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Analyzing Economic Benefits of Installing Rooftop PV on Real Apartments Buildings

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Abstract

In the context of increasing retail electricity prices, rooftop PV is a potential low-cost source of electricity for residential customers. Hence, over two million Australian homes have solar PV on their rooftops. However, the penetration of rooftop PV on apartment buildings is shallow in Australia compared to single-unit households, due to regulatory and strata issues.

This paper builds on previous research comparing the financial outcomes of different technical arrangements, business models, and battery management strategies for the deployment of PV on virtual apartment buildings. Here, we applied the same techno-economic model for 12 months of household-level interval load data for four real Sydney apartment buildings and modeled PV generation data based on the usable area and insolation on the building roof. We compare the costs and benefits of different PV systems and deployment arrangements under a range of tariff settings, and thereby identify the optimal arrangement for each building, in terms of lower individual household bills and increasing the profits for stakeholders.

1. Introduction

Retail electricity prices in Australia have increased markedly over recent years. Reasons no longer include the carbon price imposed on the industry over 2012-14 but then removed by an incoming Federal Government in order, they claimed, to reduce electricity prices (AEMC 2018). Prices are now far higher than during this carbon price period. It has been argued that there are three key drivers. Firstly, there has been the departure of old coal-fired generation, such as Northern and Hazelwood, which tightened supply-demand balance and led to an increase in the use of gas peaking plants. Secondly has been a more than doubling in gas prices on the Australian East Coast. This has markedly increased the already high operating costs of these gas plants. Finally, there is the exercise of market power by major generating companies due to lack of competition in the Australian National Electricity Market (AEMC 2018). Meeting Australia's committed contribution to limiting the global temperature rise to 1.5°C, following the Paris Agreement (Australian Government Department of the Environment and Energy 2018a), requires rapid, significant, and sustained carbon emission reductions, and the electricity sector has a pivotal role to play in this. These cost and emission reduction challenges represent an opportunity for distributed renewable generation deployed by energy consumers. The residential sector represents around one-third of electricity consumption (Australian Government Department of the Environment and Energy 2018b). Distributed PV represents a highly cost-effective as well as an environmentally beneficial option for households seeking to reduce their electricity bills, particularly given Federal Government subsidies, in the form of STCs (Small Scale Technology Certificates), and the very high retail tariffs that selfconsumed PV generation can offset. Even with the reduced tariffs paid for exported PV, the case for PV is compelling.

Cumulative installed solar PV capacity was 500GW worldwide by the end of 2018, with 99.1 GW of PV introduced in the year 2018 (IEA PVPS, 2019). Rooftop PV represents a significant proportion, although it is less than 50% of the global PV market (IEA PVPS, 2019). The residential sector comprising stand-alone houses and apartment buildings is a vital component of this rooftop PV. However, deployment of the PV system on apartment buildings is lower compared to stand-alone housing, despite attractive schemes to increase self-consumption and encourage apartment residents to install PV in some countries, including Greece and Switzerland. Other countries, including the USA, Spain, and Italy, are reviewing regulation to simplify the deployment of different PV and battery arrangements and to better protect these consumers (Waldau, A.J., et al., 2018). Australia is no exception here. It has the world's highest residential PV penetration (over 20% of households), but almost all of this is installed on stand-alone housing (APVI Live Map,2019).

One of the barriers to installing PV on Australian apartment buildings is the strata issue. Particular issues include access to the common area on the roof and elsewhere in these buildings and the question of how PV system benefits might be distributed amongst the strata members and other external stakeholders such as retailers, third party PV installers. There is also an evident need for a suitable mechanism to equitably distribute the energy resources and financial benefits between apartment residents and owners, given that many apartments are rented, and while tenants stand to benefit from reduced electricity bills, the landlord's agreement and, in many cases, capital investment, is required to undertake PV installation (Roberts, M.B., et al., 2019c)., Fleischhacker, et al. (2019b) identified that proper resource allocation and innovative ideas for using PV for tenants could incentivize residents to install PV on their rooftops while ease and transparency on network regulation, billing, and other financial flows will enhance the opportunity.

Previous research on possible deployment mechanisms for PV on apartment buildings has been conducted using "virtual building" load profiles created by combining apartment household load data from the Smart Grid Smart City dataset with common property load data from Sydney apartment buildings (Roberts, M.B., et al., 2019a), and then using these in a novel techno-economic model, as discussed in Section 3.2. These publications, which have laid the foundations for the research presented in this paper, assess the economic viability of rooftop Solar PV for different technical arrangements of PV (see Section 2) under a range of commercial settings and for different building sizes.

This paper applies the same techno-economic model to compare the costs and benefits of the different technical arrangements, but now using 30 minutes metered common property and apartment load data over 12 months for four real apartment buildings located in Sydney. A range of existing network and retail tariff settings are explored, in particular, updating the previous research to include the default market offer tariffs now available in New South Wales (Section 3.1), to determine the preferred technical and business models for deploying PV on each building. Expanding on work presented in (Roberts, M.B., et al., 2018a), a sensitivity analysis has been carried out for a range of possible internal financial settings. These include different embedded network tariff structures and rates and Solar Power Purchase Agreement (PPA) rates (see Section 3.3). It is hoped that this study will help a range of stakeholders assess how costs and benefits can be best distributed to provide incentives to all participants, that is, landlords, tenants, owner-occupiers as well as customers with different household characteristics (see Section 4).

