

ABSTRACT

As large-scale electricity consumers, industrial consumers have a key role to play in adapting the electricity system to the changes required by the energy transition. However, in the context of liberalised electricity markets, industrial consumers largely remain passive market participants. The complexity and diversity of industrial processes, the strict production compliance requirements, the lack of domain expertise, and more generally the multi-criteria decision-making perspective make industrial consumers risk-averse in the implementation of electricity market participation strategies. Electricity market participation decision-making support tools tailored to the specific requirements of industrial consumers are therefore needed to encourage active industrial consumer participation in electricity markets.

This research addresses this challenge by developing an adaptable simulation framework for electricity market participation suitability evaluation from the perspective of industrial consumers. The framework builds on parametric prefeasibility studies, agent-based modelling, discrete-event simulation, sequential bidding algorithms and multi-criteria decision making methods to provide a consistent consumer-centric evaluation approach adaptable to an industrial consumer's specific industrial process and electricity market context, while minimising model implementation efforts.

The evaluation framework consists of multiple evaluation steps, whose results feed into each other to provide a multi-dimensional evaluation of market participation strategies. Prefeasibility evaluation tools are developed to filter out unfeasible submarkets using parametric analyses based on a systematic parametrisation of the industrial process flexibility and electricity market domains. The remaining submarkets are modelled in a discrete-event agent-based simulation, representing time-dependent industrial consumer interactions with the different submarkets constituting the electricity market ecosystem. Sequential bidding algorithms are implemented for each submarket based on market design, consumer constraints, and market price information accessed through agent interactions, allowing to test and compare the suitability of different multi-market participation strategies across different market types and over different timescales. The suitability of different strategies is compared by analysing the simulation outputs of each strategy using multi-criteria decision making methods.

This framework is implemented across different industrial processes and different electricity market contexts using a matrix of case studies. On the process side, a power-to-X electrolyser, a food cooling house, and greenhouse artificial lighting process are included. The framework adaptability is tested by the differences in operational flexibility properties of each process. On the market side, the Danish electricity market and the Chinese electricity market are included. The framework adaptability is tested by the difference in scale, energy mix, market architecture, market reform priorities, and level of market intervention between the two countries.

The experiment results implemented in the matrix of case studies reveal the importance of case- and context-specific market participation strategies for industrial consumers, as strategy suitability varies greatly across case studies. Moreover, in market contexts with more time-dependent market price variations such as in Denmark, adaptive market participation strategies should be implemented since strategy rankings change over time. Results also underline the importance of considering multi-market participation strategies for multi-criteria industrial consumers, drawing on the diversity of market types available to industrial consumers in a market ecosystem. Compared to baseline inflexible strategies, multi-market strategies can significantly improve the performance of certain criteria such as financial savings or bill variability, at the potential cost of product output deviation and increased complexity. The preferred

strategy is highly dependent on the relative importance of each criterion. In the Chinese context, multi-market strategies allow compliance with minimum quotas imposed for different market types, despite not being the highest-ranking strategies from the perspective of industrial consumers.

From a methodology perspective, this research has provided a systematic and adaptable modelling and evaluation approach to provide market participation suitability evaluations tailored to the needs of industrial consumers. From the perspective of industrial consumer market integration, the results obtained from the framework implementation in different case studies have contributed to a better understanding of the importance of adaptive multi-market participation strategies for multi-criteria market participants.