Modelling interactions between market power and demand response

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Energy systems based on renewables have increasing flexibility requirements. Meeting these requirements by conventional supply side or storage technologies alone will ultimately be inefficient or not possible at all. Demand response (DR) is another source that can the required flexibility. In terms of quantifying impacts and benefits of DR, many researchers have focussed on modelling power system operations from a least cost optimisation paradigm. However, as we conduct these analyses in today's liberalised markets, it is important to go beyond such approaches and model the interaction of different (profit-maximising) generators and (cost-minimising) consumers using game-theoretic equilibrium models. Moreover, since RES generation is not just volatile but also uncertain, one can further expect that this uncertainty, which is often ignored, affects the impact of DR on power system operation. In such an environment, we are therefore particularly interested in exploring how DR affects the costs for different consumers, how it affects generator profits and how it affects CO_2 emissions. Furthermore, we also explore how the presence of market power changes each of these.

To analyse these questions, we present a stochastic mixed complementarity problem (MCP). It considers operational decisions, interactions between an energy market, a capacity market and a feed-in premium. The MCP models the optimisation problems of different players. On the supply side, we model power generating firms with different generation portfolios, i.e. specialised baseload, midload and peak-load firms as well as a specialised RES firm and an integrated firm with generation capacity across all considered technologies. We consider an oligopoly with a competitive fringe where the integrated firm and the baseload firm are the only players able to exert market power. The uncertainty of the RES supply is the model's main source of stochasticity.

On the demand side, we consider several different consumer groups, including industrial and residential consumers. We also distinguish between traditional consumers and prosumers, i.e. consumers that have their own generation from solar PV modules and diesel-powered generators. Since the PV supply is also uncertain and the different RES supply profiles (e.g., wind and PV) and their uncertainties are correlated spatially and temporally, we consider this correlation when generating input data for the model. All consumers in our model choose, within given constraints, how much of their load to shift to meet their demand at minimum costs.

We apply this model to a case study based on data for the Irish power system in 2025, which has a high penetration of wind power and a significant presence of smart meters allowing consumers, or aggregators on their behalf, to react quickly to short-term changes in the market.

In the absence of market power, we find that DR reduces consumer costs from the energy market. However, total consumer costs increase as the energy cost savings are (over-)compensated by increased capacity and feed-in premium costs. Consequently, DR can increase generator profits, particularly for renewable generators. When strategic behaviour is present in the market, all firms' profits increase substantially, regardless of whether they can exert market power or not leading to increased costs to consumers. However, for most consumers, increasing the percentage by which they can shift their load, reduces this effect and hence their costs. The exceptions are consumers who have a large amount of their own micro-generation. For them, we find that increasing their ability to shift their load does not mitigate against the negative effects of market power.

The results highlight the importance of modelling different consumer groups and different markets when considering the impacts of DR. This holds when market power is both present and absent from the market. The results also show how DR can reduce the negative effects of market power. However, the results also demonstrate that DR and other technologies such as micro-generation may be competing technologies when it comes to such migration efforts.