Neighbourhood batteries and virtual power plants can increase local solar PV consumption

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Neighbourhood batteries (NBs) are a promising new form of mid-scale energy storage (100-1,000kWh), offering numerous benefits compared to alternative forms of energy storage for the electricity network, communities, and energy users, in terms of local energy management, decarbonisation, and equity. This potential of neighbourhood batteries motivated the recent announcement in Australia by the ALP of a $200M trial of neighbourhood batteries, in which 400 neighbourhood batteries have been promised to be rolled out nationally. To date, however, no extensive modelling has been done to quantify these benefits or to compare them against alternative energy storage options, including uncoordinated household batteries (HHs) or coordinated household batteries that act as a virtual power plant (VPP). To enable the best outcome from the ALP's upcoming national roll-out, there is a significant need for such quantification and comparison to ensure we are positively contributing to our future energy systems in the most technically, environmentally, and socially beneficial way. As such, this work has modelled the impact of neighbourhood batteries, household batteries, and VPPs on local energy management.

Extensive work has shown positive impacts of battery storage on local energy management in the distribution network. For example, Shaw et al., found that household batteries increased solar self-consumption from 34% to 58% in the Australian Nextgen battery storage trial [1]. Park et al., found that a VPP reduced distribution system constraints by approximately half [5]. NBs were found to reduce peak grid demand by 28–45% in a simulation [2]. NBs were also found to significantly increase the capacity of a low voltage grid in data from the Netherlands [3]. A simulation in MA, USA, found that sharing storage required 35% less capacity overall compared to household storage and was 64–94% more effective at reducing exports from the community to the wider network [4]). The value of energy arbitrage in terms of reducing energy costs, CO2 emission reductions, and peak shaving using community energy storage systems has been studied in [4]. In addition to technical benefits, previous work has found that community energy schemes increased engagement with energy issues and supported wider participation in community initiatives [6].

Previous work has directly compared neighbourhood and household batteries, however, no studies have yet directly compared neighbourhood batteries with VPPs. Here, we modelled the impact of NBs, HHs and VPPs on local energy management in a suburb. Results were compared on the basis of local solar PV consumption and grid imports and exports. We expected that the NB reduced the peak import/export compared to the equivalent storage capacity of individual household batteries, but performed with similar results to a VPP.

Methods

We simulated the behaviour of batteries connected within a local network of 100 households. High quality data for Australian household electricity demand and solar generation (5-min resolution) was taken from the Nextgen trial, based in the Australian Capital Territory, which began in 2016 [7]. The rooftop solar panel was on average 6.5 kW per household. The aggregate battery capacity was 125kW/337.5kWh (kept constant across neighbourhood and household battery systems) where 25% of households had batteries. The spot prices used for this paper corresponded to 2021.

Simulations were based on a case study of soon-to-be-built greenfield suburb in the Australian Capital Territory, Australia, with a high rate of rooftop PV (50%). We considered the households and batteries to be situated within a bounded local subsection of a distribution network. This local network is connected to a larger upstream power system through an unconstrained connection, which allows energy to be imported and exported from the local network as needed (see Fig 1). Topological details of the network and power flows will be investigated in further work.