The rest of this paper is structured as follows. In Section 2, we present a range of technical arrangements that might be used for apartment PV. The study method is outlined in Section 3, and the results of the modeling presented in Section 4. Section 5 concludes the paper with some discussion of these findings and possible future work.

2. Technical Arrangement of PV Systems

Apartment building electrical loads comprise individual units and common property. The common property comprises corridor lighting, shared HVAC systems, lifts, carparks, swimming pools, and other shared loads. Energy and financial flows under five different technical arrangments for deploying PV on apartment buildings are analyzed. These arrangements are:

1. Business as Usual (BAU) without PV: In this arrangement, the individual user consumes energy from the grid via individual meters that record their consumption.
2. Common Property only(CP): PV energy is being only utilized to meet common property load. It is one of the most common arrangements used in apartments. It is most beneficial for high rise apartment buildings, with higher loads for common property and relatively low rooftop PV capacity, thus maximizing self-consumption. However, approximately 60% of apartments are in buildings of two or three stories, for which this arrangement is less economically beneficial. It will provide lower self-sufficiency and (as common property loads are typically smaller in these buildings) less self-consumption (Roberts, M.B., et al., 2017a).
3. Individual PV Behind The Meter(BTM Individual): In this scheme, individual PV systems are installed, behind the meter, for each apartment (and, optionally, for the common property). A net metering system is installed, and residents retain their market retailer in the same way as solar house owners. It is a simple arrangement that avoids additional network infrastructure but risks lower self-consumption and financial benefits for owners and residents. (Roberts, M.B., et al., 2017a)
4. Shared PV Behind The Meter(BTM Shared): In this arrangement, a shared PV system is installed and connected to a secondary, low-cost distribution and metering infrastructure. PV generation is distributed to apartments (and, optionally, common property) proportionally to instantaneous load.
5. Embedded Network(EN): This is a more complex arrangement but also one of the most effective arrangements in terms of PV self-consumption and tariff benefits for residents. Here, an Embedded Network Operator (ENO), either managed by the owner's corporation or a third-party, purchases electricity from the grid via a parent meter and sells the electricity generated from PV and that purchased from the network to individual units via child meters.

The associated financial flows are:

1. Business As Usual(BAU) without PV: Each consumer pays the electricity bills to the retailers based on the time of use of their energy. The electricity bills include 10% of environmental charges.
2. Common Property only(CP): The strata body pays PV capital costs, and the benefits flow back to the strata body as reduced common property bills. These benefits may be passed on to apartment owners as reduced strata fees.
3. Individual PV Behind The Meter(BTM Individual): Apartment owners pay capital costs for their PV system, and residents benefit through reduced retail bills for energy consumed from the grid. In the scenarios modeled, each apartment is assumed to have a PV system occupying an equal share of the available roof area. In the case of behind the meter for individual users and common property, a percentage of generated energy equal to the common property load as a proportion of total building load is also allocated to the common property, with the strata body covering capital costs and benefiting from reduced retail bills.
4. Shared PV Behind the Meter(BTM Shared): Two business models are analyzed. In the first model, the strata body pays the cost of installing PV and the BTM distribution infrastructure. In the second model, a third-party solar retailer leases the roof of the building at no cost and bears the cost of installing PV and distribution/metering infrastructure. Consumers sign a PPA with a PV energy distributor (solar retailer) paying a solar charge (S.C) based on instantaneous demand at the secondary meter. A dual solar tariff applies to generated electricity with one rate applied to consumed energy and a lower price (equal to the Feed-In

Tariff(FIT) received by the resident) for an exported generation. (Roberts, M.B., et al., 2019a).

5. Embedded Network(EN): The embedded network is installed and operated by an ENO. The ENO purchases electricity from the grid through a retailer, paying a network charge and energy charge, usually based on a commercial tariff (based on total building demand). The energy component of this retail tariff is negotiated between the retailer and ENO. Residents pay the ENO for their consumption at the child meter based on tariffs negotiated between the user and ENO. (Roberts, M.B., et al., 2019a).

Figure 1 presents a diagram of four of these arrangements of energy flows (shown in black) and associated cash flows (shown in red). A green connection represents a new Solar PV or distribution infrastructure added onto a building. The yellow box in the figure shows entities that do not directly influence decision making around PV deployment in the apartment buildings. Note that the common property only approach is not shown but is relatively straightforward to implement.

