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Group Formation among Electricity Market Participants Based on Their Imbalance Perceptions

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for the doctoral dissertation

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Index

1 Research Background, Rationale

In my research, I examine how electricity market participants' perceptions of their own schedule deviations shape their market decisions, and under what conditions these perceptions provide a basis for beneficial joint market participation. I approach this question by exploring the potential economic foundations of energy communities. Rather than starting from the operation of a predefined community, I investigate how the emergence of groups can be explained by participants' individual interests and decisions.

In the electricity market, commercial agreements are concluded before actual delivery. Actual consumption and generation may, however, differ from the quantities committed to in advance. Before delivery, participants can only form expectations about the direction and magnitude of their own deviations from scheduled quantities. In this research, I refer to these expectations as imbalance perceptions. These perceptions do not necessarily match the deviations that subsequently occur, yet they may already influence committed quantities, contractual terms

and prices when agreements are concluded. Imbalance is therefore not merely a matter of ex post settlement; it may also be a key consideration in decisions made before delivery.

I analyse the relationships between the day-ahead and balancing markets within a unified modelling framework. I investigate whether participants' imbalance perceptions and the alignment of these perceptions can provide a basis for forming groups that offer economic benefits to their members. In this context, I also examine the effects of financial incentives on decisions and market prices, and whether the collective objective function derived from members' individual interests is equivalent to the objective function of the trader organising the balancing group. I investigate these formally specified relationships by combining equilibrium models with agent-based simulations.

Electricity market liberalisation, the growth of renewable generation and advances in digitalisation have significantly changed the opportunities available to market participants. Consumers can also become generators,

possess energy storage and balancing capabilities, and participate jointly in the market. At the same time, regulatory frameworks and financial incentives support the establishment of energy communities. However, the fact that joint market participation is legally possible does not necessarily mean that it is economically beneficial to the participants. Similarly, the implementation of a renewable energy investment does not, in itself, reveal what additional value is created by organising participants into a community.

It is therefore necessary to understand not only how an established energy community should operate, but also which participants would benefit from forming a community and which interests would motivate them to do so. The benefits of joint market participation may depend on the composition of the group, its members' expectations and how the consequences of schedule deviations are borne by the members. Organisational similarities to balancing groups do not, by themselves, resolve this question: although both arrangements bring

participants together, they do not necessarily address the same decision problem.

The scientific rationale for this research is that, in the literature reviewed, I did not identify an approach that bases group formation jointly on participants' differing imbalance perceptions and their individual economic interests. Incorporating these perceptions allows me to examine the emergence of communities as a process arising from participants' adaptation, rather than treating their organisational structure as predetermined.

The practical relevance of the research lies in the need to consider participants' decisions together with market adjustments when supporting energy communities and designing their operating arrangements. A financial incentive may change demand and, through this, equilibrium prices. My aim is therefore not to establish that energy communities are beneficial in general, but to identify the economic relationships that explain the benefits and limitations of joint market participation.

2 Research Methods

In this research, I develop a new modelling framework comprising a sequence of models that build on one another. In constructing this framework, I draw on available knowledge of electricity market operation and my more than fifteen years of experience in the sector. Examining how the market operates therefore provides not only the background to the research but also an integral part of the modelling process. I incorporate participants' available choices, interests and information, together with trading and settlement rules, into the models so that they represent the essential relationships underlying actual market operation as closely as possible.

The modelling process starts from the fundamental relationships between demand, supply and market equilibrium. I progressively extend the initial simplified description by incorporating consumers' awareness of imbalance consequences, imbalance perceptions, the trader's intermediary role, generation constraints and the alignment of participants' perceptions. I connect the day-ahead and balancing markets through participants'

decisions and settlements. This produces a family of models in which the effects of individual factors can be examined both separately and in conjunction with the relationships introduced in earlier models.

I combine equilibrium modelling with numerical optimisation and agent-based simulation. I use analytical derivations for as long as they help identify and interpret the underlying relationships. As the models become more complex, I use numerical methods to calculate equilibrium solutions. In the agent-based simulation, agents adjust their own imbalance perceptions towards those of other agents according to specified following rules, while the resulting prices and quantities are still determined by the equilibrium model. This allows the process of group formation and its effects on the market as a whole to be examined together.

I perform the numerical calculations, simulations and visualisation of results using a computational framework that I developed in MATLAB. I use MATLAB as a programming environment; the development and software implementation of the equilibrium-finding procedures and

the agent-based simulation form part of the research itself. Using different demand functions and parameter sets, I examine how changes in the model conditions shape participants' decisions and influence the resulting equilibrium.

