Adoption of distributed energy resources under uncertainty: incorporating insights from prospect theory into an agent-based model

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Overview

The transition towards sustainable low-carbon systems requires the adoption of numerous new technologies. A class of these technologies are Distributed Energy Resources (DERs). DERs are decentralized sources of small-scale power generation located close to end-consumers that supply part or all their electricity demand [1]. Examples of DERs are solar photovoltaic systems and home battery systems.

Integrated frameworks have been proposed to explain the adoption of DERs by household owners as a function of both economic and non-economic variables [2], [3]. Nonetheless, these frameworks fail to incorporate insights from behavioral economics, such as the influence of houseowners' risk and loss aversion on the adoption of DERs. Furthermore, while these integrated frameworks provide a comprehensive description of the adoption decision making process, they fall short of providing a more rigorous analysis. Given the complexity of the decision making process involved in adopting a new technology, it is difficult to really demonstrate with a conceptual framework how the interplay of multiple processes lead to the adoption of distributed energy resources.

This study aims to provide a detailed insight into the impact of behavioral factors, such as loss and risk aversion, on the adoption of distributed energy resources. To achieve this goal, we developed a conceptual framework integrating insights from several theories, including Theory of Planned Behavior, Diffusion of Innovations, and Prospect Theory. Then, we formalized this framework into an agent-based model. This model is used as a testbed for making inferences about how behavioral factors bear on the adoption decision making. In particular, we use the model to answer the following research question: *What is the effect of houseowners' risk and loss aversion on the adoption of distributed energy resources?*

Methods

The system under study is conceptualized as a socio-technical system (see **Figure 1**). This system consists of social network(s) and physical network(s) and the Distributor System Operator (DSO). The social network comprises residential consumers, which are classified based on Rogers' adopter categories (i.e., innovators, early adopters, early majority, late majority, and laggards) [4], income class (high, middle, and low), and tenure status (owner and renter). Residential consumers are assumed to be uncertain about future electricity prices and can exhibit both risk and loss aversion. These attitudes towards risk are described by prospect theory [5], [6]. Within a social network, residential consumers may engage in social interaction with other neighbors through peer effects. These peer effects may have an influence on residential consumers' attitude to the adoption of DERs. The physical network comprises technical elements such as the distribution grid, solar panels, and batteries. The physical networks mediate the interaction between residential consumers and the DSO. The latter will respond to the net consumption of residential consumers by adjusting the distribution tariff to recover the operational costs and maintenance of the grid. Future grid investments are not taken into account in the adjustment of the distribution tariff. The behavior of the system is assumed to be driven by external factors, including battery and solar panel costs, wholesale electricity prices, electric loads, and residual demand.

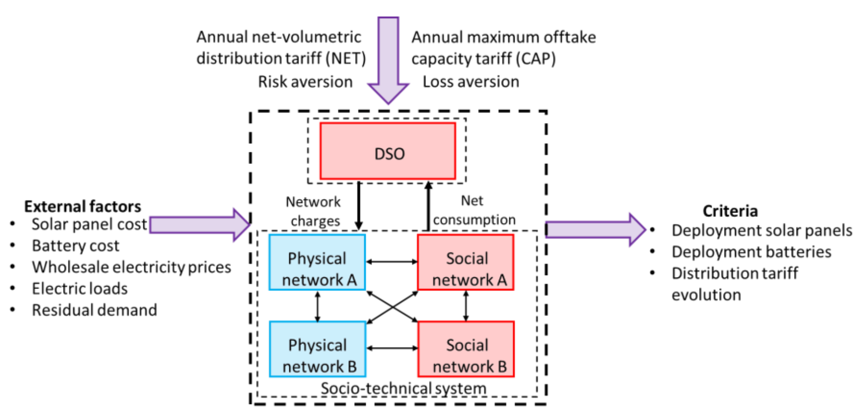

Figure 1. Conceptual model

Results

To analyse the influence of risk and loss aversion on the adoption of DERs, we compare the adoption patterns obtained when residential consumers use Expected Utility Theory (EUT) and Prospect Theory (PT) to describe their decision making under electricity price uncertainty. Consumers are assumed to be risk neutral, as well as both loss and risk averse, when EUT and PT are used, respectively. As shown in **Figure 2**, residential consumers' risk and loss aversion stymie the adoption of solar photovoltaic panels in the short-term. This is because risk and loss averse consumers derive less utility than their risk-neutral counterparts when payback periods are high. In the short-term, payback periods are high due, to some extent, to the high investment costs of solar panels. Nevertheless, in the long-term, the cumulative installed capacity of solar photovoltaic panels is higher than that obtained with risk-neutral consumers. This is due to the reduction in the investment costs of solar panels over time and the assumption that residential consumers are myopic and cannot upgrade their PV panels. This conflation of decreased investment cost and delayed adoption spur myopic consumers to adopt larger solar PV systems.

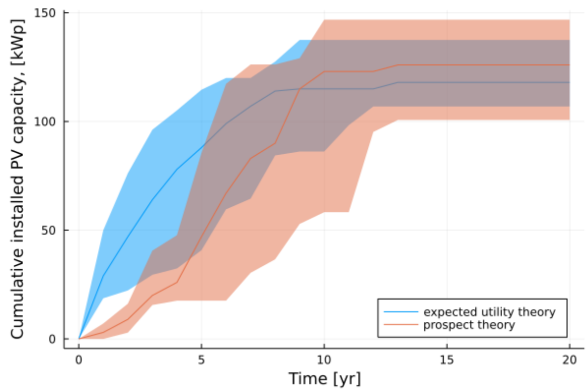

Figure 2. Evolution of the adoption of solar photovoltaic systems using expected utility theory and prospect theory to describe the decision-making under uncertainty. Annual net volumetric distribution tariff = 0.1 euro/kWh. Number of households = 50. Repetitions = 20.Solid lines represent median values, the shaded areas represent the 90% confidence interval.

Conclusions

An agent-based model has been developed to analyse the influence of both risk and loss aversion on the adoption of distributed energy resources at the household level. The results highlight the importance of considering the interaction of institutional, economic, and behavioural factors in the analysis of the phenomenon of technological adoption. From a practical viewpoint, these results suggest that, under an annual net-volumetric distribution tariff, risk and loss aversion may hinder the adoption of solar photovoltaic systems in the short-term. From a methodological viewpoint, this study bears out that agent-based modelling can be used as a representational technology enabling the restructuration of knowledge in the social sciences [7]. By capturing social science theories, such as theory of planned behaviour and prospect theory, in our agent-based model, we made their assumptions and the consequences of those assumptions explicit.

For the final conference contribution, we will conduct a sensitivity analysis to explore in more detail the impact of risk and loss aversion on the adoption of distributed energy resources. This analysis will be carried under different distribution tariff structures.

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