Oakley Greenwood

Value of a Grid Connection to Distributed Generation Customers

prepared for:
Energy Networks Association

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1. Summary of key points

The deployment of rooftop PV systems has increased dramatically in the last decade, and is forecast to continue

The number of rooftop PV systems installed in Australia has increased dramatically – from almost none in 2000 to over 1.2 million by June of 2014. These systems now represent a total nameplate generation capacity of 3,420 MW and were estimated to have generated 3,951 GWh in the 2013-14 year. Further strong growth is forecast: by 2023-24 rooftop PV systems are expected to generate 14,114 GWh representing 7.5% of the total electricity requirements of customers in the NEM[1].

Other forms of distributed generation are nearing the point where they will also start to be deployed by customers. These will include battery storage (including the use of electric vehicle batteries) to store electricity generated by the PV system and to be drawn on when needed), fuel cells and micro-wind turbines, any of which could be paired with rooftop PV systems.

Each of these types of distributed generation — either singly or in combination with others — will have its own unique impact on the electricity grid. The grid is made up of the transmission and distribution network “poles and wires” that move electricity from the sources of generation to Australian homes and businesses.

Given that rooftop PV is the fastest growing form of distributed generation in Australia – and the type likely to continue to provide the largest source of distributed electricity generation for the next five to ten years – it is important to understand the impact that these systems are having now and may have in the future on the electricity supply system and electricity customers. In addition, such an effort with regard to rooftop PV systems can also provide a methodology that can be transferred for use in considering the likely impacts of other forms of distributed generation.

The vast majority of the households that have installed rooftop PV systems have stayed connected to the grid and have derived significant benefits from that connection

The overwhelming majority of the rooftop PV systems installed to date are on homes that continue to be connected to the grid. This connection provides significant value to the customer with a rooftop PV system. The value of grid services occurs in three different areas.

- **Continuous supply** – Customers receive a continuous supply of electricity, made up of their own generation and the grid as a back-up whenever their own generation cannot provide all the electricity they need.
- **Market access** - Customers can sell the excess power generated by the PV system to retailers at the feed-in tariff rate.
- **Start-up power, power balancing and power quality** – the grid provides a number of virtually invisible services to customers. These include:
  - The ability to provide large increases in the amount of electricity delivered over very short time periods. This is important because some consumer appliances – such as air conditioners - can require significantly more power to start up than they do once they are running.

1 These figures are based on the Medium 50% POE forecast in AEMO’s *2014 National Electricity Forecast Report*, June 2014.

- A steady and even supply of electricity, which is required for appliances to operate properly and which could be difficult for a PV system to provide on its own because its output can drop quickly (even if only temporarily) due to passing clouds.
- A high level of power quality, which is important for certain home appliances, such as desktop computers.

All customers benefit from the continuous supply, start-up power, power balancing and power quality provided by the grid. Market access is an additional service that users of rooftop PV systems (or other distributed generation systems) enjoy that is available to, but not used by, other customers.

Customers with rooftop PV systems receive essentially the same service from the electricity network – but pay considerably less than other customers

To quantify the value a grid connection provides to a customer that uses a distributed generation system, we developed a case study of a residential customer with a rooftop PV system in the western Sydney suburbs, where Endeavour Energy is the electricity distribution company[2]. This quantification used the following information:

- The regulated retail tariff and the network tariff that were in place in the Endeavour Energy service area during the 2013-14 year.
- The annual consumption and half-hourly consumption profile of a typical residential customer in the Endeavour Energy service area.
- The annual and half-hourly output of an average-sized rooftop PV system in NSW.

Analysis of these inputs revealed the following:

- An average residential customer uses 5,000 kWh over the course of a year.
- A typical rooftop PV system in the Endeavour Energy area will produce 3,742 kWh under average weather conditions.
- Of that, 2,044 kWh (about 55% of the total output) would be used directly by the household, with the other 45% (about 1,698 kWh) being exported back to the grid.
- As a result, about 2,956 kWh of the total 5,000 kWh consumed annually by the average residential customer in the Endeavour Energy area would still need to be supplied by the grid.

The case study revealed that a residential customer in the Endeavour Energy service area with an average-sized rooftop PV system derives the following benefits from their grid connection:

- The ability to use their electric appliances even when the PV system is not generating electricity (such as at night), worth approximately $729 per year at 2013-14 retail electricity prices[3].
- Sales of excess electricity generated by their PV system worth about $93 per year.

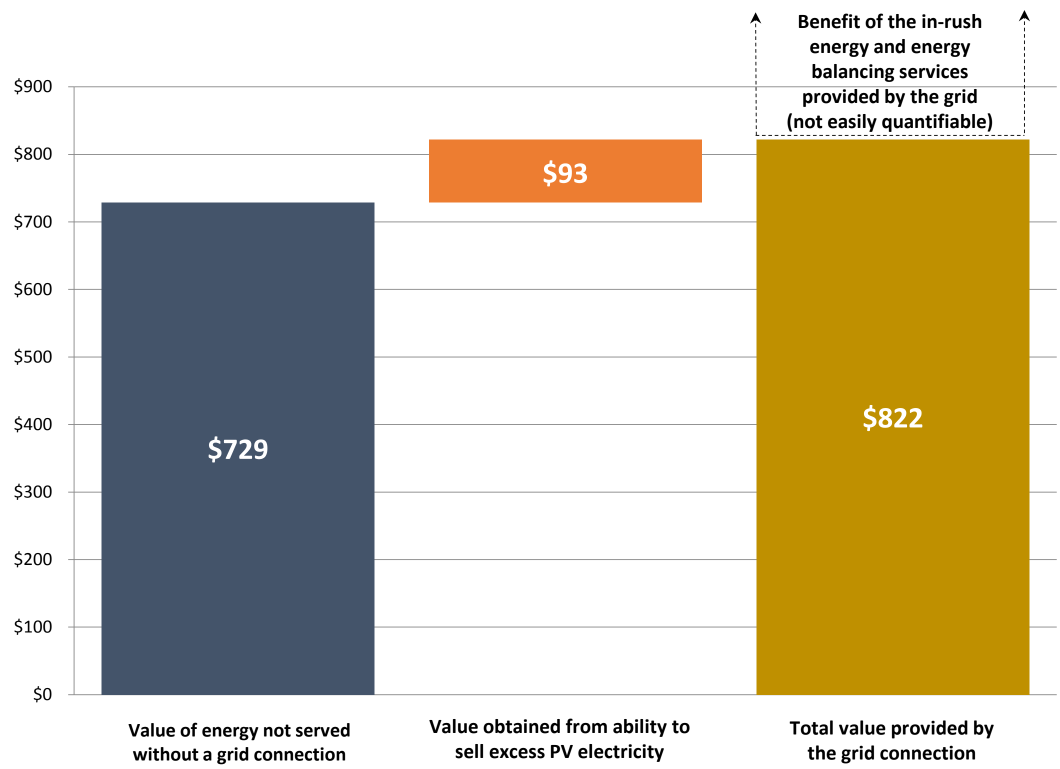
2 Endeavour Energy serves an area primarily to the west and south of Sydney including Sydney's Greater West, the Southern Highlands and the Illawarra, and which includes some of the fastest growing areas in Australia.

3 Which is calculated by multiplying Origin Energy's retail electricity price in the Endeavour Energy area by the 2,956 kWh that the PV customer still relies on from the grid. Note that all dollar figures in this document are exclusive of GST.

- Access to the in-rush energy required to start certain equipment such as air conditioning. Without such a service from the grid, the customer would either need to install sufficient onsite generation and storage or to downsize or forego the use of larger air conditioning equipment.
- Avoidance of damage to their equipment provided by the grid's ability to instantaneously balance the supply of electricity to the needs of the customer and to maintain a high level of power quality through frequency, voltage and harmonic distortion control.

Figure 1 below displays these values.

