determine whether prosumers view automation as assistance, delegation, or loss of control.

Antecedents of trust

The antecedents of trust include transparency, reliability, cybersecurity, explainability, prior experience, and institutional credibility. Research on trust in AI-based systems emphasizes that trust is context-specific and shaped by ethical concerns, system performance, and perceived governance safeguards [14]. In flexibility markets, these antecedents matter because prosumers must believe that the platform can optimize resources without exploiting private data, misallocating rewards, or creating hidden risks.

Effects of trust on participation behaviour

Trust affects participation by reducing perceived risk and lowering the cognitive burden of engaging with automated market operations. Survey-experimental work on algorithmic decision-making indicates that people differentiate between trusting an algorithm's capability and trusting the institutions that deploy it [15]. The model proposes that high trust increases initial enrollment, tolerance of automated dispatch, willingness to share data, and resilience after occasional unfavorable outcomes.

Moderating role of trust in other mechanisms

Trust also moderates the effects of fairness, incentives, and reliability requirements because the same market rule may be interpreted differently depending on whether the platform is seen as trustworthy. Research on trustworthiness suggests that durable acceptance depends less on asking users to trust and more on designing systems that deserve trust [16]. Thus, the model argues that incentives become more credible, fairness claims become more believable, and reliability requests become more legitimate when algorithmic platforms are perceived as trustworthy.

Fairness Mechanism

Fairness in flexibility compensation

Fairness in flexibility compensation concerns whether prosumers believe that payments, savings, or trading benefits reflect their contribution, inconvenience, risk, and opportunity costs. Choice experiments on peer-to-peer electricity trading show that users value socially fair and simple arrangements, not only green or profitable ones [5]. The model proposes that perceived distributive fairness strengthens participation because prosumers are more likely to provide flexibility when rewards are viewed as proportionate and non-extractive.

Procedural fairness in market rules

Procedural fairness concerns how participation rules are designed, communicated, applied, and revised across participants. Research on new electricity market models shows that value is created not only through transactions but also through the affordances that enable users to understand, control, and benefit from participation [17]. In algorithmic flexibility markets, procedural fairness therefore depends on transparent eligibility criteria, understandable dispatch rules, accessible dispute mechanisms, and consistent treatment across prosumer groups.

Perceived justice and long-term engagement

Perceived justice shapes long-term engagement because repeated exposure to unfair outcomes can erode legitimacy even when short-term compensation is attractive. Work on distributive energy justice in local electricity markets shows that fairness indicators can reveal whether market designs distribute benefits and burdens equitably across participants [18]. The model argues that fairness perceptions accumulate over time, forming a participation memory that affects retention, advocacy, and willingness to accept future automation.

Interaction with trust and incentives

Fairness interacts with trust and incentives because compensation that appears generous may still fail if prosumers suspect manipulation, while modest rewards may be acceptable when rules are transparent and equitable. Research on social acceptance of demand response suggests that cost, context, and convenience jointly influence acceptance rather than operating as separate factors [19]. The model therefore proposes that fairness amplifies incentive effectiveness by making rewards legitimate and amplifies trust by showing that algorithmic governance treats prosumers as partners rather than merely controllable assets.

Incentive Mechanism

Types of incentives

Incentives in algorithmic flexibility markets include direct payments, dynamic tariffs, bill savings, contract guarantees, convenience benefits, environmental recognition, and community-based rewards. Reviews of prosumer paradigms in sustainable energy show that participation is often linked to both economic and non-economic value creation, including autonomy, sustainability, and local empowerment [20]. The model proposes that incentives become participation drivers when prosumers can clearly connect the reward to their flexibility contribution and when the reward does not undermine their sense of control.

Incentive salience and framing effects

Incentive salience refers to how visible, understandable, and meaningful a reward appears at the moment of decision-making. Evidence on blockchain-enabled peer-to-peer electricity trading shows that consumer demand is shaped by how trading benefits are framed, especially when new market mechanisms are unfamiliar [21]. The model argues that algorithmic flexibility markets require not only technically efficient incentives but also communicable incentives that prosumers can interpret without specialized market knowledge.

