Collective Prosumerism

Accessing the Potential of Embedded Networks to Increase the Deployment of Distributed Generation on Australian Apartment Buildings

Mike B Roberts, Dr Anna Bruce
School of Photovoltaic and Renewable Energy Engineering
Centre for Energy & Environmental Markets
University of New South Wales, Sydney, Australia
m.roberts@unsw.edu.au

Associate Professor Iain MacGill
Centre for Energy & Environmental Markets
School of Electrical Engineering and Telecommunications
University of New South Wales, Sydney, Australia

***Abstract*— Despite potential advantages of load aggregation and scale discounts, few of Australia's 2.3 million apartment residents are amongst the country's 1.8 million solar prosumers. However, embedded networks can be used to distribute rooftop photovoltaic generation to households if split incentives and regulatory barriers are overcome.**

We present a model of an embedded network with PV in an Australian apartment building. Load data from real apartment households are combined with modelled PV generation to describe energy and cash flows over the course of a year. The distribution of costs and benefits between stakeholders is calculated under a range of financial arrangements.

Embedded network benefits are highly sensitive to retail and wholesale energy costs at the parent meter and to site-specific capital costs. The addition of PV can, in some circumstances, increase the financial viability of an embedded network and careful tariff design can help incentivise this investment and ensure customer retention.

Keywords—embedded network, distributed energy, solar, PV, apartments

I. INTRODUCTION

According to IEA estimates, "practically all" buildings must reach net-zero carbon emissions by 2040 [1] if the 1.5°C "safe" limit on global warming established by the Paris Agreement [2] is to be achieved. Globally, over 90GW of photovoltaics (PV) has been installed on buildings to date, often utilising unused space to generate electricity close to consumption centres and hence benefiting distribution and transmission networks as well as reducing emissions.

In Australia, early policy support, declining PV technology costs, rising retail electricity costs and an excellent solar resource have all contributed to a world-leading penetration of residential rooftop solar photovoltaics, with 1.7 million residential "prosumers" enjoying the benefits (including lower bills and reduced carbon emissions) of distributed renewable generation [3], and networks benefitting from reduced demand and lower daytime peak loads [4]. However, the 10% of Australians who live in the country's 1.4 million apartments [5] have been largely excluded from these benefits by a range of regulatory, technical, financial and organisational barriers [6,7].

As in many other countries, generous feed-in-tariff (FiT) schemes introduced in most Australian State jurisdictions from 2009 [3] supported the initial growth in deployment of residential rooftop PV. Policy makers quickly decided that these schemes were being 'too successful' and they were closed to new entrants. Now, PV residential deployment in Australia is net metered, with self-consumed PV generation saving the consumer their volumetric retail tariff, while PV exports to grid are generally paid a tariff close to the wholesale market value of the energy (typically somewhere between one quarter and one third of the retail tariff). There is, understandably, increased interest from policy makers and consumers alike in the use of PV systems and storage to maximize self-consumption of on-site generation [8]. Additionally, high network costs (comprising almost half of total energy bills in Australia, due in large part to historic over-investment in infrastructure) and a lack of cost-reflectivity in network tariffs create economic barriers to peer-to-peer energy trading, further incentivising self-consumption.

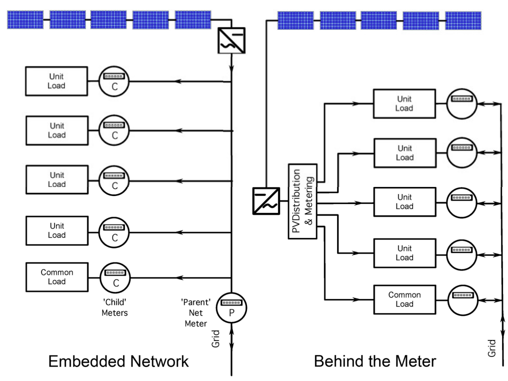

Fig. 1. Embedded Network and Behind the Meter Arrangements

In this environment, apartment buildings may have some unique advantages in allowing groups of residential customers the opportunity to co-ordinate both their engagement with the energy market and their utilization of distributed generation.