Model validation involved mathematical checks, repeated simulations and expert consultations. I used mathematical checks to verify the internal consistency of the specified relationships, while repeated simulations allowed me to examine the extent to which the results persisted under different initial conditions. Through expert consultations, I assessed the model assumptions and the practical interpretation of the results against experience of actual market operation. These procedures do not establish that the models provide a complete description of reality, but they help assess whether the relationships underlying the research conclusions are preserved despite the simplifications.

3 Research Findings

To address the first research question, I examined whether groups capable of joint market participation could be formed on the basis of participants' own imbalance perceptions. I introduced a procedure in which participants follow others and adjust their perceptions of their own expected schedule deviations towards those of the participants they follow. The simulations produced groups whose joint demand could be represented by a single aggregate demand function in their interactions with the remaining market participants, even when different demand functions were used. In the cases examined, the convergence of perceptions and the relative stability of equilibrium prices persisted even when the schedule deviation itself changed. I thus demonstrated a process of group formation arising from participants' adaptation rather than from predefined organisational boundaries.

The second research question concerned the effects of financial incentives. I introduced subsidies by modifying the demand functions and then calculated the market equilibrium resulting from the changes in participants'

decisions. The simulations showed that the effects of incentives depend on schedule deviations and how these deviations are taken into account: under certain conditions, the increase in demand induced by a subsidy led to a higher electricity purchase price. The financial incentive provided does not, therefore, reveal the economic consequences of the subsidy on own. Changes in consumers' decisions and the resulting prices must be assessed together. This does not mean that subsidies are generally ineffective, but that market adjustments cannot be disregarded when evaluating their effects.

To address the third research question, I compared group formation based on members' individual interests with the decision-making framework of the trader organising the balancing group. In the model incorporating a trader, the trader manages the financial consequences of schedule deviations and accounts for their expected cost in its pricing. In group formation, however, members' own demand functions and imbalance perceptions remain the basis for their decisions. The distinction therefore concerns not only who organises joint market

participation, but also the interests and decision-making relationships underlying it. The fact that both a balancing group and participant-formed group bring together market participants does not imply that their objective functions are equivalent. The research identified differences between these objective functions within the model. The trader's interaction with the participants at equilibrium was represented by a profit-based equation, which reduced the influence of consumers' utility-based decisions on the market as a whole. This distortion was reflected in changes in market prices and the redistribution of economic surpluses.

Key findings of the dissertation based on the model:

At low day-ahead market prices, the quantity supplied to the day-ahead market by the balancing generator may either increase or decrease. An increase in the schedule deviation does not have a uniform directional effect on this quantity.

When the balancing market price is low, the day-ahead equilibrium price increases with the schedule

deviation in the model with imbalance-aware consumers.

When a consumer perceives its own schedule deviation to be lower than the deviation anticipated by the balancing participant, this exerts upward pressure on day-ahead market prices.

When a trader enters the model, the role of accounting for imbalance shifts from the consumer to the trader. However, the profit objective is not adaptive, and schedule deviations affect the two participants' decision problems in fundamentally different ways: for the consumer through utility and as a linear cost component a trader.

The trader's equation is based on the utility of money rather than the utility derived from electricity consumption. This represents a fundamentally different approach to determining market equilibrium.

Capacity constraints are already implicitly incorporated into the consumption and generation functions.

Their separate, explicit treatment is therefore required only in specific cases.

Using simulation, I demonstrated the existence of a constructive, convergent group formation procedure for a randomly generated set of consumers. This procedure enables group members to participate jointly in the market without a trader acting as an intermediary and to obtain consumer surplus.

Simulations demonstrate that the constructive procedure can produce convergent group formation at the market level under different functional forms of consumption. The members of the resulting groups can participate jointly in their interactions with the rest of the market.

The convergence of participants' imbalance perceptions has a greater influence on stabilising the emerging market equilibrium than ongoing changes in their perception errors.

Additional electricity consumption induced by financial incentives may lead to higher costs and market

prices, depending on schedule deviations. Neither interventions in network-use charges nor capital expenditure (CAPEX) incentives necessarily benefit electricity market participants.

Based on the preceding models, energy communities can be characterised as distinct and necessary market participants that can be derived endogenously within the modelling framework. They are distinct from pre-existing entities in that their system of objective functions differs from that of every other previously defined participant. Their presence contributes to the stability of market equilibrium.

4 Key References

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5 Related Publications by the Author

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Dr. Benedek G., Pocsarovszky K.: Szimulációs módszerek alkalmazása az üzleti döntéstámogatásban, IQSymposium, 14 April 2011, Budapest

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