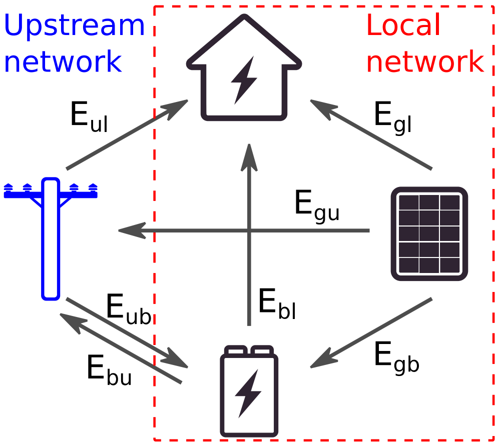

Fig 1. Schematic showing the seven possible flows of energy between the constituents of a local network segment, the neighbourhood battery scenario and an upstream network (distribution pole icon referred to as “u” for upstream). Households with excess solar generation are represented with a solar panel icon and label “g” for generation, and those with greater load than their own solar generation are represented with a house icon and label “l” for load. Energy flowing between generating households to consuming households is labelled E_{gl}, energy flowing from these households to the upstream grid is E_{gu} and energy flowing to the shared battery is E_{gb}. The neighbourhood battery is indicated by a battery icon and “b” labels. The battery can charge from the upstream grid (E_{ub}) or households’ excess solar generation (E_{gb}) and can discharge to the net load households (E_{bl}) or the upstream network Ebu. Energy flowing from the upstream network to households with net loads is labelled E_{ul}. Adapted from [8].

Batteries were scheduled to minimise the total electricity cost of households, batteries and the network based on NEM spot market prices for NSW and a hypothetical network tariff adopted from [8] (15c/kWh for energy imports from the upstream grid and 4c/kWh for imports from local solar generation or from the battery). Our simulation discouraged battery arbitrage behaviours by only considering the cost for energy imports and not for exports. Output metrics were the average daily peak import and export (at the connection point for the transformer), the total costs, and the solar self-consumption (SSC) and the self-sufficiency (SS) (equation 1 and 2) of the community.

$$(1) \quad SSC = 1 - \frac{energy\ exported}{total\ solar\ energy\ generated} \qquad (2) \quad SS = 1 - \frac{energy\ imported}{total\ energy\ used}$$

Results and Discussions

All battery options improved the total community cost, the average daily SSC and SS, the average import and export peaks, and the maximum import peak by 13-18%. Particularly, the average export peak was reduced by 73% for the NB and VPP options and by 55% for the HH option. However, all options increased the maximum export peak by 8-13%. Overall, the NB and VPP options were better than the HH option. Moreover, the NB and VPP options yielded the same results except for the total community cost where the VPP was 1% better than the NB.

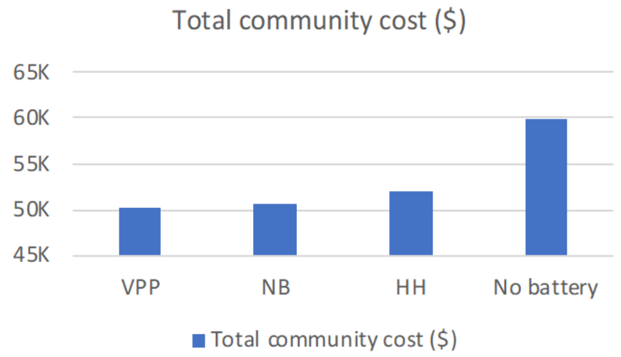

Fig 2. Total community costs reduced with all battery options. Note that the cost with NB is only slightly higher than VPP.

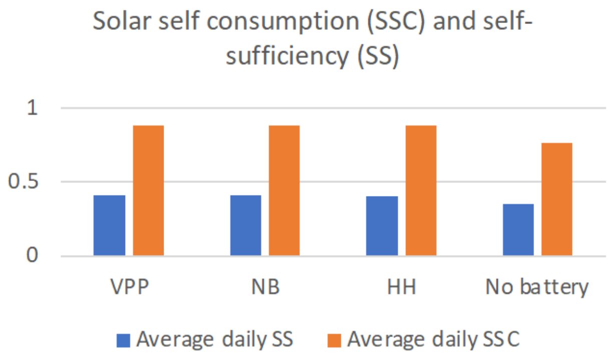

Fig 3. SS and SSC increased with all battery options. The improvements for all options are nearly the same.

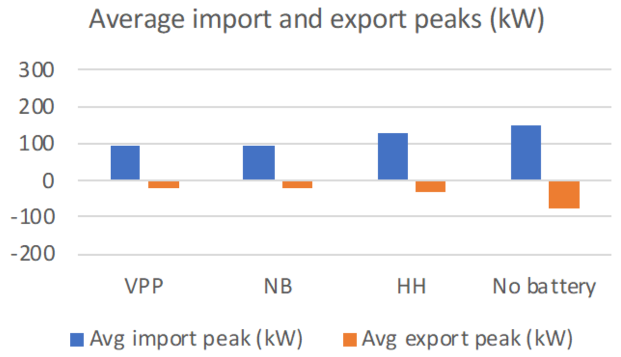

Fig 4. Average import and export peaks reduced with all battery options. The VPP and NB reduced the peaks the most.