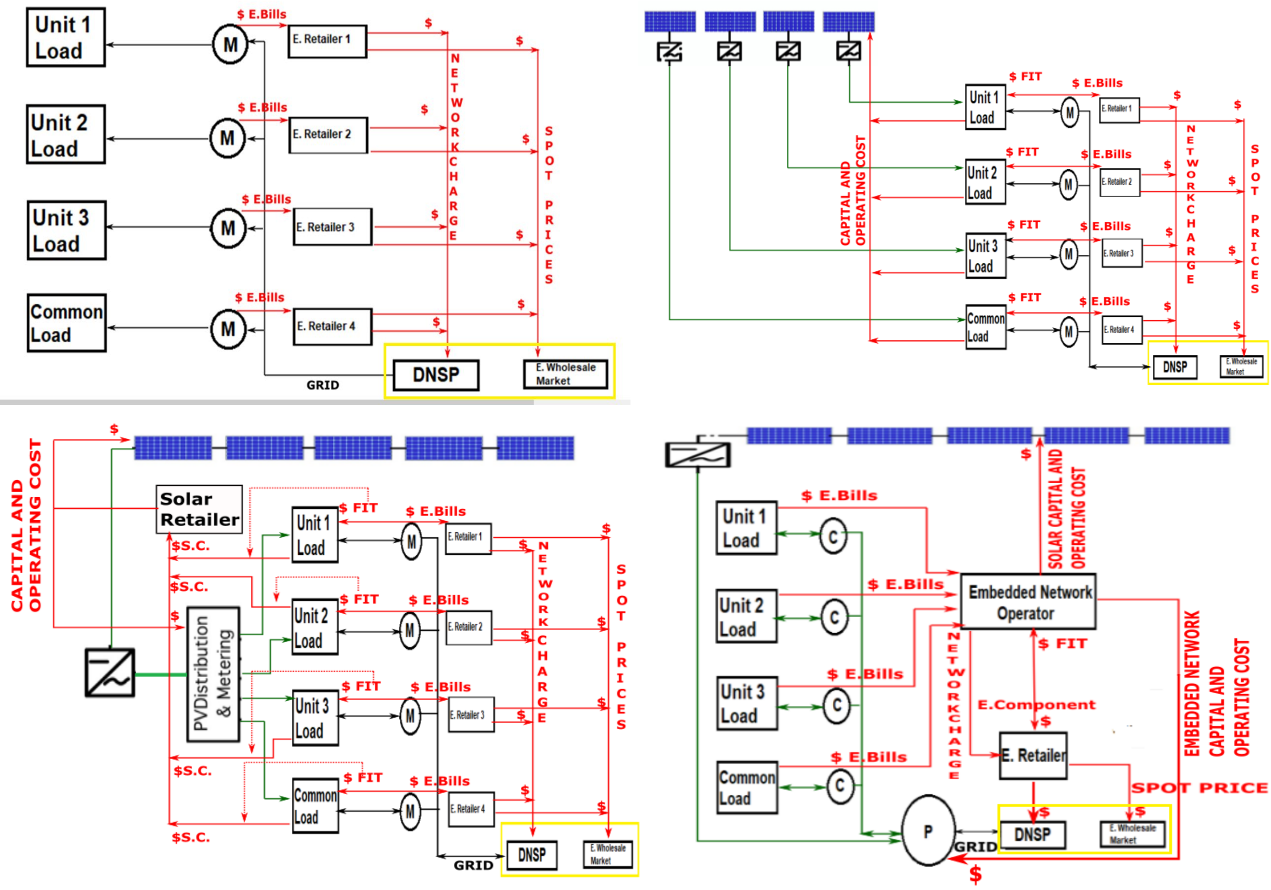

Figure 1 Possible Arrangements for PV on Apartment Buildings, clockwise from top left: Business As Usual, Behind the meter individual, Embedded Network, Shared Behind the meter (adapted from Roberts, M.B., et al., 2018a).

3. Method

This analysis involves the use of 12 months of 30-minute load data for apartments, and common property(CP) collected from meters installed in the switchboards of four Sydney buildings. Table 1 presents the necessary information about the buildings. The 'CP ratio' is defined as the percentage of common property load as a proportion of the total building load.

For each building, we have calculated the total energy consumption per year presented in Table 1. The potential PV system size is generated from Nearmap images, as described by Roberts, M.B. et al., (2018b).

Table 1: Basic Building Information

Building	Number of Units	% CP Ratio	Total Energy Consumption (MWh/year)	Number of Floors	Average Number of Occupants per unit	Roof Type	Potential PV Size Estimate (kW)
C	12	21	46	G+2	1	Tilted	10-30
T	15	6	125	G+2	1.8	Tilted	15-35
K	18	8	77.4	G+3	2.2	Tilted	10-30
W	72	40	218	G+3	3.2	Tilted	75-145

A wide range of retail tariffs was studied, as described in the next sub-section. The techno-economic morePVs (multi-occupancy residential electricity with PV and storage) Python model is then described. Finally, we discuss the sensitivity analysis used to explore the distribution of costs and benefits under different internal EN tariffs.

3.1 Tariffs

Standing offer tariffs, once regulated but then set by retailers with no discounts or incentives, were used in earlier studies but have now been discontinued. The market regulator (AER) has now introduced Default Market Offers (DMO), which are price capped (AEMC 2018). For the business as usual(BAU) scenario, a DMO tariff with a 10% discount applied to all components is used. This discount applied is to the total energy bill, and represents a typical discount offered to consumers by retailers.

Table 2 describes the tariff structures and rates used in the modeling, including some possible internal embedded network tariffs, as well as a range of solar instantaneous tariffs used for the shared behind the meter arrangement. The discount applied for tariffs is for all the components used in the tariff.