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Large roof areas offer economies of scale in PV installation, while aggregation of diverse household loads can flatten load profiles and increase PV self-consumption, as well as affording access to more beneficial retail arrangements. Embedded networks are one arrangement than can facilitate this consumer aggregation, but their successful implementation is dependent on the regulatory framework governing such arrangements and their potential distribution of benefits between stakeholders.

II. Background

Most apartment buildings in Australia operate under strata title, similar to arrangements that apply in many countries, including the USA (*condominiums*), France (*copropriété*) and Germany (*wohnungseigentum*) [9-11], under which individuals own an apartment, while sharing ownership of the common property (CP) and structure of the building - usually including the roof. An Owners Corporation (OC), comprising all the apartment owners, manages the building on their behalf.

Apartment building energy loads combine individual apartment (or 'unit') loads and common property (CP) loads. Due to the highly diverse building stock of Australian apartments, CP loads are very variable. In some buildings these loads may include lift motors, garage extraction fans, HVAC, pumps and heaters for shared hot water systems, emergency flood pumps, washing machines, pool pumps and saunas. In other buildings, by contrast, CP loads may be limited to minimal stairwell lighting.

In many high-rise apartment buildings, a rooftop PV system can contribute only a small proportion to the daytime CP load. Therefore all or most of the PV energy generated is self-consumed and financial arrangements are relatively simple – the system is owned by the OC which benefits from reduced energy bills to offset its capital expenditure. However, in many low and medium-rise apartment buildings, the potential rooftop generation far exceeds CP daytime demand [12], and there is potential to increase self-consumption either through distribution of the excess PV generation to individual apartments or by utilising battery storage. Importantly, 61% of Australian apartments are located in buildings of 3 storeys or less [5].

An alternative approach for PV deployment is for independent PV systems to be configured to supply individual apartments, but – as well as facing governance challenges related to the individual use of shared roof space – this arrangement fails to access the potential advantages of shared systems in increasing aggregate self-consumption. Distribution of generation from a shared PV system to apartments in a building can be achieved either 'behind the meter' (BTM) or via an embedded network (EN), as shown in Fig. 1.

BTM solutions can be achieved using a simple distribution device that allows each customer to draw PV-generated electricity proportional to their instantaneous load, with diode protection to prevent reverse energy flows. Integral low-cost metering of PV energy supplied allows residents to avoid engagement with complex energy retail and EN regulation, with each customer retaining an individual meter and retailer contract for grid electricity, but there are risks of lower levels of self-consumption and higher household tariffs. In contrast, as well as flattening overall load profiles to increase PV self-consumption, embedded networks, which present a single point of net-metering and retail contracting for multiple apartments, allow customers to combine their purchasing power in the energy market to access the more favourable tariff arrangements typically offered to commercial end-users. However, the complexities of the regulatory environment and costs of EN installation can create barriers to this approach.

One of the key challenges facing deployment of distributed energy resources in an apartment building is the split-incentive issue. All the apartment owners (whether owner-occupiers or landlords of tenanted units) collectively own the building and must agree - acting as the Owners Corporation (OC) - on any major infrastructure investment, whether it is financed from reserve funds, from the strata fees paid annual by the owners (which in some cases are passed on to tenants) or by a special levy on the owners. However, any benefits from reduced apartment energy bills are enjoyed by the residents who in 60% of Australian apartments [5] are tenants with no voting rights in the OC.

Additionally, under existing and proposed energy regulation, all customers in an embedded network must be able to access alternative retail offers, and an embedded network operator (ENO) must facilitate the transfer of any customer who wishes to purchase directly from a market retailer. Consequently, and as the benefits of an embedded network rely on economies of scale, it is incumbent on the ENO to ensure customer retention through a competitive charging structure that can withstand potentially highly targeted customer acquisition strategies of electricity retailers.

An OC wishing to establish an EN must therefore ensure an equitable distribution of benefits to apartment owners (whether owner-occupiers or landlords) and to tenants if all relevant stakeholders are to be suitably incentivised to participate.

The relative total costs and benefits of EN and BTM systems have been explored in a previous study [13]. This paper describes a study of the distribution of costs and benefits between different stakeholders under a range of tariffs and financial settings for an embedded network with PV in a Sydney apartment building.

