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On the influence of jurisdiction on the profitability of residential photovoltaic-storage systems: A multi-national case study

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ABSTRACT

Policy makers in many jurisdictions have implemented incentive schemes such as 'feed-in tariffs' (FIT) and upfront purchase subsidies to encourage consumers to self-generate parts of their power requirements by solar energy. We quantitatively study the impact of jurisdiction-specific solar radiation profile, the typical residential loads, the cost of system components, the price of grid electricity, and incentive programs on photovoltaic (PV) and storage system profitability in Germany, Ontario, and Austin, Texas. In each jurisdiction, for a range of PV and storage system sizes, we compute the optimal use of the system, and hence the best possible profitability of that system in that jurisdiction over a 20 year life span. This methodology allows us to quantitatively estimate the influence of a jurisdiction on the (best possible) profitability of PV-storage systems. We find that the choice of jurisdiction has significant impact on the profitability of PV-storage systems. We also find that policy makers can use the price of grid electricity as well as upfront subsidies to influence profitability, and therefore adoption.

1. Introduction

The rapid decline in the prices of solar photovoltaic (PV) systems and energy storage solutions has made it possible for residential electricity customers to weaken their ties to the local distribution grid by self-generating some parts of their power requirements (Wirth and Schneider, 2017; Erdinc et al., 2015). This has many potential benefits, including the substitution of clean solar power for dirty fossil fuels, a reduction in distribution losses, reduced investments in additional centralized generation facilities to accommodate demand growth, and enhanced grid resilience in case of natural disasters. For these reasons, policy makers in many jurisdictions have implemented incentive schemes such as 'feed-in tariffs' (FIT) and upfront purchase subsidies to encourage consumers to become 'prosumers' (i.e., energy producers as well as consumers).

Despite these incentives, other than with a few notable exceptions, residential PV adoption, and certainly residential storage adoption, has not been widespread. Interestingly, this is *despite the adoption of nearly identical policies* in different jurisdictions. For example, residential solar has been heavily adopted in Southern Germany, very likely due to its FIT program, but is quite rare in Ontario, despite the deployment of a similar FIT program there. A natural question is to ask why the same program is successful in one jurisdiction but not in another. Generalizing from this question, from the perspective of a policy maker, one would wish to know what policy actions are best suited to encourage PV and storage system adoption in a particular jurisdiction. Similarly, from the perspective of a vendor of PV and storage systems, understanding the influence of jurisdiction on system adoption would help selecting which market to penetrate, rather than to adopt a scattershot approach. Thus, the focus of our work is to understand the influence of jurisdiction on the profitability – and thus adoption[1] – of residential PV and storage systems.

From previous jurisdiction-specific profitability analyses (see Section 2) and our own understanding, we define the parameters that characterize a jurisdiction to be: its typical solar radiation profile, the typical residential loads, the cost of system components, the price of grid electricity, and incentive programs (note that some of these parameters are not under the control of the policy makers and some are). To study the impact of these factors, we use three case studies, determining parameter values for the jurisdictions of Germany, Ontario, and Austin, Texas. In each jurisdiction, for a range of PV and storage system sizes, we compute the optimal use of the system, and hence the best possible profitability of that system in that jurisdiction over a 20 year life span (similar to Kaschub et al. (2016)

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[1] System profitability and adoption are tightly correlated (Adepetu and Keshav, 2016).

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and Bertsch et al. (2017)). This methodology allows us to quantitatively estimate the influence of a jurisdiction on the (best possible) profitability of PV-storage systems. Importantly, we account for anticipated changes in future grid electricity prices, as well as the need to replace the storage system after 10 years of use. Our approach also lets us make jurisdiction-specific policy recommendations to encourage PV-storage system adoption.

We find that policy makers can use the price of grid electricity as well as upfront subsidies to influence profitability, and therefore adoption. We also find that the choice of jurisdiction has significant impact on the profitability of PV-storage systems, even when the same policy is used. For example, we find that in Germany and Austin jurisdictions, the characteristics of the magnitude and structure of electricity prices as well as residential loads contribute to differences in PV-storage system profitability despite having a comparable tariff for PV generation that is sold to the grid; furthermore, the price-point at which batteries become a profitable investment is significantly different for these two jurisdictions. However, when the FIT price is high, there is no incentive to adopt storage, as is the case in Ontario today.

Our key contributions are:

- Determining the set of parameters that characterize a jurisdiction, from the perspective of residential PV-storage system adoption,
- Using this characterization to create an evaluation methodology to estimate the return on investment and profitability of a PV-storage system of a given size in a given jurisdiction,
- Applying our methodology in a data-driven study to give policy recommendations for three jurisdictions: Germany, Ontario, and Austin, Texas, and
- A public release of our optimization model implementation (Kazhamiaka, 2017) in AMPL (Fourer et al., 1993).

