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Steering the adoption of battery storage through electricity tariff design

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ABSTRACT

The economic viability of electricity storage using batteries, under different tariff structures and system configurations, is investigated. The economic outcomes of the different combinations of tariff design and system configuration are evaluated. Based on a discussion of the relevant literature, the following tariff designs are used in the study: (i) fixed energy prices, (ii) real-time energy pricing, (iii) fixed rate capacity tariffs, and (iv) capacity dependent capacity tariffs. Next, the different simulated system configurations are outlined: (i) no battery storage, (ii) battery storage only, and (iii) battery storage and decentralized renewable energy production with PV. Our study provides insights for policy makers, showing that capacity block pricing only incentivises storage as part of an (existing) PV installation, while the combination of real time energy pricing and capacity block pricing promotes a wider adoption of battery storage.

1. Introduction

Smart grids have been widely researched as a possible solution for the decarbonisation of society's electricity demand, by allowing a greater penetration of renewable energy sources [1–3]. One possibility to arrive at such a low carbon smart grid, is the adoption of so-called micrograms. A microgrid is widely understood to be a grouping of electrical as well as heat loads and sources, being able to operate either in self-contained, islanded mode, or as part of the distribution system, in which case a microgrid is to act as a single, controllable load [4–7]. This of course raises the question of how such loads should be controlled, a discussion of standardisation and control principles can be found in [8], specifically aimed at controlling the load that microgrids represent.

A good overview of the drivers behind and challenges facing microgrids is given in [9,10] zooms in on the challenges and opportunities concerning smart grids and microgrids. In previous work [11], it has been shown that there is a dearth of research looking at the policy impacts of different tariff schemes on the economics of microgrids, as most tariff policy research focusses on the utilities.

One main recurring component which has been widely investigated in the context of microgrids, is storage, both of heat and electricity. Storage is a well-researched component, as it greatly facilitates balancing of generation and load. As shown in [12], locally available storage allows for efficient control of the grid through the use of well-designed price signals. However, a suitable and robust business case for storage remains elusive, as evidenced by various publications looking at different possibilities: using the battery capacity of electric vehicles in a vehicle-to-grid setup was investigated in [13], while [14] investigates the possibility of using arbitrage possibilities. Both papers report favourable outcomes in some, but not all, scenarios. Further evidence of the precarious business case underpinning the adoption of storage is provided in [15], showing that round trip efficiency and capital costs –both drivers for the overall cost of ownership– are still significant barriers to the wide scale adoption of energy storage technologies.

Against this backdrop of proven societal benefits from the adoption of storage on the one hand and uncertain profitability on the other hand, this paper investigates the impact of government policy on the adoption of energy storage. More specifically, we look at the impact of a capacity tariff for electricity on the household adoption of battery storage. In order to effectuate this analysis, we simulate different household microgrid configurations under varying electricity price and tariff schemes, minimizing the total operational cost of over the period of one year for a modal residential Belgian consumer. The choice of nationality is driven by ease of access to the relevant data; as the authors are attached to a publicly funded Belgian university, the Belgian transmission and distribution system operators readily made the required data available. As systems costs and technical performance of intermittent generation and storage are not only the subject of significant technological change but also important drives of the overall profitability of any given microgrid configuration [15], no a priori assumptions are made when it comes to installation costs or technical

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Nomenclature

$Q_G(i)$	kW h bought from grid at time step i
$Q_S(i)$	kW h discharged from storage at time step i
$Q_L(i)$	Load, in kW h, at time step i
$Q_I(i)$	Intermittent power production, in kW h, at time step i
$p_G(i)$	Grid price for electricity at time step i
$p_{G,fix}$	Fixed electricity price
C_b	Capacity limit of the lower capacity block, in kW
$C_{p,f}$	Fixed capacity tariff, in €/kW
$C_{p,1}$	Capacity tariff for the lower capacity block, in €/kW
$C_{p,2}$	Capacity tariff for the higher capacity block, in €/kW
$C_{cap}(i)$	Capacity payments due to exceeding the lower capacity block incurred during timestep i
S_{max}	Maximum storage capacity, in kW h
$S_{in}(t)$	State of charge of storage, in kW h, at the beginning of time step i

performance of intermittent generation or storage. The analysis made will instead indicate the tipping point, expressed as an annualised cost below which different systems configurations become economically viable.