Table 2: Tariff Description

Name	Description	Price Details	Symbols
Flat Rate	A consumer is charged a single amount based on the energy consumed.	• Energy Charge: 40c/kWh or higher • Daily Fixed Charge: $1.3/day or higher (Ausgrid 2018)	FlatRate_Discount
Time of Use TOU	• The bills are charged based on the usage of electricity at different times in a day. • There is three main times of usage: Off-peak, Shoulder, and Peak	• Peak:14:00-20:00 (43-54c/kWh) • Shoulder:07:00-14:00 20:00-22:00 (24.5-36.5c/kWh) • Off-Peak: 22:00-7:00 (15-35c/kWh) Daily Fixed Charge: $1.1/day or higher (Origin 2018)	• Table 3 shows different Tariffs used for Time of Use
Feed-In Tariff FIT	• The unused energy generated from the PV is fed to the grid via the net metering system. • An incentive is given on the electricity bills.	6c/kWh to 25c/kWh (Solar Choice, 2019).	FITCharge (FIT8)
STS	• Solar TOU Tariff based on the peak, shoulder, and off-peak solar periods. (Roberts, M.B. et al., 2018a) • It can be used as an internal tariff for an embedded network to incentivize load shifting to solar periods.	• Peak:18:00-06:00 (45.25 c/kWh) • Shoulder:06:00-10:00 14:00-18:00 (29.81c/kWh and 27.45c/kWh respectively) • Off-Peak:10:00-14:00 (23.69 c/kWh)	• STS_Discount_DMO (STS_35_DMO) • STS_DMO_Number(Discount) (STS_DMO_1) • STS_DMO_1: 10% • STS_DMO_2: 20% • STS_DMO_3: 30% • STS_DMO_4: 40% • STS_DMO_5: 50%

		Daily Fixed Charge: $1.1/day or higher (Roberts M.B. et al., 2017c)	
STC	• Solar ToU Combined tariff based on DMO ToU periods, with the additional off-peak solar period with an additional discount on all TOU rates (Roberts, M.B. et al., 2018a) • Used as an internal tariff for embedded network	• Peak:14:00-20:00 (45.25c/kWh) • Shoulder:07:00-14:00 20:00-22:00 (29.81c/kWh) • Off-Peak: 22:00-7:00 (23.69c/kWh) • Off-Peak Additional: 10:00-14:00 (23.69 c/kWh) Daily Fixed Charge: $1.1/day or higher (Roberts M.B. et al., 2017c)	• STC_Discount_DMO (STC_35_DMO) • STC_DMO_Number(Discount) (STC_DMO_1) • STC_DMO_1: 10% • STC_DMO_2: 20% • STC_DMO_3: 30% • STC_DMO_4: 40% • STC_DMO_5: 50%
Solar Instantaneous	• This tariff is used for shared behind the meter. • It has two components • One is to pay for the solar instantaneous demand based on PPA, as shown in the next column. • TOU is used for paying the energy component from the retailer. The TO can be any tariff depending on retail(shown in Table 3). (Roberts M.B. et al., 2017b)	Same rates as that of TOU. Solar Charges for different PPA PPA1: 11c/kWh PPA2: 19.8c/kWh PPA3: 22c/kWh PPA4: 25c/kWh PPA5: 30c/kWh (Roberts M.B., et al., 2017b)	PPA_Number (PPA_1)

For an Embedded Network arrangement, the tariff paid by an ENO applied to an aggregated building load is called the gateway or parent tariff, and has two components. The first is the regulated network component, paid to the Distribution Network Service Provider(DNSP), which is determined based on the voltage requirements and energy consumption. The second is the energy component (Roberts, M.B., et al., 2019a), which is set by negotiation with retailers. The retailers charge the energy component for purchases from the wholesale market (and associated hedging costs), environmental charges, overheads, and profit margin. These are added to the network tariff (Roberts M.B., et al., 2017c) A sensitivity analysis has been carried out on this negotiated retailer price. Although payment for exported generation is often unavailable for commercial customers, a Feed-In tariff may also be negotiable with the retailer. Sensitivity to a range of FIT is, therefore, explored here.

Table 3: Different Time of Use Tariffs

Tariff Symbol	Peak (c/kWh)	Shoulder (c/kWh)	Off-Peak (c/kWh)	Discount(%)	Feed in Tariff (c/kWh)	Daily Fixed Rate(c/day)
DMO_NSW1	54.879	24.629	14.928	0	0	100.265
DMO_NSW2	37.631	36.223	20.812	0	0	151.25
DMO_NSW3	43.23	28.578	35.332	0	0	105.237
DMO_NSW_10	45.246	29.81	23.69	10	0	118.9137
DMO_NSW_20	45.246	29.81	23.69	20	0	118.9137
DMO_NSW_30	45.246	29.81	23.69	30	0	118.9137
DMO_TOU_15pc_FIT8	45.246	29.81	23.69	15	8	118.9137
DMO_TOU_15pc_FIT12	45.246	29.81	23.69	15	12	118.9137

3.2 Method of Evaluation: The morePVs[1] Python Model

The analysis was carried out using the “multi-occupancy residential electricity with PV and storage” (morePVs) model, as described by Roberts et al. (2019a). It works with four aspects. The first aspect

[1] “morePVs” Python model is an open source model available on https://github.com/mike-b-roberts/morePVs

is the customer with building load data. The second is the PV energy configuration and associated financial arrangements. It then considers various tariff and PV configuration scenarios and, finally, presents the results of each scenario for different systems and building profiles.