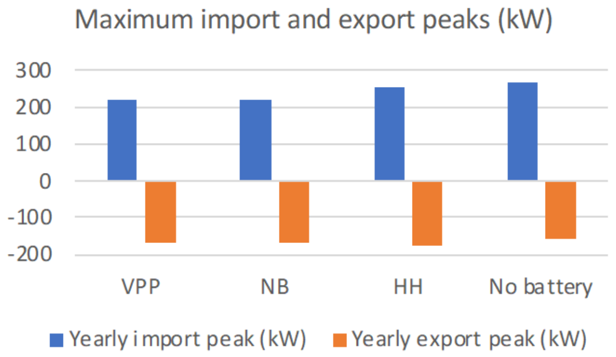

Fig 5. Max import peaks reduced and max exports increased with all battery options. The reductions for all options are similar.

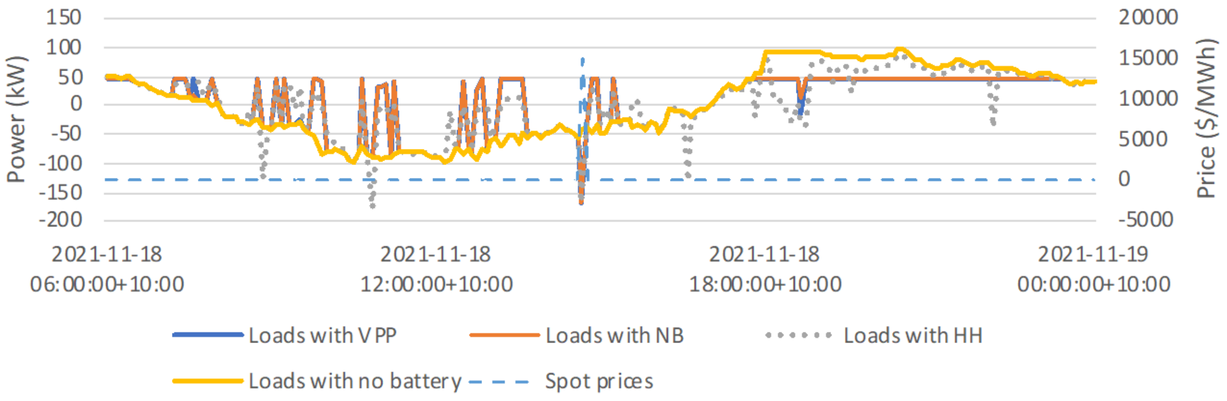

Fig 7. Examples of aggregate load for the neighbourhood for all storage options. Note that the NB and VPP both reduce solar exports and evening peak load more effectively than household batteries (HH)

Conclusions and Implications of Findings

This study presents the first comparison of neighbourhood, household and VPP storage options. We found that all battery options improved the financial, technical and environmental benefits compared to no battery by more than 13%. In particular, the average export peak was reduced by more than 55%. However, the maximum export peak was increased by 8-13%. Overall, the NB and VPP options were better than the HH option for all criteria and the VPP and NB options yielded nearly the same results.

The results suggest that neighbourhood batteries and VPPs are more efficient ways to integrate energy storage into our suburbs and towns, in terms of increased utilisation of local solar per kWh compared to household batteries. Given the complexities associated with VPPs, in terms of recruiting households into the scheme and managing their involvement, a neighbourhood battery may offer a preferable option with similar outcomes in terms of increased local solar PV consumption and decreased power exports to the upstream grid. We had expected that storage would reduce the maximum export peak to the upstream grid, however, the maximum export peak was increased for all battery storage options tested. The potential benefits of battery storage are not a given and need to be investigated further to understand the incentives required to capitalise on the ever-increasing amount of rooftop solar power being generated in the Australian grid.

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