Figure 1: Annual value of a grid connection to a residential customer in the Endeavour Energy service area with a rooftop PV system



Source: OGW analysis

As can be seen, the total benefit provided by the grid connection to a customer with a rooftop PV system in this case study comes to approximately $822, and this does not include either:

- the value of the in-rush energy capability provided by the grid, or the grid's ability to instantly top up the supply needed by the customer in the event that even very short reductions in the PV output occur due to short cloudy periods, or
- the fact that the value to the customer to have electricity at night is likely to be higher than just the cost of purchasing that electricity.

This customer would pay $453 in his or her annual bill to the network (comprised of $131 in fixed charges and $322[4] in volume-based charges) to get these services.

In order to have access to a level of electricity supply similar to that enjoyed by the average customer in the Endeavour Energy service area, a customer that wanted to use a PV system without a connection to the grid would need to install:

- a PV system of at least 4kW in capacity with sufficient battery storage to allow enough electricity to be generated in the day and stored in order to provide the electricity needed after the sun goes down and during cloudy periods, and
- a petrol- or diesel-fired generator to provide electricity during extended cloudy periods and in the event the PV system needs maintenance or repair.

The cost of such a system for a family of four including 2 school age children that uses about 5,000 kWh a year for heating, lighting, refrigeration and other appliances, but that has gas water heating and cooking would be in the order of $56,500 inclusive of GST and after all applicable renewable energy credits are taken into account. It would also require some annual costs for maintenance.

The monthly cost of such a system can be compared to the monthly cost the customer without a rooftop PV system pays:

- The total annual retail bill for such a customer in the western Sydney suburbs will be approximately $1,488 per year or about $124 per month[5], of which approximately $677 or $56 per month would be for network services (comprised of $131 in fixed charges and $546 in volume-based charges).
- The monthly cost of the standalone system can be estimated by dividing the total initial cost by the number of years of useful life the system can be expected to provide and then dividing that by twelve to get an average monthly cost. Using an estimated cost of the standalone system of $56,500 this comes to about $430 per month[6] – significantly more than the cost the average customer pays for electricity delivered through the grid[7]. If financed at the cost of a home mortgage at 5%, the finance cost would be $166 per month, requiring total repayments of $596 per month.

It should be noted that this SAPS would be able to support only a very moderate level of air-conditioning – probably no more than a single, relatively small split system. A SAPS capable of running two or three split systems – enough to cool the lounge room, master bedroom and possibly one other bedroom or study – would cost about $72,500 inclusive of GST and after all applicable renewable energy credits are taken into account. The monthly cost of such a system would be about $550. (If financed at the cost of a home mortgage at 5%, the finance cost would be $299 per month, requiring total repayments of $850 per month)

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4 This is based on the PV customer's electricity consumption from the grid multiplied by Endeavour Energy's first tier kWh price on its N70 tariff for 2014-15.

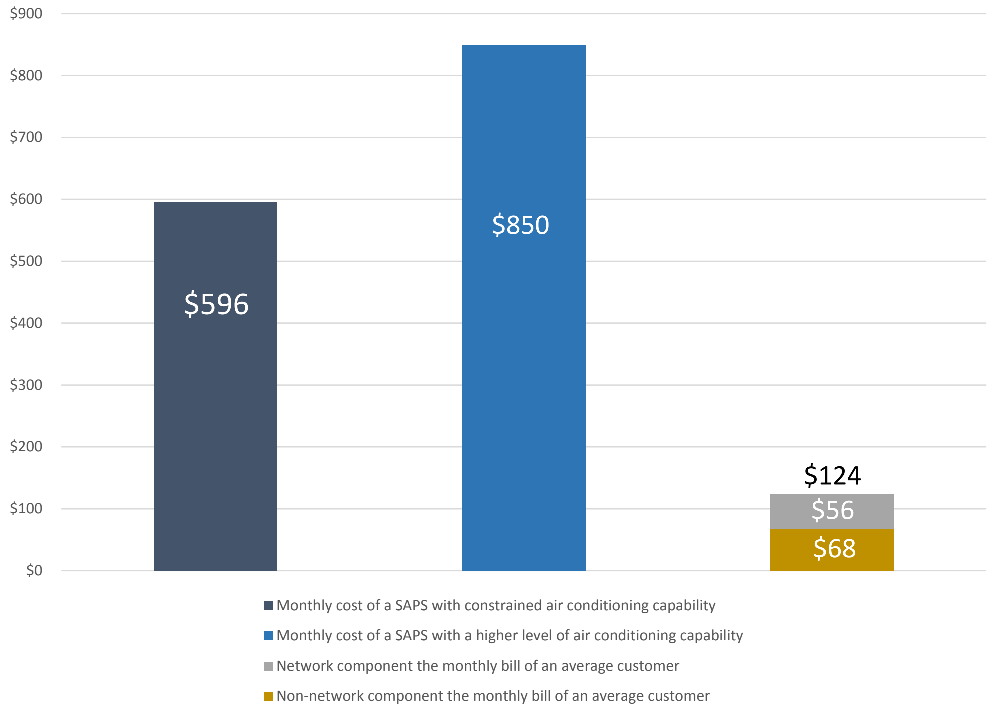
5 This is calculated based on the 2013-14 regulated retail tariff for the Endeavour Energy service area.

6 This calculation is based useful life-weighted cost of 11 years for the SAPS based on information on typical component costs and lifetimes. See Section 4.1.2 and Appendix B for more information. It is still a bit conservative in that it does not include any costs for fuel or maintenance.

7 It should be noted, however, that to date SAPS have generally only been installed in residences that are not close to existing electricity lines, and the cost of connection is therefore very high.

The monthly costs of these two SAPS and those faced by the average Endeavour Energy customer that does not have a PV system are compared in Figure 2 below.

Figure 2: Monthly costs of two SAPS with those of a typical residential customer in Western Sydney

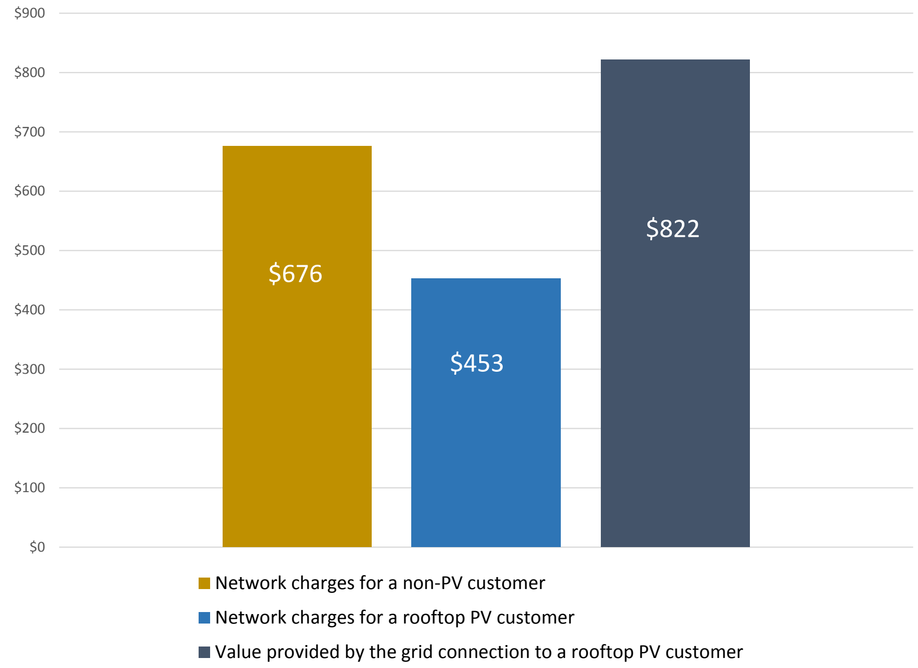


Source: OGW analysis

The high cost of these systems is likely to mean that at least for some time most customers who install rooftop PV systems to lower their bills and reduce the greenhouse gas emissions associated with their use of electricity will continue to maintain a connection to the grid. The exception will be – as it is at present – where the cost of connecting to the grid is quite high due to the distance from existing electricity lines. Expected reductions in the cost of batteries will reduce the cost disadvantage of these systems, but as the batteries account for about 40% of total installed SAPS costs, even significant reductions here will have more modest impacts on overall cost-effectiveness.

