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Modelling future uptake of distributed energy resources under alternative tariff structures

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ABSTRACT

Current residential price tariff structures in Australia, which are predominately based on a flat daily supply charge combined with a per kWh electricity charge, create a distortion to the electricity consumption pattern, leading to larger afternoon and evening peak demands across the networks. Battery storage connected to solar PV (photovoltaic) array would reduce these effects in the presence of alternative price tariffs that incentivise households to shift load and reduce the peak demand. This challenge is addressed using a choice-diffusion model to forecast PV and battery storage uptake to 2025 for a case study in Townsville, Australia. Sensitivity of uptake is tested for six different price tariffs based on flat, time-of-use and critical-peak-pricing. Uptake of battery storage connected to solar PV ranged between 3% and 5.4% of households at 2025, depending on the price tariff, with the larger PV/battery options being more popular. Percentage of households disconnecting from the grid at 2025 is in the order of one percent depending on the price tariff. A sensitivity analysis showed battery price was a major driver to uptake whilst typical financial subsidies to purchase price have a lower effect.

1. Introduction

This paper addresses the challenge faced by electricity utilities in Australia of planning for the anticipated large-scale uptake of solar PV (photovoltaic) arrays connected to battery storage (including off-grid households) towards 2025, and how this uptake may be impacted or managed under alternative price tariff structures. A choice-diffusion model is used to forecast uptake and test the sensitivity of this uptake to the value that each alternative tariff structure would provide to households.

Electricity utilities in Australia face declining network utilisation which places upward pressure on network prices and hence retail electricity prices. A range of factors including: economic volatility; improving household energy efficiency; and increasing prevalence of distributed generation, have contributed to reduced electricity consumption and deteriorating network utilisation. This is especially the case with residential solar PVs, which are cells that convert energy from the sun into electricity. At the same time peak electricity demand is growing due to a wide use of air conditioners. Of specific interest is the distortionary effect that large uptake of solar PV is having on household electricity consumption patterns and its cumulative effect on the electricity distribution network. Electricity demand patterns in Australia are complex and they depend on the season, the day of week, the hour of day and they are influenced by weather and climate characteristics in a given location [30]. In tropical and sub-tropical regions of northern Australia, such as in Townsville, residential electricity demand is dominated by the late afternoon to early evening peak associated with air conditioning and the use of many electrical appliances. Most households are charged a flat tariff charge per kWh [5], regardless of time of day, whilst households with PVs are paid a FiT (feed-in-tariff) for electricity sold back to the grid. Households under a flat tariff charge and a high FiT are likely to move electricity consumption (e.g. washing clothes) away from the daytime and into the peak period (4 pm to 8 pm) so that more electricity can be sold back to the grid. Consequently it increases the size of the electricity peak between 4 pm and 8 pm, and requires a higher capacity electricity network to support the peak.

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In Australia residential electricity prices are regulated both by Federal and State Regulators and different rules are applied for the network and retail components of these prices. Usually the available retail tariff structures and their rates are set by State Governments, providing different price offerings to households which include a flat pricing, ToU (time-of-use) and controlled load. The latter is used by households with electric hot-water systems and swimming pool pumps. In each state, a very small percentage of households are on a ToU tariff [5] with Queensland having less than 0.01% of households. Households using a ToU tariff require replacing their existing analogue meter with a digital smart meter. Households that purchased solar PVs usually already have a smart meter installed by the utility to monitor electricity sold back to the grid via the FiT.

Distributed electricity storage in the form of batteries connected to residential dwellings, with or without solar PV, has the potential to shift electricity load away from the peak periods. This has been shown for battery storage via vehicle-to-grid strategies, through trials and simulations in Brazil [6] and Australia [22], given price tariffs that provide adequate incentives. Based on industry sources, Ernst et al. [7] consider two end-user price scenarios for lithium-ion batteries in large production. For 4, 12 and 20 kWh batteries the end-user prices are 2000, 6000 and 10,000 € according to the first scenario and 4000, 12,000 and 20,000 € – for the second scenario. Rudolf and Papastergiou [26] suggest 1500 €/kWh for lithium-ion batteries, which is a very high cost, but this technology also has the highest energy density amongst all available technologies.