The inputs in this model include reference files and data files. In the data files, we have 30-minute load data for individual units and CP throughout the year. The data file also includes the estimated PV generation at 30-minute intervals throughout the year, calculated using NREL's System Advisory Model (SAM) (Roberts, M.B., et al., 2018b). The reference files include a tariff lookup table that itemizes the structure and rates for all the tariffs used in the modelling. The reference file also contains capital and operating costs (Capex) for PV and embedded networks.

The energy outputs of the model include total annual load, import, export, PV generation, self-consumption, and self-sufficiency. Financial outputs include yearly electricity bills for all residents, total building electricity-related costs, as well as costs, income, and profits for DNSPs, ENOs, and retailers.

3.3 Sensitivity Analysis

A wide range of sensitivity analyses have been conducted on the different range of tariffs, PV and embedded network and metering capital costs, operating cost, and the PV capacity to be installed on these four buildings.

3.3.1 Sensitivity to PV Size

For each building, three PV system scenarios are analyzed, based on the available roof area, as determined through analysis of aerial photographs:

1. Max Yield: This is the smallest system, based on installing PV on all suitable north-facing roofs. (Roberts, M.B., et al. 2019b)
2. Max PV: The largest system, based on full utilization of all available, unshaded roof areas. PV capacity installed is maximum in this case, but the yield (kWh/kW) is minimum. (Roberts, M.B., et al. 2019b)
3. Best Fit: This utilizes only north and west-facing roof areas, to more closely match the residential load profile. PV capacity lies in between max PV and max yield. (Roberts, M.B., et al. 2019b)

Depending on the building size, the PV capacity that can be installed varies from 10 kW up to 150 kW.

3.3.2 Sensitivity to PV Capex and inverter cost

The prices for PV Capex is derived from Solar Choice August 2019 Prices for NSW, with the inverter cost, assumed to be 20% of PV Capex (SolarQuotes, 2019). The simulation was run for a single year with Capex costs (including inverter replacement at ten years) amortized over 20 years at a discount rate of 6%. Table 4 shows the variation of PV Capex and inverter cost in $/kW. It should be noted that these prices are not applicable for the individual behind the meter configuration, where individual apartments install their own smaller PV systems, with sizes ranging from 0.5kW to 1.5kW. That is, each user installs the PV capacity equal to the total capacity divided by the number of apartments. In this case, the PV Capex for the individual behind the meter is kept at $1840/kW (Solar Choice 2019), and inverter cost at $368/kW.(SolarQuotes, 2019)

Table 4: PV Capex and Inverter cost for different sizes of PV

PV Capacity	PV Capex($/kW)	Inverter Capex($/kW)
10	1180	236
15	1180	236
20	1150	230
25	1150	230
30	1150	230
35	1150	230
75	1130	226
110	1060	212
150	980	196

3.3.3 Sensitivity to Tariff

Sensitivity with respect to Solar Instantaneous PPA tariff for Shared Behind the meter

Given present uncertainties with retail prices, we have used a wide range of solar charges, from 11c/kWh up to 30c/kWh. The relevant outputs of this analysis are the residential household bills and the profits that the solar retailer will earn on selling their generation.

Sensitivity Analysis to Parent Tariff and Capital Cost for Embedded Network

As described in section 3.1, the energy component of the commercial tariff charged to the ENO at the parent meter is determined by negotiation. Hence a wide range of tariffs and FIT's have been analyzed. The price difference between the network tariff and the parent tariff varies from 8c/kWh up to 20c/kWh. Also, for Feed-in tariffs, we analyzed the range from 0 c/kWh up to 17c/kWh. (The tariff description is as follows: xg shows the difference in network tariff and parent tariff, and in xg_FITy, y represents FIT) The main goal is to look at which parent tariff offers a low building cost (i.e., higher Net Present Value(NPV) of annual savings, calculated on a per-apartment basis). The NPV calculation was done using a 6% discount rate for 20 years. This tariff will be used to study the embedded network operator profits and individual residential bills for the different range of internal tariffs, as stated in Table 2.

The research looked into different capital and operating costs for different arrangements for PV systems for embedded networks. The capital cost for embedded network comprises of site Capex and metering costs. For this research, we used a "medium" Capex scenario (Roberts M.B., et al., 2017c) based on a sum of $20,000 for parent meter installation plus switchboard and wiring upgrades, plus an estimated as $400 per apartment for child meters installation.

Sensitivity to Internal Tariff

The three big retailers for residential electricity are Ausgrid, Essential Energy, and Endeavour (Origin, 2018)(mentioned in Table 3 as DMO_NSW_1, DMO_NSW_2, DMO_NSW_3 respectively). All of them have different charges for different times of use and discounts as well. We have taken an average of these three retailer's DMO tariffs and provided a discount in the range of 10-30% and used a wide range of FIT's and also designed some internal tariffs based on solar periods (described in Table 2). We use these tariffs to compare how individual residents in an embedded network are charged and how much profit does the embedded network operator makes from this wide range of possible internal tariffs.

4 Results and Discussion

Our study compares average household bills for behind the meter (shared and individual) and embedded networks by comparison with business as usual (no solar) scenario for all four buildings. It also assesses the benefits for other stakeholders, including solar retailers (for shared behind the meter) and ENO (for embedded network).

4.3 Average Household Electricity Bills

The average household bill for different PV arrangements for each building under a wide range of tariffs and FIT arrangements shown in Figure 2.