Dynamic incentives and habit formation

Dynamic incentives can encourage repeated participation when they help prosumers develop routines around automated flexibility provision. Stochastic local flexibility market designs show that bidding, dispatch, and distribution-grid operation require repeated coordination between flexible resources and network needs [22]. The model proposes that when dynamic incentives are stable enough to be learned but flexible enough to reflect system conditions, they can convert episodic participation into durable market engagement.

Substitution and crowding-out effects with trust/fairness

Incentives may substitute for weak trust or fairness in the short term, but they may also crowd out intrinsic motivation if prosumers feel that market design ignores justice, autonomy, or collective purpose. Research on motivational game-theoretic approaches to peer-to-peer trading suggests that participation is stronger when incentives align individual benefit with broader system or community objectives [23]. The model therefore argues that incentives are most effective

when embedded in trustworthy and fair governance rather than used as compensation for mistrust or perceived exploitation.

Grid Reliability Mechanism

Perceived and objective reliability constraints

Grid reliability requirements create the macro-level conditions under which flexibility markets operate, but prosumers respond to these requirements through perception as well as technical reality. Grid-influenced peer-to-peer energy trading shows that local exchanges must account for network constraints rather than treating all trades as physically equivalent [24]. The model proposes that prosumer participation increases when reliability constraints are translated into understandable market signals, but decreases when constraints appear arbitrary, opaque, or punitive.

Prosumer responsibility and collective action

Algorithmic flexibility markets ask prosumers to contribute to collective system reliability through individually owned resources. Coalition-based peer-to-peer trading models show that cooperation among distributed actors can create collective benefits when participation rules support coordination and mutual gain [25]. The model therefore conceptualizes reliability participation as a form of collective action in which prosumers accept limited automation when they believe their contribution is meaningful, fairly rewarded, and shared across participants.

Impact of reliability events on participation

Reliability events can either strengthen or weaken participation depending on how prosumers interpret the event and the platform response. Ancillary-service frameworks for peer-to-peer energy communities show that local flexibility can support broader system services when community resources are coordinated through appropriate market arrangements [26]. The model proposes that successful reliability events can reinforce trust and perceived usefulness, whereas poorly explained curtailment, forced dispatch, or compensation disputes can reduce future willingness to participate.

Integration with market signaling

Reliability requirements become behaviourally meaningful only when converted into market signals that households can understand and act upon. Game-theoretic models of prosumer-based community microgrids show that trading mechanisms must coordinate individual decisions with operational constraints to preserve system performance [27]. The model argues that algorithmic platforms mediate this translation by connecting grid needs to prices, dispatch instructions, participation rules, and feedback about the prosumer's contribution.

Theory Model

Overview of the integrated model

The integrated model proposes that prosumer participation in algorithmic flexibility markets is jointly shaped by trust, fairness, incentives, and grid reliability requirements. Peer-to-peer energy trading potential depends on technology availability, tariffs, and the practical value that households can obtain from participation [28]. Building on this logic, the model treats participation as a multi-mechanism outcome in which prosumers evaluate whether automated flexibility provision is trustworthy, fair, worthwhile, and systemically necessary.

Figure 1 presents the article's integrated theory-building model, showing how trust, perceived fairness, incentive salience, grid reliability requirements, and participation experience jointly shape enrollment, automated-dispatch acceptance, data sharing, compliance, and long-term engagement in algorithmic flexibility markets.