Finally, Figure 3 compares the $677 in annual network charges paid by a typical residential customer in Western Sydney that does not have a rooftop PV system with the $453 in annual network charges paid by a typical residential customer that uses a rooftop PV system and the $822 that the customer with a rooftop PV system receives in value from his or her grid connection.

Figure 3: Comparison of the network charges paid by a customer without a PV system with the charges paid and value received by a customer with a rooftop PV system



Source: OGW analysis

Rooftop PV systems have impacts on the grid

A rooftop PV system that is connected to the grid has two important impacts on the grid that can affect customers' bills:

- It can reduce peak demand on the grid, which can delay and/or reduce the need for capital expenditure by the grid and therefore exert *downward* pressure on grid costs and the network prices that need to be charged to customers in order to recover those costs.
- It reduces electricity consumption supplied by the grid. Given that network revenue is primarily recovered through charges on consumption, this puts *upward* pressure on the per kilowatt hour (kWh) price the grid charges its customers.

Where the fall in revenue recovered from customers with rooftop PV systems is greater than the reduction in future capital costs, rooftop PV system will have a net upward pressure on network prices. To the extent that this upward pressure results in a higher price for each kWh of electricity consumed, the annual bill of an average residential customer without a rooftop PV system will go up more than the bill of an average customer with a rooftop PV system, simply because the latter will consume less electricity than the former. This essentially constitutes a cross-subsidy from non-PV customers to customers with rooftop PV systems.

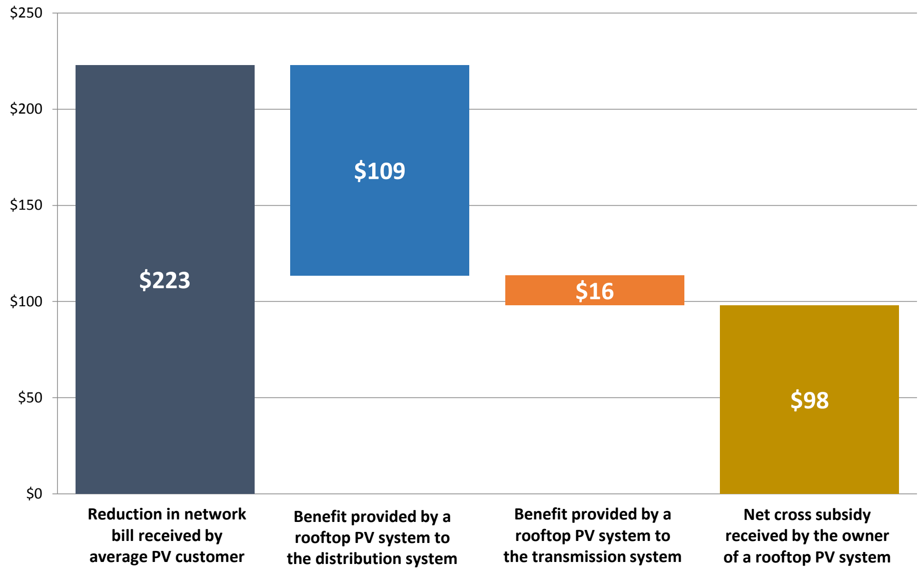
On the other hand, If the reduction in future capital costs is greater than the fall in revenue recovered from customers with rooftop PV systems, the use of the rooftop PV system would exert a downward pressure on network prices, which would benefit all customers of the grid.

Analysis of these impacts in the Endeavour Energy service area indicates that use of a rooftop PV system will:

- reduce the network component of the bill of the average residential electricity customer in the Endeavour Energy distribution system that uses a typical rooftop PV system by approximately $223 per year[8];
- reduce the future annual capital expenditure requirements of the grid by approximately $125 per year (made up of a fall in distribution network costs of approximately $109, and transmission network costs of approximately $16 per year)[9]; and
- thereby result in an annual cross-subsidy from non-rooftop PV residential customers to each customer with a rooftop PV system of about $98.

Figure 2 displays these values.

Figure 4: Annual impacts of a rooftop PV system on the Endeavour Energy network and other customers



Source: OGW analysis

The calculation of the cross-subsidy discussed above was undertaken assuming that peak demand on the grid occurs at 4:30 PM Eastern Standard Time. However, the level of the subsidy is very sensitive to the actual time of grid peak demand. For example, if the time of peak demand were 5:30 PM instead of 4:30 PM, the cross-subsidy increases substantially – from $98 to $163 per annum. This is because the benefits accruing to the network business are smaller, due to

8 Calculated by multiplying the 2,044 kWh in reduced grid-supplied electricity due to the PV system multiplied by Endeavour Energy; variable charge for electricity consumption of 10.8934 cents per kWh.

9 Based on the published long-run marginal costs of Endeavour Energy and TransGrid.

the fact that the PV system produces much less energy at 5:30 PM than it does at 4:30 PM[10]. However, because the PV system generates the same amount of electricity regardless of when peak demand occurs, and because customers are charged based on their total consumption and not when that consumption occurs, the fall in the revenue from customers with rooftop PV systems that needs to be recovered through higher charges remains the same regardless of when peak demand occurs[11].

In this regard, it should be noted that:

- the time of maximum demand can differ from one distribution system to another,
- as well as from one local area to another within a given distribution system, and
- the time of peak demand in most distribution systems is occurring later in the day due in significant part to the installation of rooftop systems which provide the electricity needed by the household in the daylight hours but which rely on the grid once sun angles get low in the late afternoon.

Conclusion

It is clear that customers who install rooftop PV systems and maintain a grid connection derive significant value from that connection. However, these systems can also provide benefits to the grid in terms of reduced peak demand which can reduce the future capital expenditure requirements of the grid. The balance between the reduction in future capital costs and the loss of revenue recovered from customers with rooftop PV systems will determine whether network prices go down, with benefits to all customers, or go up and impose a cross-subsidy from customers who do not use rooftop PV systems to customers that do.

In the Endeavour Energy service area, as discussed previously, customers with rooftop PV systems receive significant benefits from those systems, but pay materially less for the grid services they receive than do other customers, despite the fact that those other customers do not receive any additional services from the grid. It is also the case that a significant portion of the difference in the amounts paid is a cross-subsidy from customers who do not have rooftop PV systems to customers that do.

These findings also reinforce the need for pricing reforms that reflect the factors that drive the cost of providing network services. The current reliance on revenue recovery through charges on energy consumption (a) increases the financial attractiveness of rooftop PV systems (and other measures) to customers, (b) results in potential cross-subsidies when that take-up occurs, and (c) thereby feeds the risk of a so-called ‘death spiral’.

In sum, the form of pricing currently used provides a poor signal to customers of both:

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10 If the time of peak demand were earlier, the PV system would produce more energy, and its impact on peak demand would be greater and the cross-subsidy smaller. There are other factors that also affect these outcomes. In addition to the impact of reduced (or increased) impact of the PV system on network peak demand described above, the cost of augmentation is also important. Where augmentation costs are lower, the cross-subsidy will be higher – because the reduction in peak demand has a lower benefit. It must also be remembered that augmentation of the network is undertaken at the local area level. The time of peak demand may vary across these local areas, as will the cost of the augmentations required. The examples above have used average figures for simplicity.

11 An additional complicating factor is that there may already be sufficient capacity in the network. In such a case, the network will not experience an actual reduction in capital expenditure in that year. More generally therefore, the actual value of the cross subsidy will change over time as the balance of the supply and demand of network capacity in the local area changes over time.

- the factors that drive the cost of grid services, and
- the value a connection to the grid provides.

Given this, it would seem worthwhile to consider alternative pricing structures that better reflect the cost incurred by the network in serving the customer. This would encourage more economically efficient investment decisions – that is, decisions that would reduce or avoid cross-subsidies between customers, and reduce the long-term costs for all consumers.