Section 3 introduces the load and PV generation data used for the study and the choice of financial and tariff settings utilised. Section 4 presents some initial results, the implications of which are discussed in Section 5, where we also draw some tentative conclusions and suggest areas for further exploration.

III. Method

This study utilises an open-access EN model[1], built in Python, to model energy and cash flows within a given apartment building under a range of tariffs and financial scenarios, using 30-minute interval load data and PV generation data.

A. *Load data*

Because of the dearth of published interval load data for Australian apartment buildings, this study adopts a novel

[1] The model is available at https://github.com/mike-b-roberts/morePVs

approach by creating 'virtual apartment buildings' (VBs) from real customer load data, utilising a dataset of 30-minute interval load data collected from 3700 apartments across eight local government areas in New South Wales (NSW) for the Smart Grid Smart City (SGSC) Project [14]. Details of the project and dataset are provided by Motlagh et al. [15], in the SGSC Executive Report [16] and SGSC Technical Compendia [17-19]. For this study, apartment households with 90% or more complete data for the 2013 calendar year and where energy demand was not significantly impacted by the interventions of the project, were selected. Missing data were filled using data belonging to the same customer from time periods with similar loads across the dataset, following a method used in [20] and [21].

Load profiles were then selected at random from the group of 2080 apartments with greater than 90% data for 2013, and combined with the common property load profile of a four-storey, 44 unit Sydney apartment building (collected for a building energy audit), to create a 'virtual building' (VB). Although the available common property profile was from a different period (August 2013 – August 2014) to the unit profiles, it did not include any weather-specific loads such as heating, cooling or pool pumps, and so is unlikely to vary significantly from one year to the next. This process was repeated to generate 50 different VBs of this general configuration.

B. *PV Generation*

A visual analysis of the actual apartment building rooftop was carried out using multi-viewpoint aerial imagery to assess usable area and estimate the height of projections. A simple geometric model was used to calculate shading from obstructions and the Nearmap [22] tool used to arrange arrays flush with the roof, avoiding areas shaded between 10am and 2pm on the winter solstice, in line with previous studies [23]. Compared to a method limiting arrays to north-facing roofs, or mounting them at optimal tilt, this design method sacrifices optimal array performance in order to maximize the energy generated from the available roof.

The output of the PV system (nominally 76.75kW or 1.74kW per unit, arranged as three sub-systems with orientations of 58°, 237° and 326° tilted at 30°) was modelled using the PV Watts model in NREL's System Advisor Model (SAM) [24, 25]. A real year weather file for the year 2013 was created using Bureau of Meteorology (BOM) gridded satellite-derived irradiance data [26], together with temperature and wind recordings from the nearest BOM Automatic Weather Station. On average, the PV would generate 55% of the annual total (CP and units) energy demand for the building, resulting in daytime export as shown in Fig 2.

A second PV system was modelled with a reduced capacity of 46.5kW (or 1.06kW per unit), utilising only roof spaces with orientations of 58°, and 326°. This system generates an average of only 37% of the total building load with average self-consumption increased from 64% to 79%, and an average daily profile as shown in Fig.3.

For each household load profile, a 'self-consumption metric', measuring alignment of the load with PV generation

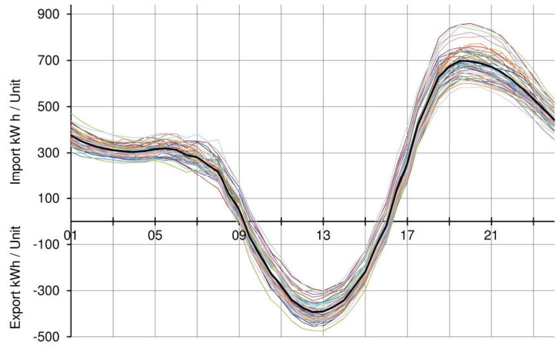

Fig. 2 Average daily load profile for 50 VBs with PV = 1.74 kW_p/unit

(from the whole-roof system) was calculated using equation (1) where p is the normalised annual PV generation profile and e is the normalised annual load profile, both expressed as column vectors.

$$M_{self-consumption} = \boldsymbol{p} \cdot \boldsymbol{e} / \boldsymbol{p} \cdot \boldsymbol{p} \times 100\% \qquad (1)$$