The following section provides a more in depth literature review concerning the issues of interest directly linked to the research question at hand. Section 3 states the research goal as well as the central research hypothesis, thereby also clearly delineating the contribution of this work. Section 4 details the research methodology used, and discusses in order the research method, the research variables and the design of the simulation model. A presentation of results and a discussion of these results and policy implications closes this paper.

2. Literature review

Research into microgrids is fertile field, as evidenced by the comprehensive literature review establishing a functional layer based classification [16]. This review provides a good starting point and provides a broad overview of microgrid concepts as well as existing microgrid test beds. As [16] provides a good basis of information, the remainder of this section will be explicitly focussed on the areas of interest of this paper, being policy measures used to influence system configuration on the one hand, and microgrid modelling and simulation on the other hand.

As mentioned in the introduction, little research has been done on the impact of policy on microgrid economics [11]. A popular investigated policy intervention is carbon taxation, as it is present in a majority of earlier work [17–22]. The reported results of this policy intervention are mixed however: either they result in no noticeable impact on the microgrid, compared to the no intervention scenario [17,18,22] or they incentivise the installation of solar PV, but only when combined with a feed-in tariff for electricity generated by these panels [19,20]. Only one case reports a somewhat favourable outcome of carbon taxation where renewable generation is concerned [21].

As already outlined above, economic incentives in the form of feed in tariffs can be effective [19,20], while sufficiently high tax credit, amounting to 50% of the installation cost in [22], will have a significant impact on the installed system configuration, heavily favouring the adoption of wind power. When the operation of the installed system is considered as well, the results are more mixed: conventionally fired CHP units still contribute the majority of the generated power in the system modelled in [22], while some of the considered feed-in tariffs are higher than the grid price of electricity, leading to the system buying all needed power from the grip, while selling all generated power from the solar panels at the same time.

Less work has been done on investigating the impact of different tariff systems, and the work available focusses exclusively on energy time of use pricing, however, once again, the impact is found to be negligible [18], or sometimes even negative, if emission costs are considered [23].

Time of use pricing is generally more studied as a measure to steer consumer loads [24], without taking the resulting economics into account [25]. Along a similar vein is the work presented in [12], capacity instead of energy price signals are used to steer a controllable load. The choice for using capacity pricing as a signal as opposed to energy pricing is made because this better reflects the economic realities distribution system operators are faced with, when serving the connected consumer loads. Furthermore, these measures are found to be effective in their stated goal of steering consumer loads.

There is a broad consensus in existing research where the simulation and modelling of microgrids is concerned: simulations are set-up and mathematical optimization based on mixed integer programming is carried out [17,22]. The scope of different presented models in the literature differs however: some models are operational models, focussing exclusively on operational parameters [18], while others are investment models, taking both the investment and operational costs into account [17,19,20].

3. Research goal and hypothesis

Based on the review outlined above in Section 2 and the findings reported in [11] a clear research gap becomes evident: to the best of the author's knowledge there has been no research focussing on using capacity tariffs to encourage the uptake of storage technologies. The contribution of this paper is that it closes that research gap, by presenting the impacts of a capacity tariff scheme, both by itself as well as in conjunction with real time energy pricing and evaluating the impact of these pricing schemes on a residential microgrid. In doing so, this paper not only extends the breadth of scientific knowledge surrounding microgrids, but also expands the toolkit of policymakers, by providing evidence of the impact of capacity tariffs on the economics of different microgrid system configurations.

The above contribution translates itself to the following research hypothesis: capacity tariffs will be effective in differentiating between different system configurations, where the economics of these different systems are concerned, specifically favouring system configurations including storage. The reasoning behind this hypothesis is that system with storage will be able to engage better in peak-shaving behaviour, allowing them to avoid the higher costs incurred for high peak usage of capacity. This hypothesis will be tested by simulating different system configurations -with and without storage as well as with and without intermittent generation-, under a no intervention scenario, a scenario with capacity tariffs, and a scenario with both capacity tariffs and real time energy pricing. This research aligns itself with those papers taking an operational approach, deliberately choosing not to take investment cost into account, but instead aiming to provide policy insights that are relevant regardless of the current installation costs of the investigated technologies.

4. Research methodology

This section discusses in detail the methodology used to test the hypothesis outlined in Section 3. A first subsection details the research method used, detailing both the simulation model as well as the optimization problem being solved. The second subsection delves deeper into the policy interventions investigated, while the third and final subsection elaborates on the particulars of the simulations.