2. Background and purpose

2.1. Current and forecast use of rooftop PV systems in the NEM

The dramatic increase in the use of small-scale distributed electricity generation systems – particularly rooftop solar PV systems – has been well documented. From virtually none of these systems being used at the household or business level in 2000, the Clean Energy Regulator estimates that, as at 1 June 2014, a total of 1,237,152 solar PV systems had been installed around Australia with a total nameplate generation capacity of 3,420 MW[12].

These systems have delivered material reductions in the electricity bills of the customers that have installed them, and have also reduced the greenhouse gas emissions associated with the electricity consumed by these end users. It is also clearly the case that, as long as electricity peak demand occurs during daylight hours, rooftop PV systems are likely to help satisfy that demand.

Further, a number of studies – including the most recent forecast issued by the Australian Energy Market Operator (AEMO) – project that installations will continue to grow based on continuing reductions in the price of PV panels. Battery storage systems are also expected to experience material reductions in cost, which will provide the potential for consumers to further reduce their reliance on the grid for the electricity they need. There is also evidence that the average size of the systems being installed is increasing. For example, the average size of the rooftop PV systems that have been installed to date in NSW is about 2.6 kW – but the systems going in at present tend to be in the 4 kW range[13]. New business models and potential changes in the National Electricity Rules (NER) may also facilitate significant increases in take-up by commercial and industrial end users. As will be discussed later, the potential for continued upward pressure on electricity prices would also encourage more take-up of rooftop PV systems – especially if those price increases are predominately placed on the cost of each kWh of electricity consumed.

More specifically, AEMO's *2014 National Electricity Forecast Report* (NEFR) anticipates that electricity consumption among residential and commercial customers will ***fall*** by 0.5% annually through 2016-17, and that the key drivers of this are strong growth in (a) rooftop PV installations (forecast at 24% annually), particularly in Queensland and Victoria, and (b) energy efficiency savings (forecast at 10% annually). In the medium to long term (2016-17 to 2023-24) AEMO forecasts residential and commercial electricity consumption to increase slightly, with the average annual increase over this period being 0.2%. This results in virtually no change in residential and commercial sector consumption from the estimated 2013-14 level of 131,985 GWh to the 131,970 GWh forecast for 2023-24.

12 http://ret.cleanenergyregulator.gov.au/REC-Registry/Data-reports#Smallscale-installations-by-installation-year

13 Based on information from the Clean Energy Regulator website on the average size of PV systems installed from January 2013 through May 2014.

At the same time, AEMO also forecasts that PV systems will be generating 14,114 GWh of electricity in 2023-24, which is just under five times as much electricity as was generated by PV systems in 2012-13[14]. Based on those figures, PV systems will account for 7.5% of the total electricity requirements in the NEM in 2023-24.

AEMO also forecasts the impact of PV on the maximum electricity demand at the state level across the NEM jurisdictions. Changes here reflect a more complex picture because a number of factors affect the impact of PV on peak demand. The most important of these factors, somewhat counter-intuitively, is the amount of PV that has already been installed. This is because all of the states in the NEM (except Tasmania) experience their maximum demand for electricity in later afternoon and early evening hours on summer weekdays during extended periods of high temperatures. This is primarily due to how much extra electricity is used in residential air-conditioning on those days. There is often a relatively good level of sunshine available at those times, which means that PV systems are generating electricity. As more PV systems are installed, they can remove more of the demand at that time from the grid. However, as it gets later, temperatures do not reduce nearly as quickly as does the strength of the sunlight that is available, resulting in more of the air-conditioning load needing to be met by grid-delivered electricity. As a result, peak demand on the state-wide electricity system occurs at a later time of day. To the extent that non-residential loads may be reducing by that time, this can result in the peak at that new time being lower than it would have been at the earlier time.

Things are a bit more complex again at the distribution network level of the grid, because the mix of customers within a given local area (for example a feeder or a zone substation) may be very different from the mix across the state as a whole. A zone substation may primarily supply residential customers, for example. Where this is the case, peak demand is likely to be later in the day than would be the case in an area where there is a significant level of commercial or industrial load – even without the impact of significant numbers of rooftop PV systems being installed. As a result, additional PV penetration in that area may have relatively little impact on peak demand, and will certainly have very little effect after some quantum of PV has already been installed.

These trends present a significant challenge for network businesses using the traditional pricing approach whereby the costs incurred by the network are predominately recovered by charging customers for the electricity they use. Under the conditions forecast by AEMO, that is lower levels of consumption, unit electricity charges will have to increase, as there will be fewer units of electricity sold to support the grid that is already in place, and that will likely require at least some augmentation[15].

If these price increases are applied to kWh charges, it will make energy efficiency measures and PV systems more cost effective. Take-up of those energy efficiency measures and PV systems would then further reduce the amount of electricity consumed through the grid (and the revenue associated with it), and put further upward pressure on prices. This is the so-called ‘death spiral’ that has received considerable attention over the past several years.

14 Figures are for the Medium case in NEFR_2014_NEM_forecasts templates values.xlxs, available at http://www.aemo.com.au/Electricity/Planning/Forecasting/National-Electricity-Forecasting-Report

15 Even where maximum demand at a state level is falling (and that is not the case in all of the NEM jurisdictions) growth patterns are not evenly spread. Some areas (for example, areas where new housing estates are built) will experience growth even while total peak demand falls. This local growth will in many cases require capital investment by network businesses.

However, customers with rooftop PV systems that remain connected to the grid – as is discussed below – continue to derive material benefits from that connection, but pay significantly less than similar customers without rooftop PV systems. This suggests that the current pricing of grid services is likely to be providing a relatively poor signal to customers regarding both:

- the factors that drive the cost of grid services, and
- the value a connection to the grid provides.

2.2. Objective of this report

This report describes the set of grid services delivered by typical electricity distribution networks, and provides an initial empirical estimate of the value that:

- the grid provides to users of rooftop solar PV systems, and
- a rooftop solar PV system provides to the grid.

The hope is that this discussion will aid in understanding these values and the implication of the deployment of rooftop PV systems for the costs and revenues of the grid and the prices that will need to be charged to recover these costs. It may also contribute to the current consideration of how network pricing arrangements could be refined to better reflect these values and thereby enhance equity in network pricing and furtherance of the National Electricity Objective, which is to promote efficient investment in, and efficient operation and use of, electricity services for the long-term interests of consumers.

3. Services the grid provides

The grid provides several services to customers using rooftop PV systems, including:

- **Continuous supply** – Customers receive a continuous supply of electricity, made up of their own generation and the grid as a back-up whenever their own generation cannot provide all the electricity they need.
- **Market access** - Customers can sell the excess power generated by the PV system to retailers at the feed-in tariff rate.
- **Start-up power, power balancing and power quality** – the grid provides a number of virtually invisible services to customers. These include:
  - The ability to provide large increases in the amount of electricity delivered over very short time periods. This is important because some consumer appliances – such as air conditioners – can require significantly more power to start up than they do once they are running.
  - A steady and even supply of electricity which is required for appliances to operate properly and which could be difficult for a rooftop PV system to provide on its own because its output can drop quickly (even though only temporarily) due to passing clouds.
  - A high level of power quality, which is important for certain home appliances, such as desktop computers.

Each of these areas of value is discussed in further detail below.

3.1. Access to a continuous supply of electricity

To date, almost all of the rooftop PV systems that have been installed have been relatively simple, consisting of the PV panels which convert sunlight to direct current electricity, and an inverter that converts direct current electricity to the alternating current used by household appliances. Most consumers that have installed these systems have done so to reduce their electricity bills, to insulate themselves from future electricity price increases, and/or to reduce greenhouse gas emissions.