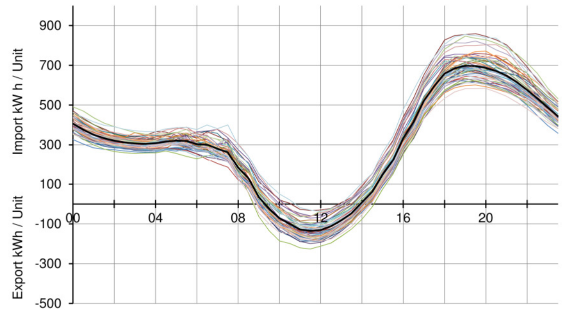

Fig. 3 Average daily load profile for 50 VBs with PV = 1.06 kW_p/unit

C. *Capital & Operating Costs*

The average installation cost for a 75kW commercial rooftop PV system in NSW in Sept 2017 was around \$1.09 / kW[2] [28], inclusive of federal government subsidies under the Small-scale Renewable Energy Scheme (but exclusive of grid protection and meter installation). Capital costs for embedded networks depend on a number of factors, including whether installation is in a brownfield or greenfield site. Installation of a suitable (smart) meter to each unit is likely to be required because of current Australian regulatory and ownership arrangements for meters (even if suitable smart meters are already in place), involving costs of approximately \$400 per apartment, while the cost of a parent or gateway meter is around \$2,000 [29]. Additional costs are dependent on the age and design of the building, jurisdictional regulations, and connection standards set by local distribution network service providers, and may include upgrading wiring and switchboards, adding ventilation or access doors, and even constructing new meter rooms. To investigate sensitivity to the

[2] All financial costs in this paper are quoted in AU\$ and include general sales tax of 10%. AU\$1.00 = US\$0.7715 [27]

high variability of total EN capital costs, a range of values were used as shown in Table 1.

TABLE I. EMBEDDED NETWORK COST SCENARIOS

Scenario	1	2	3
Parent meter	$2,000	$2,000	$2,000
Child meter per unit	$400	$400	$400
Switchboard & wiring	$0	$18,000	$48,000
Operating costs per unit	$250	$250	$250
Annualised cost (8 yrs) per unit	$320	$385	$492
Annualised cost (12 yrs) per apartment	$302	$350	$430

In NSW, typical residential PV installations on stand-alone housing can expect payback in 5-7 years [30], whilst perceived long payback periods amongst apartment owners (particularly compared to other sustainability retrofits) can act as a barrier to investment in PV [6, 31]. Therefore, notwithstanding that the typical lifetime of a PV system (allowing for inverter replacement each 10 years) is 20-25 years, capital expenditure was amortized over 8 and 12 year periods at a nominal annual rate of 6%. For consistency, the capital costs of the embedded network were treated similarly.

Embedded network operating costs include components for meter-reading, billing, marketing, customer-assistance, maintenance of the embedded network and an amount to cover the risk of bad customer debts. With the exception of maintenance of the EN, these cost elements are common to a retailer in the energy market, for whom these costs have been estimated by the Australian Competition and Consumer Commission to be $241 (16% of the total bill) for an average residential customer in the NEM, and $230 (15%) for an average NSW residential customer [32]. As actual EN operating costs are obscured by commercial confidentiality, a value of $250 has been used in the modelling to align with these published retailer costs.

D. *Tariffs*

Australian electricity tariffs are primarily made up of a regulated network component and competitive retail and wholesale energy components. Larger commercial customers face a network tariff dependent on the voltage at their point of network connection and annual energy use, and a market energy tariff often negotiated with the retailer. The distinction is less clear in the offers available to smaller commercial and residential customers, which include a (previously regulated) 'standing offer' tariff, which is less competitive but has more consumer protection than market offers, and a multiplicity of discounted and differently structured tariffs.

1) *Business as Usual*

The 'business as usual' (BAU) scenario for the model uses the 2017 standing offer (SO) time of use (TOU) tariff, with fixed and volumetric charges discounted by 15% to align with the price paid by a representative NSW residential customer paying the representative market offer [33].

