AN ENERGY SYSTEM PERSPECTIVE ON RESIDENTIAL DEMAND-SIDE FLEXIBILITY: FLAVOR OR CRITICAL INGREDIENT FOR THE GREEN TRANSITION?

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Overview

Supply and demand for electricity will play a pivotal role in the transformation toward an energy system that achieves the targets of the Paris Climate Agreement, especially when considering the necessary electrification of the heating and transportation sector and their integration with the electricity sector. The European Commission, with its *Clean Energy for all Europeans* package released in 2016, calls for stronger participation of residential electricity consumers—individually or through communities—in energy production and sharing as well as a flexible and responsive demand side. Demand-side flexibility, that is, the temporal shift of electricity can be achieved either by using storage technologies like batteries or by an actual shift in the use of electricity-consuming devices. The demand for electricity and the flexibility of electricity demand will ultimately determine the need to invest in renewable electricity capacity and transmission and distribution infrastructure and hence largely determine the cost-efficiency of energy systems.

When analyzing potential flexibility in household electricity demand, it is important to consider the non-technical aspects that affect how easily consumption can be shifted from one time period to another. Broadly speaking, there are two different routes to realizing the potential of demand flexibility from usage changes. The first strategy relies on consumer behavior change, that is, manually shifting consumption to accommodate the challenges of supply. The second strategy relies on the automation of appliances, which can facilitate an automatic demand response with little or no consumer action. The latter is dependent on a technical update of household appliances which again depends on the rate of technology adoption. McKenna et al. (2018) therefore classify demand response in three dimensions: technology, service expectations, and activities referring to the distinctions made above.

In the literature, many studies are focusing on flexibility from white goods and active changes in consumer behavior. With the advancing electrification of heating systems and the individual transportation sector, new (semi-)automatable flexibility potential in the electricity sector emerges that is not necessarily reliant on occupants' behavior and thereby imposes costs in terms of time use or restraints to their living comfort level.

Extending the existing literature, this paper transcends the focus on these non-behavioral demand-side flexibility potentials, by taking a wider energy system perspective on both the potential for and the value of flexibility in electricity demand. The energy system perspective further allows the paper to investigate how synergies with decarbonization beyond the power sector can benefit the system and reduce system costs. In addition, a comparison of flexibility versus energy savings is used to determine the value of both (non-exclusive, integrative) pathways.

Methods

The paper applies the IntERACT framework (Andersen et al. 2019). It has been developed to have a satisfactory description of both the Danish economy and the Danish energy system, and especially the link between the two. The model setup consists of a top-down macroeconomic model and a bottom-up energy system model (TIMES-DK; Balyk et al. 2019). TIMES-DK describes the Danish energy system using detailed technical modeling of both the production and use of energy and is based on the international TIMES modeling framework.

To investigate the effects and the value of flexibility to the system, the paper analyzes energy system costs, installed capacity of renewables, full load hours/curtailment of renewables, emissions, average electricity prices, and household energy expenses for the year 2030.

Two main scenarios are tested: flexibility versus pure energy savings. Each of them has three sub-scenarios varying in flexibility provision or energy savings from either selected household appliances, electric vehicles, or heat pumps. A separate sensitivity scenario looks at the flexibility effects of a more centralized renewables-based district heating system compared to the decentralized system with heat pumps installed in households.

Results and Conclusion

Our preliminary findings show that the provision of short-term flexibility to the energy system from electricity demand shifting has great potential. Yet, it has to be distinguished between flexibility provided via changes in behavior that are harder to achieve due to (hidden) consumer costs and pure technological changes as "low-hanging fruits". While heat pumps and battery electric vehicles belong to the latter category and have the larger potential, household appliances are harder to activate but also have lower potential. We find some evidence of energy systems effects, namely that additional household flexibility adversely affects the price of electricity associated with hydrogen production and PtX.

References

Andersen, Kristoffer S., Lars B. Termansen, Maurizio Gargiulo, and Brian P. Ó Gallachóirc. 2019. "Bridging the Gap Using Energy Services: Demonstrating a Novel Framework for Soft Linking Top-down and Bottom-up Models." *Energy* 169 (February): 277–93. https://doi.org/10.1016/j.energy.2018.11.153.

Balyk, Olexandr, Kristoffer S. Andersen, Steffen Dockweiler, Maurizio Gargiulo, Kenneth Karlsson, Rikke Næraa, Stefan Petrović, Jacopo Tattini, Lars B. Termansen, and Giada Venturini. 2019. "TIMES-DK: Technology-Rich Multi-Sectoral Optimisation Model of the Danish Energy System." *Energy Strategy Reviews* 23 (January): 13–22. https://doi.org/10.1016/j.esr.2018.11.003.

McKenna, Eoghan, Sarah Higginson, Philipp Grunewald, and Sarah J. Darby. 2018. "Simulating Residential Demand Response: Improving Socio-Technical Assumptions in Activity-Based Models of Energy Demand." *Energy Efficiency* 11 (7): 1583–97. https://doi.org/10.1007/s12053-017-9525-4.