Very few of the rooftop PV systems that have been installed to date have included any means for storing electricity that is generated in excess of the instantaneous needs of the customer. Rather, the owners of these systems continue to rely on the grid to provide the electricity they need at night, during the periods of the day when sun angles are low (typically early morning and very late in the afternoon), and during cloudy or overcast periods when the output of the PV system is well below its rated output. These customers also rely more heavily on grid-supplied electricity in the winter, when the days are shorter and therefore less electricity can be generated by the rooftop PV system than is the case in the summer.

The grid also provides a back-up source for meeting the customer's full electricity requirements in the event that the rooftop PV system is not operating due to breakdown or the need for maintenance.

The use of the grid as a supplementary and emergency source of electricity is of significant value to the customer with a rooftop PV system. In the absence of these grid services the customer would have to either invest in a significantly larger and more complex electricity source – potentially a larger PV system coupled with battery storage and possibly an on-site fossil-fuelled emergency generator – or be willing to endure a certain number of hours every day without electricity.

3.2. Market access: the ability to sell excess power generated by the PV system

The grid also provides the customer with a rooftop PV system with the ability to sell any electricity generated by the system that is not needed to meet the customer's own needs. In the absence of the grid connection, the opportunity cost to the customer would be to either:

- let the excess energy 'go to waste', or
- purchase battery storage, so that the excess energy could be used at another time of the day when the production of energy from the PV system is not sufficient to meet the customer's internal requirements.

The former sacrifices value, while the latter requires additional capital expenditure by the customer[16]. In either case, the customer would still be likely to experience regular interruptions to their electricity supply[17].

16 Without the grid connection the customer might also decide to purchase a smaller PV system, which would reduce the upfront capital cost of the system, but also reduce the electricity bill savings the customer would experience.

17 This would be case unless the customer installed a system that could meet all their electricity needs. This type of system is discussed in section 4.1.2.

3.3. Start-up power and power quality

The output of the rooftop PV system can vary – not only over the course of the day but over very short time periods due to passing clouds. Virtually all electrical equipment used in homes is designed to operate on relatively constant sources of electricity supply. A grid connection compensates for the inevitable variations in the output of the PV system, resulting in the consistent frequency and voltage that the customer's end-use equipment is designed to run on, and avoiding the voltage fluctuations and harmonic distortion[18] that can damage some end-use equipment, such as computers.

An important related service is the fact that the grid connection can provide high amounts of power transfer on an instantaneous basis. This is critical for certain types of equipment – including air conditioners – which require a high amount of 'in-rush' energy when starting. Without a grid connection, care would need to be taken to ensure that the PV system was large enough to provide the in-rush energy required by the home's air conditioner. PV systems of the average size currently being installed would be quite limited in the size of the air conditioner they would be able to start on their own. As a result, in the absence of a grid connection, customers seeking to use solar PV systems would likely have to either (a) use air conditioning equipment with a lower capacity rating (i.e., less cooling capability), or (b) install a larger PV system or battery storage to provide the needed start-up power for a larger air conditioner.

4. Value of a grid connection to a distributed generation customer

The three services discussed above are delivered[19] to all customers with a grid connection – including customers with a rooftop PV system – but they are not explicitly and separately priced. Rather, the cost of providing these services is recovered through network charges – which for small customers is primarily done through a charge for each unit of electricity consumed. Customers with rooftop PV systems pay less than similar customers without such systems (because they consume less electricity), but receive the same level of service in the three areas discussed above.

This section of the report provides an indicative quantification of the value that the user of a rooftop PV system that is connected to the grid derives from that connection, in terms of the three services discussed above.

A typical home in the Endeavour Energy distribution network area[20] is used as the case study. The Endeavour Energy service area provides a reasonable choice as an illustrative case study in that it:

18 Harmonics also cause heating in some equipment such as appliances, motors and air conditioners, which can reduce their useful life. An alternative to relying on a grid connection for this service is to purchase – at a not insignificant cost - power conditioning equipment to correct for harmonic distortion and ensure suitable power quality is maintained.

19 While market access is available to all customers, it is only delivered to customers that export electricity. The other services -- continuous supply, and start-up power and power quality – are delivered without the customer explicitly requesting them.

20 Endeavour Energy serves an area primarily to the west and south of Sydney including Sydney's Greater West, the Southern Highlands and the Illawarra, and which includes some of the fastest growing areas in Australia.

- serves a largely metropolitan/suburban area that is reasonably representative of the building stock on which rooftop PV systems are being deployed throughout Australia, and also includes significant greenfield development;
- has a solar resource which is better than that available in Victoria, but not as good as in Queensland[21];
- has residential customers that, on average, use more electricity than their counterparts in Victoria, but a similar amount to those in South Australia and less than those in Queensland;
- has residential retail electricity prices and feed-in tariff levels that are representative of the prices for those commodities across Australia; and
- has a peak demand that occurs at a time that is roughly similar to that of other distribution service areas and a cost for adding grid capacity that is broadly representative of most other distribution areas.

4.1. The value of the continuous supply provided by a grid connection

As noted above, the overwhelming majority of the rooftop PV systems installed to date have been put on homes that continue to be connected to the grid. This type of PV system reduces the amount of grid-provided electricity used by the household, while the grid connection itself provides the household with a way to continue to consume as much electricity as it wants at night and on cloudy days when the output of the PV system is reduced, and in the event that the PV system breaks down or requires maintenance.

Two different approaches can be used to estimate the value the grid connection provides in terms of reliability of supply:

- **The value of unserved energy:** This approach calculates the value of the electricity that the customer using a rooftop PV system would ***not*** receive in the event that they did not also have a connection to the grid.
- **The cost of a standalone power system that delivers an equivalent service to that provided by the grid:** This approach is based on the cost the customer would need to incur to purchase and operate a small-scale distributed generation system that would provide an equivalent level of service as that provided by the grid, but without a grid connection.

The two approaches constitute different ways to reflect the opportunity cost of grid services to a customer with a rooftop PV system who is not connected to the grid. The value of unserved energy provides a measure of the inconvenience and loss of amenity that the consumer would need to accept if they only used the type of rooftop PV system that has been installed to date without a connection to the grid. The cost of a standalone power system, by contrast, constitutes the actual amount the consumer would need to spend (or finance) on a distributed generation system in order to enjoy a level of service equivalent to that provided by the grid. In theory, the value to the customer of the continuous supply of electricity provided by the grid connection should be equal to at least the lower of these two costs.

21 The amount and intensity of solar radiation varies from place to place and is a primary determinant of how much electricity a PV panel will produce, and therefore the amount by which the customer's electricity consumption from the grid will reduce and how much electricity the customer will be able to sell back to the grid.

4.1.1. The value of energy that the customer would not receive without the grid connection

The methodology used to calculate the value of unserved electricity, if a customer were to disconnect from the grid and rely solely on a rooftop PV system similar to the majority of the systems installed to date, used the cost of that electricity as a proxy for its value to the customer. This represents the lower bound of the value of that electricity given the fact that most customers choose to remain connected to the grid and pay those costs rather than shut off all their appliances and equipment. In actual fact, the value of the use of that electricity to the customer may be significantly higher than its cost[22].

The methodology involved the following steps:

1. estimate the amount of electricity consumed by an average residential customer in the Endeavour Energy service area in each half-hour period, in each season,
2. deduct from this average half-hourly consumption, the estimated amount of electricity that would be produced by a typical rooftop PV system and used to displace grid-supplied electricity in each half-hour period, of each season[23], and
3. multiply the remainder – which is the amount of electricity that a typical residential customer with rooftop PV system would go without if they did not have a connection to the grid – by the marginal retail electricity price[24].