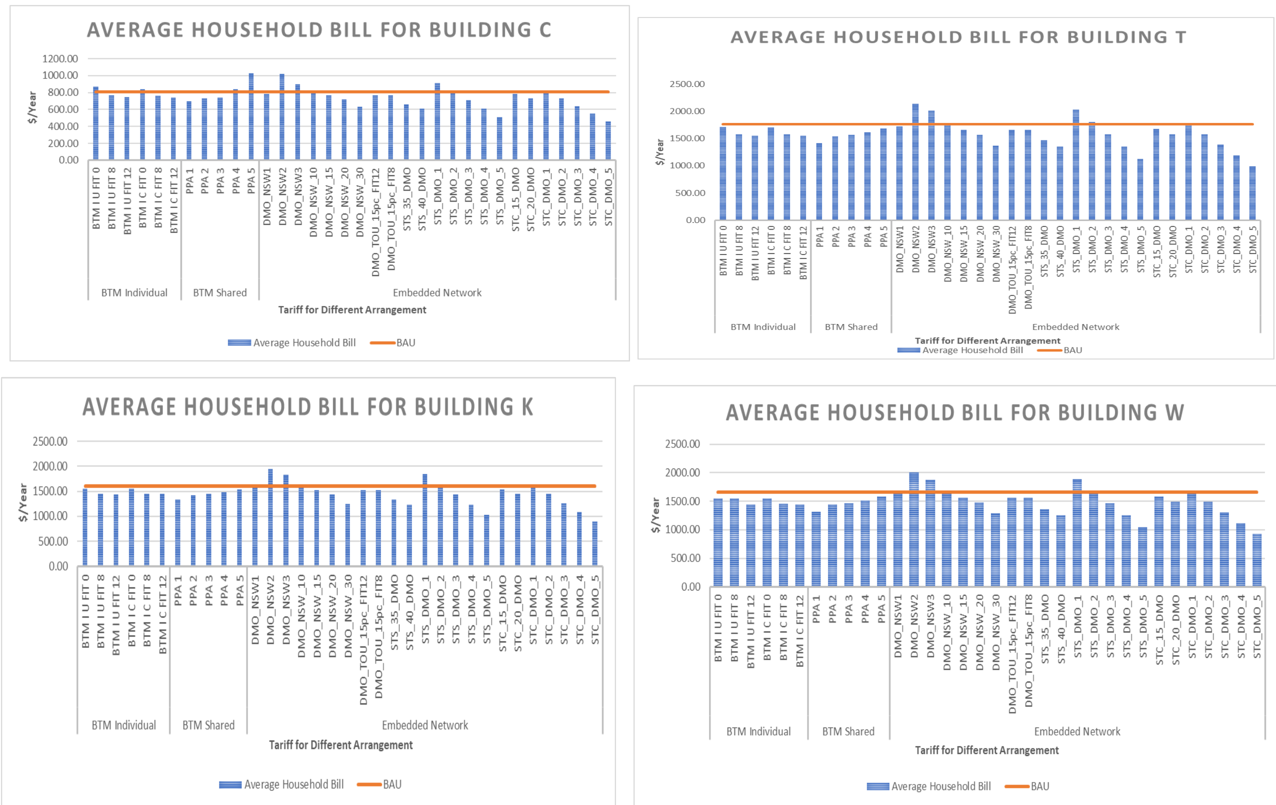

Figure 2 Average Household Bills Per Year for 4 buildings in Sydney.

For Individual PV Behind The Meter, average household bills are similar to business as usual for all the buildings. Additionally, individual users have to install their PV. So in such a case, business as usual (no solar) is likely similar in costs and certainly more convenient than behind the meter individual PV deployment.

Average bills are lower for a lower solar instantaneous charge, while household bills increase beyond business as usual for a very high solar instantaneous cost. For embedded networks, a wide range of internal tariffs is studied. Examining the internal tariff designed for embedded networks, which is STS and STC (Table 2), we find that both of them offer a better choice for individual users. STC having an additional solar off-peak period provides an advantage for the user to shift their demand in that period to reduce their electricity bills. Hence, STC bills are a bit lower compared to STS. Benefits will be different for each user, and that will depend on their load consumption throughout the day. However, we also need to check whether the other stakeholders (retailer, solar retailers, and ENO) can also make money out of this approach.

4.4 Solar Retailer Profit for Shared Behind the Meter

Figure 3 shows Solar retailer profit per year for different sizes of building for a wide range of FIT's. We have used the max yield PV configuration for this analysis.