2) *Embedded Network Tariffs*

Three structures were utilised for internal embedded network tariffs:

- TOU: Time of use tariff based on standing offer TOU tariff periods (peak 14:00 to 18:00 weekdays, off-peak 20:00 to 07:00 every day, shoulder at other times);
- STS: Solar tariffs with 'solar time period' aligned to PV generation (off-peak 10:00 to 14:00, shoulder 06:00 to 10:00 and 14:00 to 18:00 and peak at other times);
- STC: Solar tariffs with a 'combined time period' corresponding to the SO TOU periods with an additional off-peak period 10:00 to 14:00 every day).

For each of these, a range of discount rates was applied to the fixed and volumetric charges from the SO TOU tariff to ensure competitive customer pricing.

3) *Gateway Tariffs*

In common with many commercial tariffs in the Australian energy market and elsewhere, the network tariff (EA305) seen by the embedded network, determined applicable according to total building load size, is a TOU tariff with a daily capacity charge based on the customer's peak load in a 12 month period and a high ratio of fixed and capacity to volumetric charges. The energy component is determined by negotiation and for this model two scenarios (9.5c and 11.5c) have been applied: one approximating to the rate paid by a representative NSW customer (11.84c inclusive of environmental charges) and the other representing a significant negotiated discount appropriate for the size of load. Although a feed-in-tariff of 12.5c/kWh is available to residential customers on the SO-TOU tariff, there is no automatic payment for exported generation under this commercial tariff[3], so no export tariff was applied in the model.

IV. RESULTS

A. *Customer Benefits*

Average customer benefits for each internal tariff scenario are calculated (Table 2). TOU20, STS35 and STC15 all give similar average savings as a percentage of BAU, as do TOU25 STS40 and STC20.

TABLE II. CUSTOMER SAVINGS

	Mean Customer Benefit ($)	Mean Saving as % of (BAU) Bill
TOU15	$0	0%
TOU20	$72	6%
TOU25	$144	12%
STS35	$45	4%
STS40	$136	11%
STC15	$51	4%
STC20	$120	10%

The discounted TOU tariffs, by definition, give all customers the same % saving compared to BAU, so could be

[3] Although the network service provider does make payments for avoided transmission use of service costs (ATUOS) to eligible embedded generators, eligibility depends on demonstration of network benefit.

seen to be more equitable. On average, the STS tariff structure gives greater benefit to customers whose load profiles align with PV generation (Fig. 4). However, it requires a significant discount (35%) to compete with BAU, due to the peak pricing of the evening peak demand period, and even at 40% discount 10% of customers are worse off than BAU.

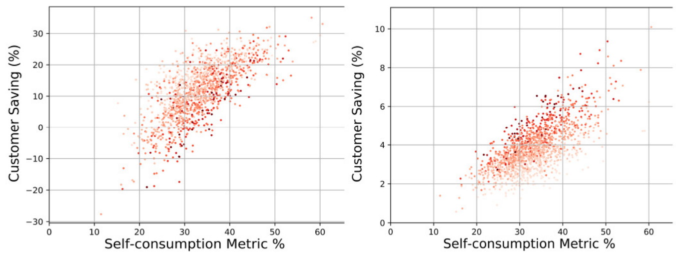

Fig. 4 Customer savings for STS40 (left) and STC15 (right) tariffs (darker colours represent higher loads)

The STC tariffs, in contrast, give savings to all customers, even at 15% discount (as they include an additional off-peak period), with greater savings for those with high self-consumption metrics (Fig. 4).

B. *Embedded Network*

Figs. 5 and 6 show the average annual embedded network income including avoided common property energy charges (after energy purchases and PV capital repayments), normalized for the number of apartments in the building, with and without PV for different internal tariff scenarios, calculated under retail and wholesale tariffs of 9.5c/kWh and 11.5c/kWh respectively at the parent meter.

