DEVELOPING A MODEL FOR CONSUMER MANAGEMANT OF DECENTRALIZED OPTIONS

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Overview

Achieving deep decarbonization in Europe will require the penetration of innovative, low-carbon technologies across all sectors. The electricity sector was one of the first to begin revolutionizing its generation fleet, e.g., via the adoption of solar and wind plants. However, other sectors have proven difficult to reform. The heating market, in particular, has shown extremely low replacements rates: In Germany, only 3.4% of heating systems were replaced in 2015 (BEE, 2016). In other words, a complete transformation of decentral heating systems in Germany would take about 30 years to complete. Yet the German government has issued decarbonization targets for 2030 for its buildings fleet to reduce carbon emissions by 40% compared to 2014. Newer low-carbon distributed generation technologies such as heat pumps and mini combined-heat-and-power (CHP) motors may help the end consumer in contributing to reaching these national climate goals. However, the question arises if, when and to what extent these technologies may penetrate the heating market and whether additional incentive mechanisms are necessary to accelerate the replacement of older fossil-fuel based systems.

With the potentials for distributed generation technologies growing and the role of the end consumer evolving, it becomes increasingly important to understand the economic drivers and implications of generating, supplying and consuming energy in a decentralized landscape. Therefore, the paper at hand seeks to address the following research questions: i) how can linear programming methods be used to simulate investment in and operation of distributed generation and storage technologies to optimize the total energy use of end consumers?, ii) what technological, regional and regulatory aspects must be accounted for in order to model the decisions surrounding end consumers' energy use and provision?, and iii) what role may emerging technologies play in helping end consumers in Germany achieve a cost-minimal energy mix and how may variations in the electricity price structure due to an increasing share of renewable electricity sources affect the consumer's energy decisions?

Within the scope of this paper, the model "Consumer Management of Decentralized Options" (COMODO) is developed to determine the cost-minimal energy provision for an end consumer or consumer group according to each energy use type (EUT), i.e., electricity, water heating and space heating. The model uses mixed-integer linear programming to perform a partial-equilibrium investment and dispatch simulation, accounting for a wide range of distributed generation as well as storage technologies. End consumers may invest in these technologies to cover their energy demand or buy electricity or district heating from an energy provider. Regulatory frameworks and energy market conditions may be adjusted to examine economic impacts of current, future or hypothetical developments. In doing so, COMODO not only serves to analyze the profitability of distributed generation and storage technologies but may also help to understand the key economic and regulatory drivers affecting the end consumer's energy consumption behavior.

In order to demonstrate the capabilities of the model developed, an exemplary scenario is presented to simulate the investment and energy use decisions of both a newly constructed and an existing single-family home in Germany up to 2040. Two scenarios are considered and then compared: the business-as-usual solution and the electric-revolution case. In both scenarios, households are not limited in their investment or energy use decisions and are assumed to choose the rational, least-cost option to cover their electricity as well as space and water heating needs. Consumers optimize their energy consumption and production behavior against an hourly electricity price that reflects the market conditions at that time—which vary across the two scenarios. Whereas the business-as-usual solution assumes a moderate share of renewable energy sources (RES) in German electricity production by 2040, the electric-revolution case requires that a very large share of German electricity production in 2040 comes from renewable generators. In other words, the scenarios seek to investigate the resulting investment and dispatch decisions of the two household types under moderately fluctuating electricity prices (i.e., moderate deployment of fluctuating RES) and highly fluctuating electricity prices (i.e., high deployment of fluctuating RES).

Methods

The model "Consumer Management of Decentralized Options" (COMODO) is a mixed-integer problem that uses linear programming methods to minimize the total system costs of supplying energy to a specific consumer class or group. Consumer classes are defined according to criteria such as building type (e.g., single-family home, multi-family home, industry building), building age, renovation level, living area, available roof space, number of inhabitants and location. These key criteria, in turn, determine how the consumers are parameterized according to, e.g., their demand levels, load profiles, investment options, generation potentials as well as economic and regulatory conditions. COMODO then determines the cost-minimal energy provision for a consumer class according to each energy use type (EUT), i.e., electricity, water heating and space heating. The model developed determines the consumer's private economic optimum in satisfying its electricity and heating demand using a partial-equilibrium investment and dispatch simulation.[1]

In order to cover the consumer's energy needs, COMODO may choose an investment object from its extensive catalogue or may purchase electricity or district heating from the grid. The current technology catalogue accounts for 20 distributed generation and storage technologies.[2] All technologies are subject to their specific investment and installation costs, operating costs and other fixed costs as well as technical specifications such as efficiency, technical lifetime and availability. Several investment objects require natural gas or oil as input, which can be bought at the local commodity price. Others require electricity, which can either be produced and supplied by the consumer or bought from the electricity market at the retail price. In the case of PV and solar thermal, the energy input is solar irradiation and depends on the weather conditions in the consumer's region. Weather conditions may also affect other technologies such as heat pumps, whose efficiency may, e.g., decrease in colder temperatures.

Next to the investment decision the model also optimizes the resulting consumption, generation and storage-use profiles of the distributed technology in order to satisfy demand off all EUTs in all hours. For electricity, demand may be both exogenous and endogenous as the consumer's immediate electricity needs--the exogenous part--may be accompanied by an endogenously-determined heat-driven demand for electric power from, e.g., heat pumps. Space and water heating demand, on the other hand, is defined completely exogenously. The standard temporal resolution of the model is hourly but can be adjusted to account for fewer (via clustering) time slices or higher time resolutions.

The model is able to accommodate current as well as planned or hypothetical regulatory frameworks and energy market conditions relative to the location of the consumer. These include, among others, end consumer energy prices and their components such as taxes and fees as well as remuneration mechanisms such as investment subsidies, feed-in tariffs, market premiums and direct marketing of distributed generation. The tariff structure may also be adjusted for energy (Euro/kWh) and capacity (Euro/kW) prices. Further constraints to account for, e.g., emissions reduction targets may also be applied. The model can be simulated for future years by adjusting, among others, the regulatory and market conditions as well as the economic and technological assumptions. In doing so, COMODO provides the opportunity to analyze the diffusion processes of distributed generation technologies over time for specific consumer classes or accumulated consumer groups.

Results

Preliminary results show that differences in the penetration of renewable electricity sources in the generation mix may affect the profitability of distributed energy technologies if end consumers are exposed to hourly market prices. More specifically, variation in hourly electricity prices could lead to a hybridization of energy generating technologies for the end consumer's heating and electricity use. For example, hours with lower electricity prices may increase the value of electricity-based heating technologies whereas a fossil-fuel heat source could be more economical when faced with higher electricity prices during times of, e.g., low renewable generation.

Conclusion

Increased fluctuation of the electricity price due to, e.g., increased renewable generation may cause other sectors in Germany such as mobility and industry to boost electrification. In turn, this increase in demand may shift the merit order and affect the investment and dispatch decisions of the end consumers. Finally, an increased decentralized hybridization could have positive effects for the carbon emission reduction of single end consumers, especially if the future electricity generation mix becomes increasingly more renewable.

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[1] It may be interpreted as a social planner problem in which the social planner minimizes total system costs under perfect foresight for investments in and operation of generation and storage capacities.

[2] The model structure allows for the technology catalogue to be expanded to include additional electricity or heat production, storage and/or consumption technologies