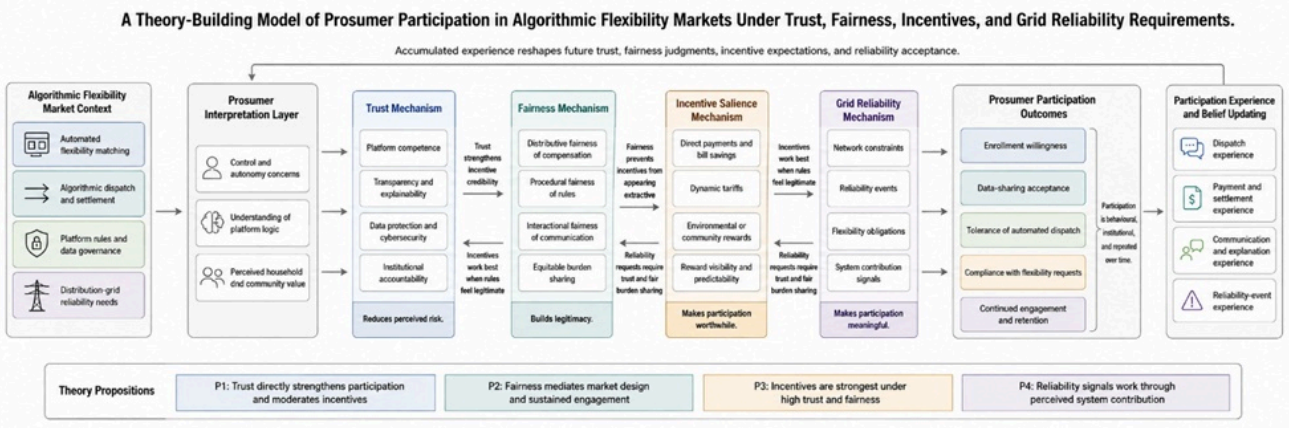


Figure 1. Integrated Theory-Building Model of Prosumer Participation in Algorithmic Flexibility Markets

Causal pathways and feedback loops

The model proposes several causal pathways linking mechanisms to participation. Trust reduces perceived risk, fairness increases legitimacy, incentives increase perceived benefit, and reliability requirements increase perceived system relevance, while participation experiences feed back into future beliefs about the platform. Blockchain-based pricing studies show that algorithmic settlement and trading design can influence how prosumers perceive value and strategic opportunity [29], suggesting that feedback from market outcomes is central to sustained participation.

Moderating and mediating effects

The model further proposes that the four mechanisms moderate and mediate one another rather than operating independently. Trust moderates the relationship between incentives and participation because rewards are more persuasive when the platform calculating them is credible, while fairness mediates the relationship between market design and engagement because rules shape whether outcomes appear legitimate [10]. Reliability requirements also moderate participation by changing the perceived importance of flexibility, especially when grid stress makes prosumer contributions more visible and socially meaningful [12].

Boundary conditions and assumptions

The model assumes that prosumers have at least minimal access to enabling technologies, such as smart meters, controllable devices, storage, or platform interfaces. It also assumes that algorithmic flexibility markets operate under institutional rules that allow prosumers to enroll voluntarily, receive compensation, and observe some explanation of market outcomes, conditions that are consistent with emerging prosumer market designs [2]. The theory is most applicable to residential and small-scale prosumers in digitally mediated markets, and less applicable where participation is mandatory, infrastructure is absent, or market governance is not visible to participants.

Table 2 presents an integrated theoretical model showing how trust, perceived fairness, incentive salience, grid reliability requirements, and participation experience jointly interact to shape prosumer engagement in algorithmic flexibility markets through reinforcing and moderating mechanisms that determine sustained participation.

Table 2. Integrated Theory Model: Constructs, Mechanisms, and Key Propositions

Core construct	Mechanism in the model	Causal role in participation	Expected interaction with other mechanisms

Trust in algorithmic platform	Reduces perceived uncertainty about automated decisions, data use, settlement, and dispatch	Strengthens enrollment, continued use, data sharing, and tolerance of automation	Amplifies incentive credibility and makes reliability requests more acceptable
Perceived fairness	Shapes judgments of compensation, procedures, access, and treatment	Strengthens legitimacy, retention, and willingness to accept repeated flexibility requests	Reinforces trust and prevents incentives from appearing extractive
Incentive salience	Makes financial and non-financial rewards visible, meaningful, and actionable	Strengthens willingness to provide flexibility when rewards are understandable and credible	Works best when supported by trust and fairness; may weaken engagement if perceived as manipulative
Grid reliability requirement	Translates system needs into market rules, dispatch signals, and flexibility obligations	Strengthens participation when prosumers perceive their contribution as useful and legitimate	Depends on trust in platform decisions and fairness in burden sharing
Participation experience	Provides feedback from enrollment, dispatch, payment, and communication episodes	Shapes future participation through accumulated confidence or disappointment	Converts one-time participation into durable engagement when all mechanisms align

Propositions

Trust-related propositions

The model proposes that higher perceived trustworthiness of an algorithmic flexibility platform will increase prosumer willingness to enroll, share data, accept automated dispatch, and remain engaged after unfavorable outcomes. Work on automated decision-making shows that trust depends on how users evaluate algorithmic capability and institutional accountability [9]. Accordingly, the first proposition is that trust has a direct positive effect on participation and a strengthening effect on the relationship between incentives and participation.