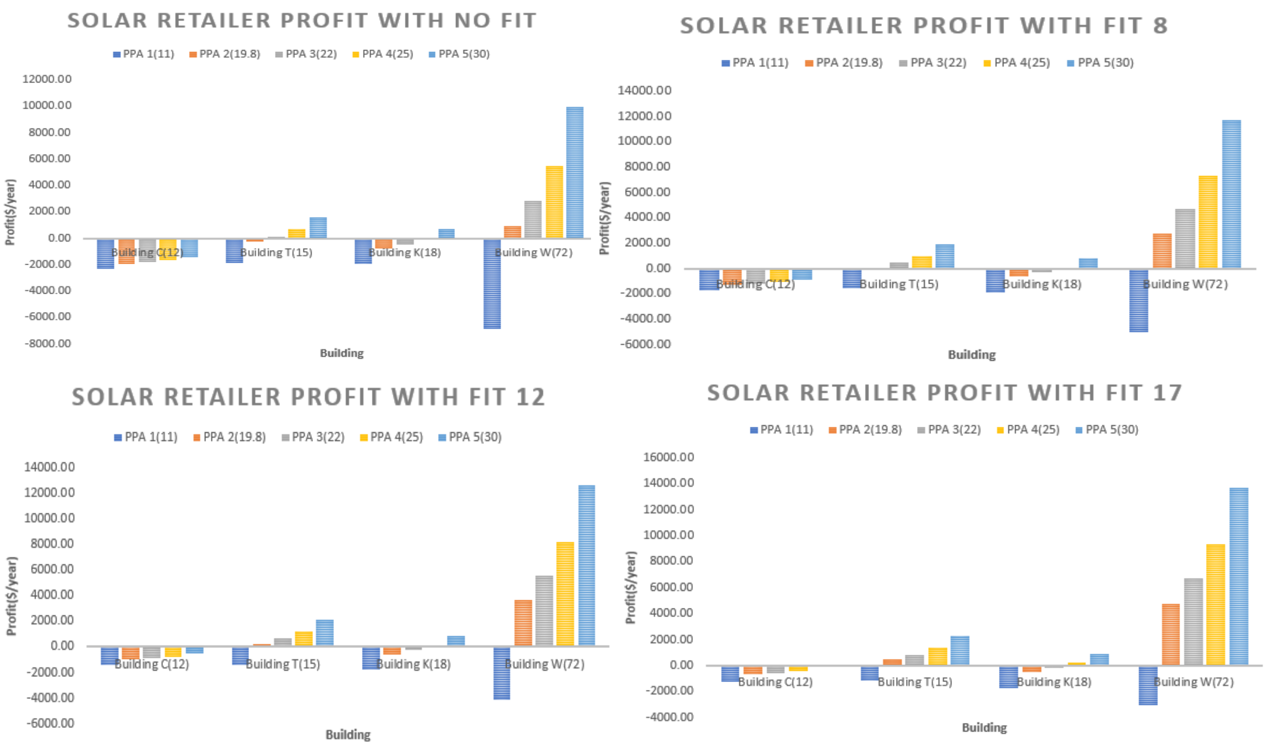

Figure 3 Solar Retailer Profit for different FIT's for all the buildings.

We see that for Building C, the solar retailer cannot make any profit even if we increase the PPA rates. Due to the small customer base and low load, it cannot recover the PV and distribution Capex and operating costs. For buildings T and K, the solar retailer earns marginal profit for higher values of solar charges. However, in comparing Figure 3 and Figure 2 for building T and K for PPA 5, the average household bills are very close to business as usual. In this case, a PPA 3(22c/kWh) or PPA 4(25c/kWh) would be a win-win for retailers and apartment users. For a larger building size, the larger is the customer base, which increases the profit marginally from this value. Hence building W can go for any PPA rates from PPA 2(19.8c/kWh) to PPA 4(25c/kWh).

4.5 Results for Embedded Network

We compare the NPV per apartment (calculated from the savings over 20 years) for a medium site Capex and Max yield PV configuration for the embedded network of all the buildings (see Figure 4). We find that building C, being a small building, earns marginal profits for lower parent tariffs. Profits increases as the size of the building increase. This is evident in Figure 4:

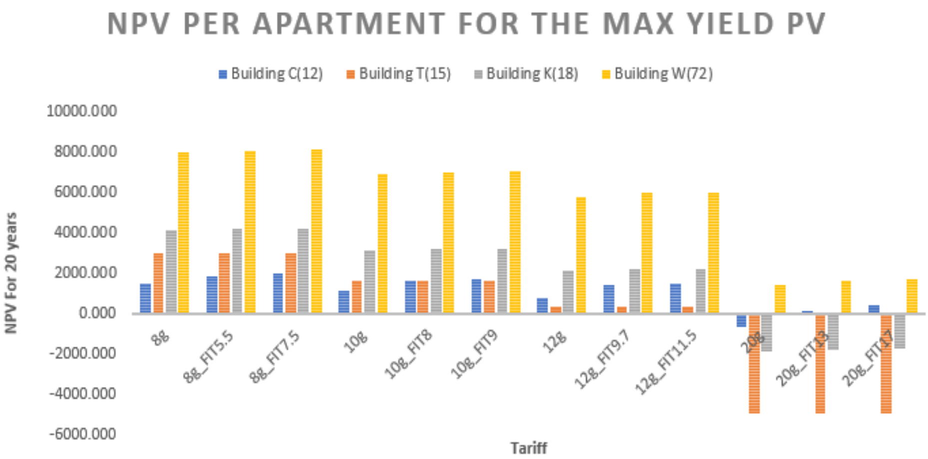

Figure 4 NPV per apartment for all the buildings.

It is clear that, for lower parent tariffs, it is beneficial for the strata body to invest in an embedded network. Given these Capex settings, and provided that a suitable relationship is established between the ENO and strata body to ensure that a share of the benefits flows back to the strata body and apartment owners, all stakeholders can benefit. From Figure 4, it appears that a parent tariff with 8g_FIT7.5 would be a better option.

Now, the ENO earns its profits mainly from its users, and if there is some significant export, then the FIT's also add to the profits. We see that for larger buildings and higher internal tariffs, the embedded network profits are higher and vice versa. Figure 5 allows a comparison of the household bill for all the buildings and the ENO's profits.