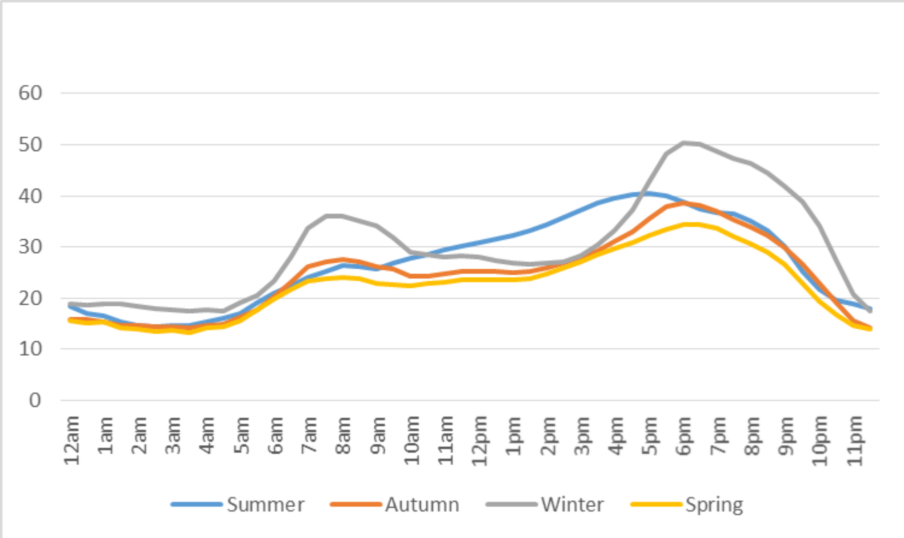
22 A number of studies have been undertaken that illustrate this, including one undertaken in NSW in 2012, available at http://www.aemc.gov.au/Markets-Reviews-Advice/Review-of-distribution-reliability-outcomes-and-st/Final/AEMC-Documents/Fact-sheet-NSW-customer-survey. AEMO is currently conducting an update of that assessment using a more sophisticated survey technique.

23 This step also produces a half-hourly estimate of the amount of electricity that would be produced in excess of the needs of the average residential customer and that would be sold back through the grid. This is discussed in Section 4.2 below.

24 The marginal retail price has been used as a proxy for the value that a customer derives from the consumption of energy services. In theory, this is likely to underestimate the value that a customer derives, as it focuses on the marginal price the customer would pay for that energy, as opposed to the actual value that they derive from the consumption of that unit of energy.

The specific data that was used in the calculation is shown in Figure 5 and Figure 6. Figure 5 shows an estimate of the total amount of electricity consumed in each of the various half hours of the day over the course of each of the four seasons for a typical residential electricity customer served by Endeavour Energy[25]. Figure 6 shows the amount of electricity produced each half hour in each season by an average-sized rooftop PV system installed in the Endeavour Energy area[26].

Figure 5: Estimated half-hourly seasonal consumption of the average residential customer (Endeavour Energy 2013)[27]



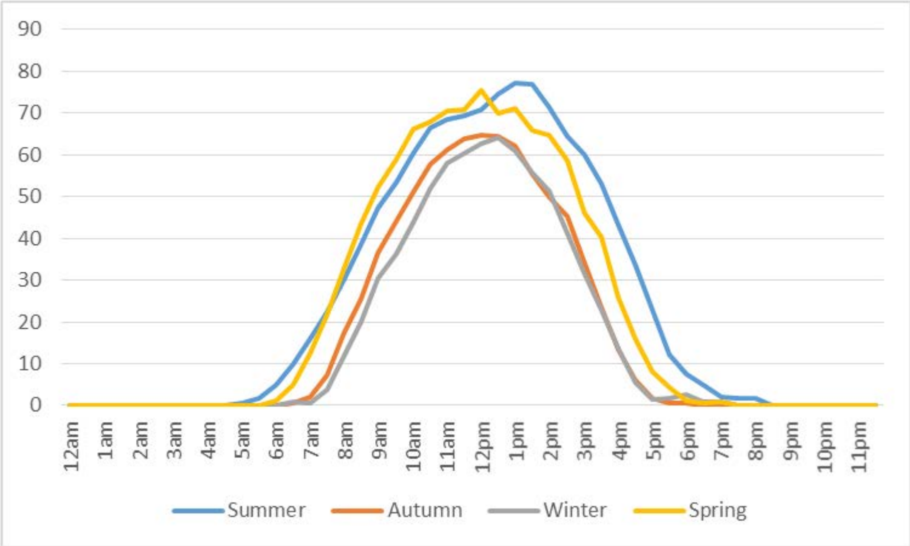
Source: AEMO

25 The estimate of the amount of energy consumed by a customer in each half-hour period of each season was based on Endeavour Energy's 2013 net system load profile. The net system load profile (NSLP) is the total generation system profile within a specific distribution area minus all interval metered loads, controlled loads (such as off-peak water heating) and deemed loads (such as street lighting). The NSLP, therefore, essentially represents the aggregate load profile of all small, non-interval metered customers. Most of these are residential customers, but a sizeable proportion of the consumption within the NSLP will be small commercial customers. Their load is generally flatter and more business-hour oriented than the residential profile, which is likely to result in the NSLP being less 'peaky' than the residential load profile.

26 The estimate of the amount of electricity produced by an average-sized rooftop PV system, by season, in Endeavour Energy's area, was based on information on the electricity generation of rooftop solar PV systems in NSW obtained from the Australian Photovoltaic Institute (www.apvi.org.au).

27 All times are Australian Eastern Standard Time (AEST).

Figure 6: Seasonal half-hourly PV output in kW (Australian Eastern Standard Time) - NSW[28]



Source: Australian Photovoltaic Institute (www.apvi.org.au)

The analysis determined that:

- A typical rooftop PV system in the Endeavour Energy area will produce 3,742 kWh under average weather conditions.
- Of that, 2,044 kWh (about 55% of the total output) would be used directly by the household, with the other 45% (about 1,698 kWh) being exported back to the grid.
- As a result, about 2,956 kWh of the total 5,000 kWh consumed annually by the average residential customer in the Endeavour Energy area would still need to be supplied by the grid.
- Based on Origin Energy's regulated inclining block tariff (IBT) in the Endeavour Energy service area, the cost of the electricity ***not*** delivered by the rooftop PV system would be $729[29].

As noted above, this is simply the retail cost of the electricity that would need to be purchased. The ***value*** of that electricity – the amount the customer might be willing to pay, for example, to be able to have electricity at night – might be materially higher than its cost.

28 Note that the Summer profile in this graph has been adjusted to AEST. This follows practice in the NEM to use AEST all year long. No adjustment of the Winter profile is required as all of the winter season occurs during Eastern Standard Time. Both Autumn and Spring include periods in AEST and Australian Eastern Daylight Time (AEDT), and it was not possible in this project to adjust these profiles fully to AEST. This will not materially impact upon the results, as these periods do not coincide with periods when system peak demands occur, and it will only have a relatively minor impact on the amount of energy that is calculated as being 'unserved'.

29 Note that this is based on the cost of that energy at the per-kWh price charged in the regulated retail tariff. It does not include the fixed charge.

It is also worth noting that the total annual bill of an average residential customer without a rooftop PV system on Origin Energy's regulated IBT tariff would be $1,488. By contrast, the total annual bill of an average residential customer with an average-sized rooftop PV system on Origin Energy's regulated IBT tariff[30] would be $984, but the customer would also receive a feed-in credit of $93, resulting in a total annual saving of $607 for the customer with the PV system[31].

Further detail on the approach and data sources used in these calculations is presented in Appendix A.

4.1.2. Cost of a standalone power system (SAPS)

Another way of estimating the value of the continuous supply of electricity provided by the grid connection is to quantify the cost of providing a typical customer with an electricity service that is essentially equivalent to that provided by the grid through some other means.

Standalone power systems (SAPS) have been used for decades by homes located in remote areas, where it is extremely expensive to connect to the grid due to the length of new distribution line required. The cost of these standalone systems is decreasing as the cost of PV systems and battery storage systems decrease, and there is significant interest and debate regarding when such systems can be expected to be cost-competitive with a connection to the grid and mains power[32].

As part of this study two NSW SAPS design and installation professionals accredited by the Clean Energy Council in NSW were asked to specify and price a SAPS. The SAPS was to be designed to meet the electricity requirements of a typical 3 to 4 bedroom home in the western Sydney suburbs inhabited by a family of two adults and two school-age children that uses 5,000 kWh per year and has electric heat and air conditioning, but uses gas for water heating and cooking[33].