Fairness-related propositions

The model proposes that perceived fairness will increase participation by making both outcomes and procedures appear legitimate. Evidence from local energy justice research indicates that fairness must be evaluated across distributional and procedural dimensions, especially when market designs allocate benefits and burdens unevenly [18]. The second proposition is that perceived distributive and procedural fairness mediate the relationship between market design and sustained prosumer participation.

Incentive-related propositions

The model proposes that incentives increase participation when they are salient, predictable enough to be trusted, and framed in relation to household and collective value. Peer-to-peer trading research shows that sustainable user participation depends on market arrangements that align individual incentives with system-level coordination [11]. The third proposition is that incentives have the strongest positive effect on participation under conditions of high trust and high perceived fairness, but weaker or unstable effects when either mechanism is low.

Reliability-related propositions

The model proposes that grid reliability requirements increase participation when prosumers perceive flexibility requests as necessary, fairly allocated, and technically well governed. Market designs for local flexibility demonstrate that reliability constraints must be incorporated into bidding and dispatch if distributed resources are to support grid operation effectively [22]. The fourth proposition is that reliability signals strengthen participation when mediated by perceived system contribution and moderated by trust in the platform's reliability-related decisions.

Figure 2 translates the proposed theory into a market-design logic, illustrating how algorithmic flexibility markets can fail when incentives are not supported by trust, fairness, reliability transparency, and positive participation experience.

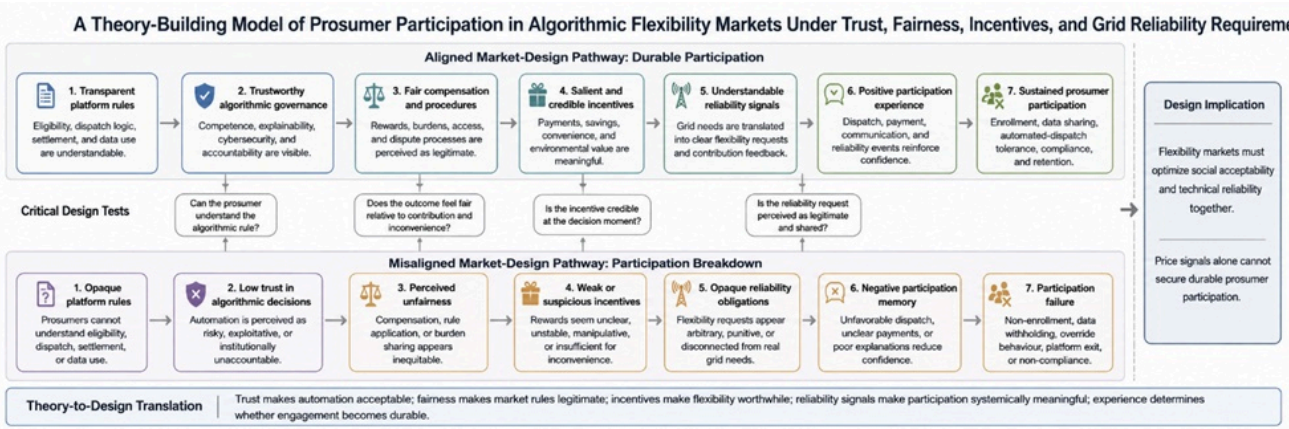


Figure 2. Participation Failure and Market-Design Logic in Algorithmic Flexibility Markets

Conclusion

This article developed a theory-building model of prosumer participation in algorithmic flexibility markets. The model explains participation as the outcome of four interlocking mechanisms: trust, fairness, incentives, and grid reliability requirements.

The theoretical contribution is to integrate micro-level perceptions with macro-level system constraints. Prosumers are not modeled as purely price-responsive actors but as participants who interpret automated market participation through credibility, justice, reward meaning, and perceived contribution to system reliability.

The model also offers practical value for the design of algorithmic flexibility markets. Platforms that seek durable participation should not only optimize dispatch and compensation but also make rules understandable, distribute benefits fairly, communicate reliability needs clearly, and demonstrate trustworthiness through governance.

Future empirical research can test the propositions through surveys, interviews, experiments, field studies, and comparative market analysis. Such work can refine the model, identify boundary conditions, and support flexibility markets that are technically reliable, behaviourally realistic, and socially acceptable.

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Conflict of interest

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