The remainder of the paper is laid out as follows. Section 2 discusses prior work on the topic of PV-storage systems. Section 3 describes our methodology for calculating the profitability of deploying PV-storage systems, as well as the core differences between the jurisdictions which affect the calculation. Section 4 describes the data that we use as input for our profitability calculations. In Section 5 we present the profitability results and policy recommendations. We conclude the paper in Section 6.

2. Background and related work

There is a fast developing literature on the deployment of storage in combination with residential roof-top PV systems (e.g. Luthander et al., 2015; Malhotra et al., 2016). Some research focuses on the operation of these systems (e.g. Li and Danzer, 2014; Ratnam et al., 2015), while others focus on system sizing (e.g. Dufo-López, 2015; Erdinc et al., 2015). Researchers have compared different local storage technologies (e.g. Telaretti et al., 2016) as well as the impact of different electricity tariffs (e.g. Ren et al., 2016) and some analysis shows that profitable operations is already possible for commercial buildings (Merei et al., 2016). In the future, stationary storage (not necessarily Li-Ion) might be even profitable by outbalancing the electricity demand during dynamic tariffs alone (Graditi et al., 2016). Besides the focus on residential PV-storage systems, storage-alone systems have also been analyzed; e.g. Dufo-López (2015) shows that arbitrage with hypothetical dynamic tariffs in Spain would be sufficient to make decentralized storage profitable.

Most studies focus on a single jurisdiction. For example, Linssen et al. (2017), Weniger et al. (2014), and Johann and Madlener (2014) focused on Germany, Lorenzi and Silva (2016) on Portugal, Yoshida et al. (2016) on Japan, de Oliveira e Silva and Hendrick (2016) on Belgium, Telaretti et al. (2016) on Italy, Parra and Patel (2016) on Switzerland as well as Nicholls et al. (2015), Ratnam et al. (2015), and Ren et al. (2016) on Australia. Only a few studies compare different jurisdictions; e.g. Quoilin et al. (2016) compare the application of PV-storage systems in several European jurisdictions, Zucker and Hinchliffe (2014) focus on Italy and Germany, and Bertsch et al. (2017) focus on Ireland and Germany. These studies have found that not all jurisdictions allow a profitable operation of PV-storage systems. However, the results depend strongly on the assumed electricity tariffs, battery prices, battery life time, household load patterns, etc. Moreover, rapidly decreasing battery prices make future increased profitability in most jurisdictions probable. Consequentially, our work focuses on the core parameters that influence the profitability of PV-storage systems in domestic households, which are described in detail in Section 3.2, in three different jurisdictions: Germany, Southern Ontario, and Austin, Texas.

More recent literature includes also electric vehicles into considerations. For example, Kaschub et al. (2016) have carried out a comprehensive analysis of the profitability of PV-storage systems in German households including time-dependent electricity demand from electric vehicles as well as battery degradation similar to Yoshida et al. (2016). Their model approach is similar to ours, however, they focus on the synergies between stationary storage and electric vehicles and do not compare different jurisdictions. They find that while the charging of the electric vehicles increases domestic electricity demand and therefore increases the profitability of the system, enabling the electric vehicle to feed electricity back to the grid (V2G) competes with the battery and leads to a *decreasing* net present value (NPV) of the batteries. The underlying optimization problem is a MILP, which optimizes system configurations and operation of the PV-battery systems for empirical PV and household load data over 20 years. The authors identify a positive NPV of installations after 2018 for most German households considered.

3. Methodology

3.1. System model and problem formulation

The system of interest is a PV-storage system that is composed of a set of PV panels (called the PV module in the following) and a Lithium-ion battery located in a private household. The homeowner is assumed to have some inflexible intrinsic load. This load must be met using a combination of the power produced and stored by the PV-storage system as well as from the main electrical grid. Our goal is to compute the benefit to a home-owner of investing in such a residential PV-storage system.

The initial capital expenditure on the PV-storage system is offset by a reduction in payments to the utility, and, in some jurisdictions, the sale of excess generation to the utility (i.e. if there is a feed-in tariff). Given a particular system sizing, i.e. peak power output from the solar panel and the energy capacity of the storage, we compute the optimal operation of the system (i.e. scheduling the battery charging and discharging process) using an optimization problem expressed as an integer linear program (ILP). Our optimization objective is to maximize the 20 year return on investment (ROI), where the investment comprises the system capital expense in the initial year (i.e. 2016) added to recurring operating expenses[2] over the lifetime of the system (in constant prices). A positive ROI implies a profitable investment, which can be directly compared to the rates of return from alternative investment vehicles (see Section 5). The ROI is defined as follows:

$$\mathrm{ROI} = \frac{PayNS - PayS + Rev - Investment}{Investment} \tag{1}$$

where *PayNS* is the total payment to the grid for meeting the load in a scenario with no system. *PayS* is the remaining payment to the grid

[2] While there are many recurring costs, we only take into account the replacement of the battery, which is the dominant recurring cost over the lifetime of the system.