ESTIMATION OF LOAD SHIFTING IMPACT ON ENERGY EXPENSES AND SELF-CONSUMPTION IN THE RESIDENTIAL SECTOR

Pietro Lubello, Università degli Studi di Firenze, pietro.lubello@unifi.it
Ilian Bensana Tournier, Ecole normale supérieure Paris-Saclay, ilian.bensana tournier@ens-paris-saclay.fr
Carlo Carcasci, Università degli Studi di Firenze, carlo.carcasci@unifi.it
Sylvain Quoilin, Université de Liège, squoilin@uliege.be

Overview

Demand side management is an increasingly diffused practice for large energy consumers, while the disaggregated nature of residential loads makes its adoption in the residential sector more complex. Among the demand side management practices, load shifting allows to match demand and production. In the case of prosumers, harnessing the load shifting potential from available technologies allows to increase self-consumption ensuring benefits both for the customer and the local grid. In order to evaluate the actual potential of load shifting in the residential sector, two major steps are needed: (1) a reliable and disaggregated, both with respect to time and technologies, estimation of demand curves and, (2) an evaluation of the actual possibility to shift each load and its corresponding impact on self-consumption and energy bills. In this work, both steps have been conducted for the Belgian residential sector. Stochastic demand curves have been obtained for a set of representative cases through a framework composed of different open-source models, allowing to obtain the electricity consumption from appliances, electric boilers for domestic hot water, heating through heat pumps and electric vehicles charging. Load curves have been validated by comparison to historical real-world data. The load shifting potential has then been estimated, both considering time-of-use tariffs and, in case photovoltaic panels were present, self-consumption maximation, also through batteries. Results have highlighted the contribution to load shifting from each different technology, suggesting that correctly structured tariffs could reduce peak hour demand and increase self-consumption.

Methods

All thermal and electrical energy consumption are modelled in a bottom-up fashion and with a one-minute time step through a set of open-source models:

- StROBe is a stochastic residential occupant behaviour model based on Markov chains and has been used to obtain electricity consumption associated to appliances and lights, and to estimate internal heat gains, hot water withdrawals, and the household's members occupancy profiles [1].

- Building thermal demand has been obtained through a dedicated RC-equivalent building model following the implementation of Jayathissa et al. [2].

- Hot water and house heating demand have been converted to electrical demand through two ad-hoc developed models of an electric boiler and a heat pump.

- Finally, charging profiles for electric vehicles have been obtained through RAMP-mobility, a tool for the generation of European electric vehicles mobility and charging profiles at high temporal resolution [3].

The models have been integrated in a unified framework for the generation of electrical load curves in the residential sector and have been complemented with a set of rule-based control actions for the evaluation of load shifting and demand side management. Such functions have been defined both for the displacement of loads based on time-of-use tariffs and, in the case of prosumers installing photovoltaic panels, for self-consumption maximization. In the latter case, the possibility of installing an electrochemical battery has been considered and its usage strategy has been modelled according to a methodology developed in previous works [4].

Among all household appliances, only wet appliances (namely dishwashers, washing machines and tumble dryers) have been considered as time-shiftable. The adopted modelling approach is based on the definition of admissible time windows for the shifting, combined with a user-defined probability of the shifting to actually happen. Such admissible time windows have been defined according to the case to be simulated and could hence be based on the presence of households' members at home, energy prices and the availability of energy from PV panels.

Electricity demand from the electrical boiler for domestic hot water has been modelled through a battery-equivalent approach. The capacity of the boiler to store energy has been defined considering the size of the hot water tank, and the possibility of pre-heating water in correspondence of low energy prices or when excess energy from the PV panels is available.

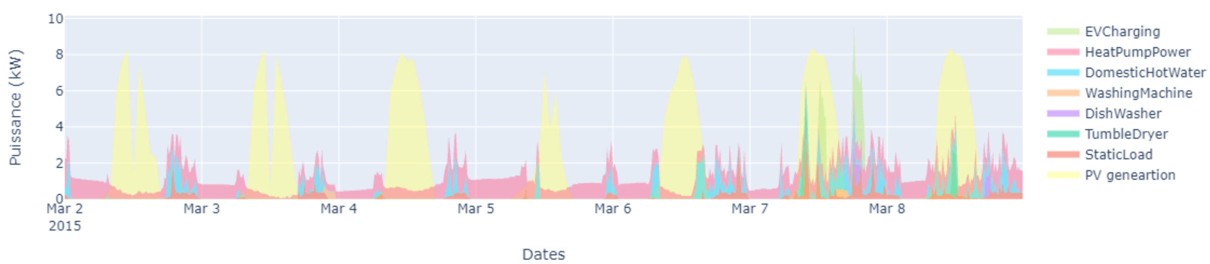
House thermal demand has been shifted by modifying the thermostat setpoints, increasing the temperature requested to the heating system of a fixed offset in order to preheat the house during time windows of up to three hours prior to the actual demand.

Electric vehicles have been considered batteries connected to the household energy system. The available capacity has been obtained from evaluating when the car is parked and plugged-in at home and the minimum state-of-charge needed to ensure enough charge will be available for the next drive, estimated with a perfect-foresight of the car usage throughout the year.

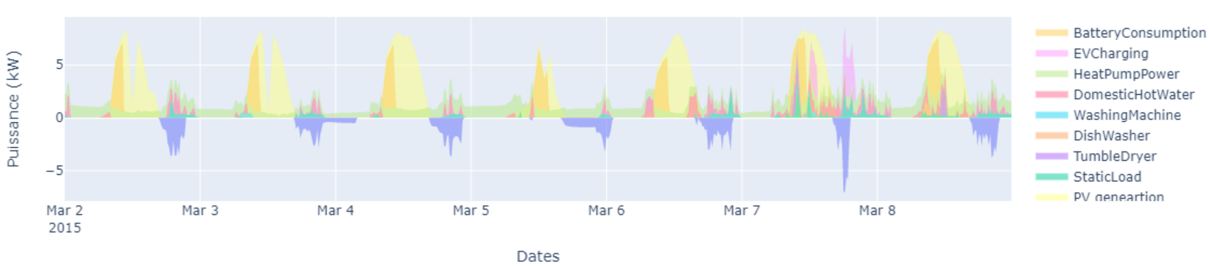
Results and conclusions

Results consist of a set of demand curves representative of the Belgian residential sector and of an analysis of the potential contribution of each technology to the displacement of electricity demand. The impact of different strategies on self-consumption and consumers' energy bills has been assessed. We present here an extract from the results obtained for a single freestanding household composed by four people.

Load demand profile before shifting



Load demand profile after shifting



Looking for example at the case of the shifting of electricity demand for domestic hot water and house heating when photovoltaic panels are installed, results have shown a potential increase in self-consumption of almost 5%, increasing from 24.4% to 29.2% and reducing the annual electricity bill from 3051 €/year to 2216 €/year. Similar results, obtained in the other cases considered, suggest that load shifting, if adopted in combination with well-structured time-of-use tariffs, has the potential to allow for significant increases in self-consumption and reductions in energy expenses for the users.

References

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