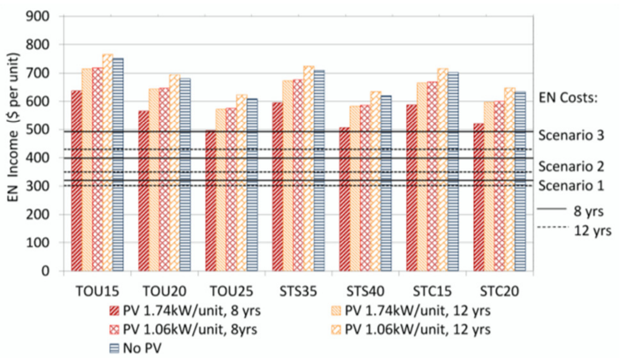

Fig. 5. EN income with 9.5c retail & wholesale tariff at parent meter

With no PV system, and paying 9.5c at the parent meter, the embedded network returns a positive income to the ENO with either TOU tariff in all cost scenarios, but note that only the TOU25 and STC20 tariffs give significant bill savings that would incentivise most residents to stay in the EN. With the higher parent tariff, the benefits of the EN are therefore marginal in the higher cost scenario.

In the absence of a feed-in tariff, the larger PV system significantly reduces the net EN income compared to the no PV case, and renders the EN unviable in the high cost scenario and marginal in the medium cost scenario if capital cost recovery is required within 8 years. Because of higher self-consumption, however, the smaller PV system (with costs amortized over 12

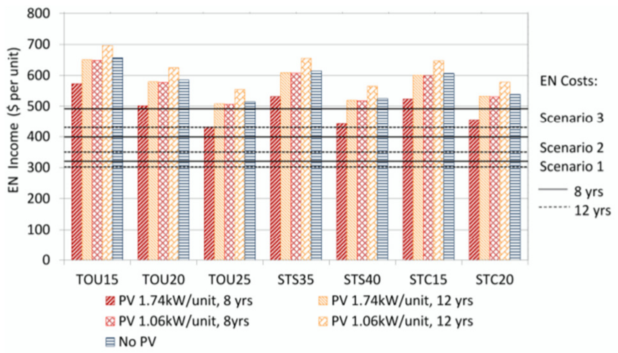

Fig. 6. EN income with 11.5c retail & wholesale tariff at parent meter

years) does not reduce net EN income, and with the higher parent tariff, it marginally increases the viability of the EN.

The distribution of benefits between owner-occupiers, non-resident landlords and rent-paying tenants for the high self-consumption PV system under the TOU25 and STC20 tariffs are shown in Table 3[4].

TABLE III. DISTRIBUTION OF BENEFITS

a	Tariff	Tenant	Landlord	Owner-Occupier
Parent 11.5c	TOU25	$144	$96	$240
Parent 11.5c	STC20	$120	$121	$240
Parent 9.5c	TOU25	$144	$155	$299
Parent 9.5c	STC20	$120	$179	$299

a. PV = 46.5kW, Cost Scenario 2, 12 years

V. DISCUSSION AND CONCLUSION

The results demonstrate the sensitivity of EN income to the negotiated retail and wholesale tariff applied at the parent meter and to capital cost scenarios that are highly specific to the building and network location. They also highlight the importance of appropriate PV system design to maximise self-consumption, particularly in the absence of a feed-in tariff.

Although the increased benefits due to the addition of PV to the embedded network are marginal at best in the scenarios modelled, this is largely due to the requirement to repay capital costs over 8 or 12 years and it would therefore be of interest to model an alternative cost scenario with capital expenditure amortized over the expected life of the PV system. After all, this period represents the typical time frame for paying off the purchase of an apartment. It is expected that in this scenario, PV could greatly enhance the viability of an embedded network faced with high retail and wholesale tariffs.

In favourable circumstances, careful tariff design can be used to distribute benefits between owners and residents in such a way as to incentivise investment and retain customers, whilst also encouraging customers to align their demand to PV generation, which could help reduce network peaks and maximise EN benefits. An assessment of the potential impact of this demand shifting (for a range of tariff structures) on network costs and on demand charges at the parent meter could

[4]These figures assume a suitable mechanism is used to distribute net EN income to all owners, e.g. through reduced strata fees.

be fruitful, as could an exploration of the addition of battery storage to the model.

In conclusion, embedded networks used with appropriately designed financial settings to distribute on-site PV generation to apartments can bring financial benefits to both owners and residents, provided retrofitting costs are not excessive. Similarly, the addition of a correctly designed PV system to an embedded network can provide hedging against high retail and wholesale energy charges.

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