A household can charge the battery during the off-peak electricity periods (11 pm to 6 am) and discharge the battery during the peak period (4 pm to 8 pm) to reduce the peak demand. A tariff structure, based on ToU or CPP (critical-peak-pricing) is required that provides sufficient financial returns to households to purchase a battery and reduce peak demand. Whilst there is a financial benefit for households with PVs to purchase a battery, under a flat price tariff a household would likely use the battery to further shift load away from the day to the evening peak to maximise revenue from the solar PV. Compared to solar PV, battery storage has had minimal adoption in Australia to date, primarily due to their high capital costs and low returns compared to PVs. This is expected to change with a forecasted 50% reduction in battery price (minus installation costs) by 2030 [12] coupled with a saturated market of solar PVs. To plan for large-scale uptake of battery storage in the future, there is a growing urgency to design suitable price tariff structures and incentives.

2. Background

Tariffs based on CPP and ToU have been well studied in the literature, mostly in terms of their impact on electricity costs and shifting load from peak periods. In a Californian pilot of 483 households in 2004 [13,14], average consumption dropped by about 5% during the period of CPP, though a higher energy charge during CPP did not have a significant additional cost effect. This was consistent with findings by Faruqui and Sergici [8] who surveyed 15 pilot programs across North America, France and Australia, and the peak demand reduction was as much as 44% when the household was supported with communication equipment to help plan electricity use during these periods. The effect of price tariffs on renewable energy adoption has mostly been analysed in the context of FiTs on accelerating uptake of solar PVs and wind power. Sijm [28] looked at the effect of FiT on renewable energy adoption in three European countries in the 1990's and found that the tariffs created a distortion on competitive pricing. More recent papers such as Couture and Gagnon [4] look at the advantages of different FiT structures (fixed and variable pricing models) on investment in electricity from renewable sources. The analysis, which was based on past experiences, found that premium price policies create incentives for electricity generation when most needed. Whilst these papers reflect valuable experiences from tariff structures, they are not able to forecast impacts into the future or test the sensitivity of renewable energy uptake to new tariff structures.

Diffusion models, particularly the Bass and logit models, have been applied extensively to forecast uptake of solar PVs with and without consumer incentives [11,15,31]. These diffusion models contain features or additional parameters (e.g. Generalised Bass Model) based on marketing, prices and costs, which allow sensitivities to interventions (e.g. incentives, tariffs) to be tested. In practice, adoption of solar PVs and batteries is more complicated than represented by a basic diffusion model, as households often upgrade their solar PV or add a battery later on. There have been some diffusion model extensions that incorporate repeat purchases either due to an upgrade or upon product failure [21,25].

In the diffusion of solar PVs, a household can choose from several options. Jun and Kim [18] implement a choice based diffusion model that includes the decision of first time purchase and product replacement (after failure), when the consumer has a choice amongst product options available. Geographical sensitivity of solar PV and battery storage is an important consideration for the electricity network. High uptake of solar PV and batteries will substantially change the net electricity demand profiles (total and by time of day) at some locations. Distribution substations or feeders servicing these areas are impacted by the ability to meet increased peak demand and provide electricity reliably. There are limited geographically sensitive choice models in the literature to date, though Bhat and Guo [3] and Sener et al. [27] developed versions for transport mode choice. Higgins et al. [16] implement a combined choice-diffusion model for uptake of solar PVs in New South Wales, Australia. The model considers spatial sensitivity of uptake, where each geographical unit of housing stock contains differences in demographics and types of building stock. Timing of first time purchase or upgrade is a value function of variables (e.g. purchase price, payback period) that influence the household of when to adopt a solar PV option, which can be used to test the sensitivity of uptake to different financial incentives. The choice-diffusion model developed for uptake of solar PV and batteries under different price tariffs required several technical innovations compared to that used in Higgins et al. [16] by accommodating:

- Compatibility of each solar PV or battery option to dwelling types.
- Price of adding a battery to an existing solar PV or upgrading/downgrading a solar PV (e.g. increasing the number of panels), which is less than the price for a first time adopter.
- Representative effects of modelled choice probabilities in the presence of large differences in price and annual electricity savings between the PV/battery options. Also, solar PVs now have an established market, whereas batteries have so far had negligible market penetration and are much more expensive. Incorporating both solar PV and batteries in a single choice-diffusion model was more difficult as a result.

The choice-diffusion model is applied to forecast uptake of eight solar PV and battery options under different price tariffs (including ToU and CPP and the current flat price tariff offered to residential customers) using a case study of residential building stock in Townsville. Uptake forecasts are produced for each geographical unit containing about 180 households. These geographical units, as defined by the Australian Bureau of Statistics (ABS) Statistical Area 1 (SA1), were necessary to discern differences in uptake and subsequent grid impacts at each feeder or substation on the