The system that was designed in response included the following primary components:

- 16 x 250 watt PV panels (total panel capacity of 4 kW)
- 5 kW constant inverter (with15 kW surge capacity)
- 24 x 1,402 amp batteries
- 1 x 9kVa petrol generator.

30 Retail electricity prices were deregulated in NSW as of 1 July 2014. The regulated retail tariff that pertained in the Endeavour Energy service area in 2013-14 was used in this analysis as it provides a reasonable basis from which to assess the difference in the amount a typical residential customer would pay with and without a rooftop PV system.

31 All figures exclusive of GST.

32 For example, a study entitled *What Happens When We Unplug?* that was prepared for the Consumer Advocacy Panel in February 2014 by Energy for the People, an energy services company, and the not-for-profit Alternative Technology Association, found that regional towns and new housing estates in Victoria could function viably without connecting to centralised electricity and, in some scenarios, centralised gas grids by 2020. The major components of the standalone system analysed in the study for use on a single home basis (the report also considers standalone systems for 500-home developments) were PV panels, a battery storage system, and a petrol-fired generator for use during periods of exceptionally long cloudy periods and in case of the need for repairs of the PV and/or battery storage systems.

33 In fact, a well-designed SAPS will often provide better power quality than the grid because the electricity it supplies cannot be affected by harmonics introduced by other customers.

The cost of a SAPS like this – inclusive of GST and after the value of the Small-scale Technology Certificates (STCs)[34] that such a system is eligible for under the Small-scale Renewable Energy Scheme (SRES) – would be in the order of $56,500, depending on the particular components selected[35].

Use of such a system, as analysed above, could be expected to save the typical residential electricity customer $1,488 annually at current retail electricity prices. It is important to note, however, that such a system would:

- incur some operating costs – for example, diesel for the generator and annual system maintenance – which would be likely to run to somewhere between $500 and $1,000 per year[36], and
- require replacement of parts from time to time – while the PV panels are expected to have a useful life of 15 to 18 years, the diesel generator is likely to require replacement in about 8 years, the inverter in about 10 years, and the batteries in anywhere from 5 to 12 years depending on their usage and how low a residual capacity is acceptable.

The monthly cost of such a system can be compared to the monthly cost that a customer without a rooftop PV system pays:

- The total annual retail bill for such a customer in the western Sydney suburbs will be approximately $1,488 per year of which approximately $677 would be for network services (comprised of $131 in fixed charges and $546 in volume-based charges). On a monthly basis this would come to about $124[37],

34 The SRES is part of the Renewable Energy Target (RET). STCs were put in place to encourage the use of small-scale renewable energy technologies as a means for reducing greenhouse gas emissions. Under the RET electricity retailers are required to surrender a specified number of credits associated with the deployment of a small-scale renewable energy technology, or pay a penalty price for any credits not surrendered. This creates a price that provides some value for the environmental externality created by one tonne of greenhouse gas emissions. The costs of purchasing the credits is borne in the first instance by electricity retailers, and it is assumed that they will seek to recover those costs in the prices they charge electricity consumers. The STCs do not affect network businesses' costs or revenues (except to the extent that the inclusion of those costs in the overall price charged to customers has a price elasticity effect on total consumption and therefore network businesses' revenues).

The Commonwealth Government's recently completed RET Review has recommended two options regarding the SRES: either closing the scheme entirely or accelerating its closure to 2020. The price of STCs (and therefore their impact on the final price of rooftop PV systems) will also be affected by the Government's decision on the LRET.

35 These costs are similar to those reported by a homeowner in Little River, Victoria. See http://reneweconomy.com.au/2014/how-to-live-off-the-grid-even-near-sunny-melbourne-81801. That system was purchased in 2012 for a total cost of $60,090, including around $7500 in government rebates, and was somewhat larger than the system above (5.5 kW of PV panel and 7 kW inverter), but did not include a generator.

36 Estimate provided by one of the NSW SAPS design and installation professionals that was consulted.

37 This is calculated based on the 2013-14 regulated retail tariff for the Endeavour Energy service area.

- The monthly cost of the standalone system can be estimated by dividing the total initial cost by the number of years of useful life the system can be expected to provide and then dividing that by twelve to get an average monthly cost. Using an estimated cost of the standalone system of $56,500 this comes to about $430 per month[38] – significantly more than the cost the average customer pays for electricity delivered through the grid[39]. In most cases, the purchase of such a system would be financed rather than paid for outright. Assuming the SAPS was financed at 5% as part of a mortgage, the additional monthly cost for the loan would $166, making the monthly repayment amount $596.

It should be noted this SAPS would be able to support only a very moderate level of air-conditioning – probably no more than a single, relatively small split system. A SAPS capable of running two or three split systems – enough to cool the lounge room, master bedroom and possibly one other bedroom or study – would cost about $72,500 inclusive of GST and after all applicable renewable energy credits are taken into account. The monthly cost of such a system would be about $550, excluding the costs of finance. If financed at the cost of a home mortgage, the additional cost would be $299 per month, making the total monthly repayment amount about $850.

Appendix B contains further information on the specific components and costs included in the SAPS systems used in these examples.

4.2. The value of market access provided by a grid connection

As noted above, a grid connection also provides the customer with the ability to sell any electricity generated by the rooftop solar PV system that is in excess of the instantaneous needs of the household. Without a grid connection (or installed storage capacity) that electricity would go unused and provide no value to the customer.

The half-hourly seasonal analysis described in Section 4.1.1 above and detailed in Appendix A also allowed quantification of the amount of electricity that the average-sized rooftop PV system would produce in excess of the needs of an average residential household. This amount was 1,698 kWh, or 45% of the overall amount of electricity generated by an average rooftop PV cell.

That amount was then multiplied by Origin Energy's feed-in tariff ($0.0545/kWh)[40].

This process determined the value provided annually by the grid in allowing the average residential customer with an average-sized rooftop PV system to sell their excess PV generation is $93.

Further detail regarding the approach and data used is presented in Appendix C.

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38 This calculation is based on a weighted average cost of the SAPS and a useful life of 11 year of the system components, based on information on typical component costs and lifetimes. See Section 4.1.2 and Appendix B for more information. The calculation of monthly costs is somewhat conservative in that it does not include any costs for fuel for the back-up generator or for maintenance.

39 It should be noted, however, that to date SAPS have generally only been installed in residences that are not close to existing electricity lines, and where the cost of connection is therefore very high.

40 Feed-in tariffs in NSW under the state's Solar Bonus Scheme (SBS) used to be significantly higher, ranging from $0.20 per kWh for exported electricity to $0.60 per kWh for every kWh generated by the PV system (even the kWh used in the home). While many PV users are still receiving these payments, the SBS is no longer available to new PV installations. For customers who installed PV systems under the SBS, the value provided by their connection to the grid in terms of the money they would receive for the sale of their PV electricity would range from 4 times to 24 times higher than that available under the Origin Energy feed-in tariff.

