DECENTRALISED ENERGY TRANSFORMATION: A MIXED COMPLEMENTARITY PROBLEM AND ITS APPLICATION TO ENERGY COMMUNITIES IN GERMANY

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Overview

In the course of the energy transition, the number of options for locating generation technology grows as size of technology varies from small to large. In terms of capacity location and market participation, large renewable generation behaves similar to today's centralized conventional plants. In contrast, small-scale technology can have a very different role in the energy system that differs in location, capacity and ownership. A widespread installation of e.g. rooftop solar panels, residential heat pumps, single wind turbines or combined heat and power plants at micro level changes the market setup in various characteristics. A major change is the increasing number of possible electricity suppliers with generation technology at any level in the system which moves the system from a strictly top-down structure to a set up with generation and consumption reaching from residential to high-voltage levels. While in the presence of market participants at the level of electricity distribution the network operators face the challenge of bi-directional electricity flow and its coordination, market operators needs to handle a growing number of participants with a great variety of available capacity. Especially small-scale producers up to a specific capacity (around 100 kW) create a challenge to the market and are in most countries regulated under specific roles. Most of these producers can be seen as prosumers who self-consume large shares of their own production. In the case of excess generation they are allowed to feed into the grid instead of individually participating in the wholesale electricity market auctions, and they will be remunerated at a fixed rate (Butler and Neuhoff 2008; Wand and Leuthold 2011) or can give the rights to manage their production to an energy supplier (Purkus et al. 2015).

Current discussions claim that these small-scale technologies should not be further deployed (Mathiesen et al. 2017) due to high system costs and e.g. in Germany there is an expiration date on remuneration tariffs that – under current legislation – will soon be reached. In order to be able to investigate in these system affects, the economic characteristics as well as new business models or incentive mechanisms, we develop a model that illustrates a set-up of small-scale prosumers, consumers and a market operator in a regional/connected context. It is adjustable to new mechanisms or market designs as well as endogenously determines a willingness to pay for electricity for a group of prosumers and consumers. For an application, we perform a run for energy communities in Germany where we compare different incentive mechanisms based on the same structural group of electricity prosumers.

Methods

We develop a mixed complementarity model (MCP) applicable to energy markets with participants that have different characteristics. Our model consists of three groups of equations each representing a type of participant. First, we have electricity consumers and prosumers that act with the objective to minimize their cost of electricity given an inelastic demand. Second, we consider a market operator that aims at balancing an interconnected market and has access to procure electricity from outside the community. i.e. the distribution grid. And third, we consider a storage entity that can vary in its ownership structure. The model is implemented in the Julia Language. In our case study, we solve the model for a community of 14 households using consumption data from the "Low Carbon London" project in the greater London area1, production data for a location in the North of Germany and fees and electricity prices from the German electricity market. The model is adjustable for a time period of investigation. Our case study is run for two weeks in each season. The model takes consumption, production, and price data on levies and taxes as given and determines the costs of electricity for consumers, the earnings for prosumers, a willingness to pay for electricity among these consumers in the presence of own production, and a storage usage pattern.

Preliminary Results

We run different cases to compare different market setups. First, we run a case of today's market: fixed electricity prices, determined feed-in tariffs and today's levies and taxes. Second, we allow for "local interchange", which represents a balance of production and consumption and determines the willingness to pay for this electricity. Note that also local balancing will be charging grid fees and levies. Renewable energy sources are depending on weather

[1] https://data.london.gov.uk/dataset/smartmeter-energy-use-data-in-london-households

conditions and therefore need to rely on flexibility options to balance gaps in production. Thus, for a third case we introduce storage technology. Any storage technology or production plant that has the same characteristics as a storage can come into place here. In a fourth run, we introduce dynamic prices for consumers as demanded by European legislation (EP, CONSIL 2019).

Conclusions

The mixed complementarity model opens up the opportunity to model a set of heterogeneous players in an energy market environment. Each of them sees a different objective function subject to their individual constraints of balancing their demand and production. In addition, it is possible to observe a minimum rate at which the overall community would sell electricity to outside of the local area in times of heavy overproduction. The use of flexibility resources can be observed in the storage device and we see how arbitrage potential can be avoided by efficiently managing this resource.

References

Butler, Lucy, and Karsten Neuhoff. 2008. “Comparison of Feed-in Tariff, Quota and Auction Mechanisms to Support Wind Power Development.” *Renewable Energy* 33 (8): 1854–67. https://doi.org/10.1016/j.renene.2007.10.008.

EP, CONSIL. 2019. *Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on Common Rules for the Internal Market for Electricity and Amending Directive 2012/27/EU (Text with EEA Relevance.). 158*. Vol. OJ L. http://data.europa.eu/eli/dir/2019/944/oj/eng.

Mathiesen, Brian Vad, Andrei David, Silas Petersen, Karl Sperling, Kenneth Hansen, Steffen Nielsen, Henrik Lund, and Joana Brilhante das Neves. 2017. “The Role of Photovoltaics towards 100% Renewable Energy Systems: Based on International Market Developments and Danish Analysis.” Department of Development and Planning, Aalborg University. https://vbn.aau.dk/da/publications/the-role-of-photovoltaics-towards-100-renewable-energy-systems-ba.

Purkus, Alexandra, Erik Gawel, Marc Deissenroth, Kristina Nienhaus, and Sandra Wassermann. 2015. “Market Integration of Renewable Energies through Direct Marketing - Lessons Learned from the German Market Premium Scheme.” *Energy, Sustainability and Society* 5 (1): 12. https://doi.org/10.1186/s13705-015-0040-1.

Wand, Robert, and Florian Leuthold. 2011. “Feed-in Tariffs for Photovoltaics: Learning by Doing in Germany?” *Applied Energy* 88 (12): 4387–99. https://doi.org/10.1016/j.apenergy.2011.05.015.