For building C, the ENO earns profits for higher average household tariffs while making a loss for lower tariffs. Thus, with limited tariffs (shown in Table 5), the embedded network does not appear suitable for this building. To have a viable embedded network for building K, they must negotiate for a lower energy tariff with the retailer at parent tariff. Table 5 shows tariffs for specific buildings where embedded network operators will earn the profit.

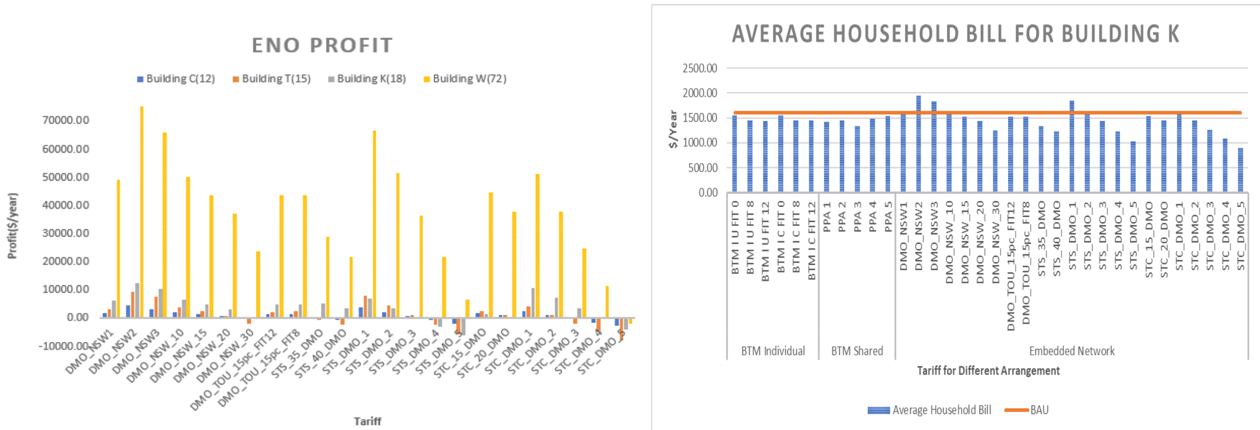

Figure 5 Embedded Network Operator Profits for all the buildings.

Table 5: ENO Profits for Specific Tariff

Building	Tariff
C(12)	DMO_NSW1, DMO_NSW_10, DMO_NSW_15, DMO_NSW_15pc,FIT8, STS_DMO_3, STC_DMO_2
T(15)	DMO_NSW1, DMO_NSW_10, DMO_NSW_15, DMO_NSW_20, DMO_NSW_15pc,FIT8, DMO_NSW_15pc,FIT12, STS_DMO_3, STC_DMO_2,
K(18)	DMO_NSW1, DMO_NSW_10, DMO_NSW_15, DMO_NSW_20, DMO_NSW_15pc,FIT8, DMO_NSW_15pc,FIT12, STS_DMO_3, STC_DMO_2, STC_DMO_3
W(72)	DMO_NSW1, DMO_NSW_10, DMO_NSW_15, DMO_NSW_20, DMO_NSW_30, DMO_NSW_15pc,FIT8, DMO_NSW_15pc,FIT12, STS_DMO_3, STS_DMO_4, STS_DMO_5, STC_DMO_2, STC_DMO_3, STC_DMO_4

5 Conclusions

There are three main aspects of this research. The first one is to establish which technical and financial PV arrangement would be a better option for a particular apartment building by comparing them with business as usual. Then, within those arrangements, we select the financial parameters (residential tariff, network tariff) that would be appropriate for all associated stakeholders (residential apartment users, retailers, solar retailers, and ENO's). We seek to ensure that all the stakeholders enjoy the economic benefits of PV deployment (lower bills for residential users while sustainable business models for enabling participants). The final aspect is to show a comparison amongst different building sizes and understand how each arrangement that's appropriate for one building would differ for different sizes of buildings.

Comparing average household bills for Behind The Meter PV Shared against business as usual, we find that the electricity bills for households are lower for lower PPA rates and vice versa. However, at the same time, lower PPA rates create a poor business model for solar retailers. We also see how, for a small building like Building C, this arrangement will not be ideal for solar retailers. For the rest of the buildings, both user and retailers would enjoy the benefits of shared behind the meter for specific PPA rates (described in Section 5.2)

For embedded networks, the average household bills depend entirely on the selection of internal tariffs. Lower tariff rates lower the average household bills, but the embedded network operator may not earn sufficient revenue. For small buildings, embedded networks may not be economically viable. For medium-sized to large-sized buildings embedded network would be a good option for a specific range of internal and parent tariffs.

Thus, we can conclude that smaller apartment buildings with good solar PV potential might be best served by installing PV as Individual Behind The Meter, keeping in mind that their annual household bills should not exceed the business as usual case. For medium-sized buildings, shared behind the meter can be a good option if the savings can be shared appropriately across the apartment owners and solar retailer. They may also go for an embedded network under certain circumstances. For larger buildings, the installation of an embedded network may well be the best. Future work could look at designing and adding a battery system to maximize self-consumption and again compare these techno-economic parameters with other options. A more extensive range of buildings could also be studied.

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