4.3. The value of start-up power and power quality provided by a grid connection

As noted above, a grid connection provides value to customers with rooftop PV systems in terms of:

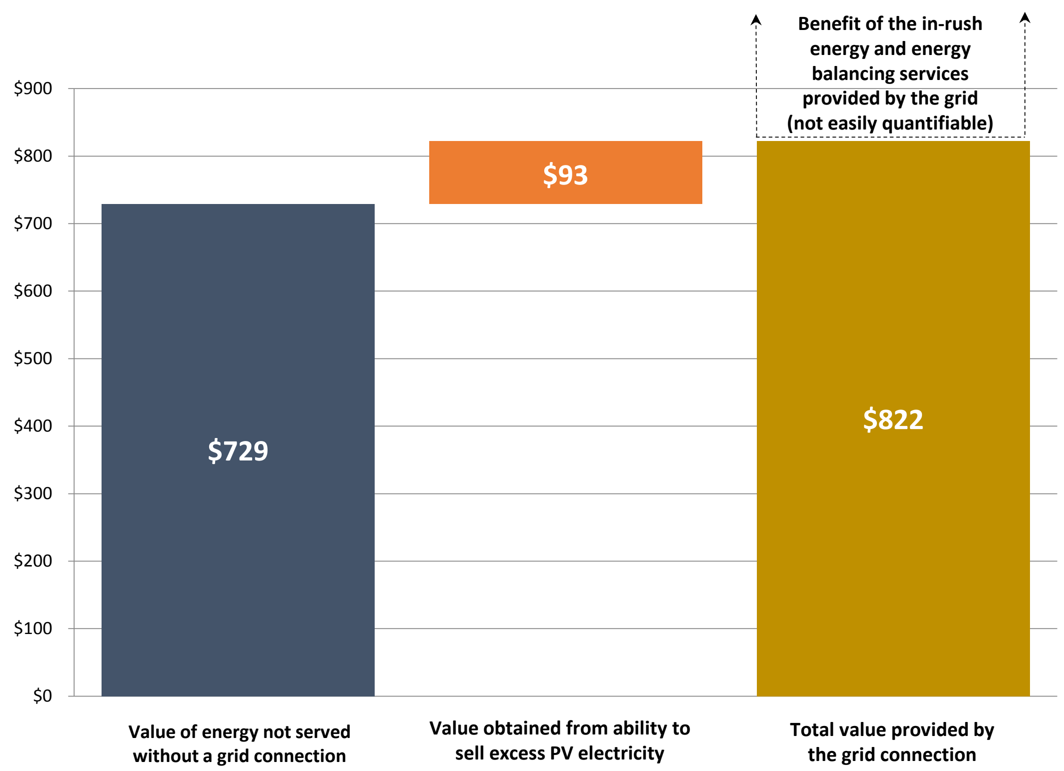
- the instantaneous balancing of supply and demand, including the ability to provide the high levels of in-rush energy required by some end-use equipment, and
- frequency, voltage and harmonic distortion control, which can protect end-use equipment from damage.

The value of these services is not easily quantified as it will vary significantly based on the types, sizes and technical specifications of the customer's end-use equipment; how the customer uses that equipment; and the relationship of the output capacity of the customer's PV system to the power requirements of the end-use equipment. However, while the value of the services is difficult to quantify, it is certainly not zero, and could be material for a significant proportion of the customers currently using rooftop PV systems.

4.4. Summary of the value provided by a grid connection to a customer with a roof-top PV system

Figure 7 below summarises the value provided by a grid connection to a customer with a rooftop PV system in Endeavour Energy's service area.

Figure 7: Annual value of a grid connection to a residential customer in the Endeavour Energy service area with a rooftop PV system



Source: OGW analysis

As can be seen, the total benefit provided by the grid connection comes to about $822, and does not include either:

- the value of the in-rush energy capability provided by the grid or the grid's ability to instantly top up the supply needed by the customer in the event that even very short reductions in the PV output occur due to short cloudy periods, or
- the fact that the value to the customer to have electricity at night might be higher than just the cost of purchasing that electricity.

It is also the case that a residential customer in Endeavour Energy's service area that uses a typical rooftop PV system pays only $453 (comprised of $131 in fixed charges and $322[41] in volume-based charges) in his or her annual bill to the network to get these services[42].

5. The value and other impacts rooftop PV has on the grid

The previous section considered the value that a grid connection provides to customers with rooftop PV systems. However, the grid is also impacted by rooftop PV systems. The two most important of these impacts are that:

- Rooftop PV systems can reduce peak demand on the grid, which can delay and/or reduce the need for capital expenditure by the grid and therefore exert *downward* pressure on grid costs and the network prices that need to be charged to customers in order to recover those costs.
- Rooftop PV systems reduce electricity consumption supplied by the grid. Given that network revenue is primarily recovered through charges on consumption, this puts *upward* pressure on the per kilowatt hour (kWh) price the grid charges its customers.

Where the fall in revenue recovered from customers with rooftop PV systems is greater than the reduction in future capital costs, rooftop PV system will have a net upward pressure on network prices. To the extent that this upward pressure results in a higher price for each kWh of electricity consumed, the annual bill of an average residential customer without a rooftop PV system will go up more than the bill of an average customer with a rooftop PV system, simply because the latter will consume about 2,044 kWh less electricity over the course of a year than the former. As a result, the customer without a rooftop PV system will pay more of those additional costs than the customer with the rooftop PV system. That additional amount constitutes a cross-subsidy from all non-PV customers to each customer with a rooftop PV system[43].

Analysis of these impacts indicates that use of a rooftop PV system will:

- reduce the network component of the bill of the average residential electricity customer in the Endeavour Energy distribution system that uses a typical rooftop PV system by approximately $223 per year;
- reduce the annual capital expenditure requirements of the distribution network by approximately $109, and those of the transmission network by approximately $16, per year; and

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41 This is based on the PV customer's electricity consumption from the grid multiplied by Endeavour Energy's first tier kWh price on its N70 tariff.

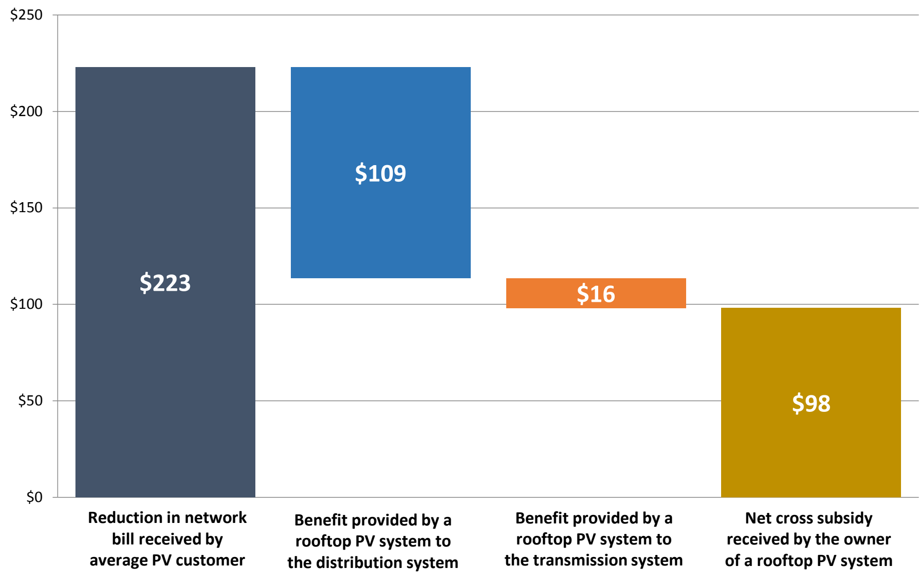
42 By contrast, the network portion of the annual electricity bill of an average residential customer in Endeavour Energy's area is about $677.

43 This additional amount can be calculated by multiplying the amount by which the revenue reduction exceeds the cost reduction by the difference in consumption between the rooftop PV user and the customer that does not use a rooftop PV system.

- thereby result in an annual cross-subsidy from those residential electricity customers without rooftop PV systems to each customer with a rooftop PV system of $98.

These costs and their relationship are shown in Figure 8 below. Appendix D provides further detail on the calculations used in this analysis.

Figure 8: Annual impacts of a rooftop PV system on the Endeavour Energy network and other customers



Source: OGW analysis

It should be noted, that a number of averaging assumptions have been made in deriving these estimates. Most important is the assumption that Endeavour Energy's capital expenditure program is driven by peak demand at 4:30 PM AEST[44]. In actuality, the timing of Endeavour Energy's peak demand will vary spatially, depending on the types of customers connected to the grid in particular geographic regions. For example, in areas which are predominately residential, distribution networks tend to peak in the early evening (e.g., 5.30 PM to 6:00 PM AEST). If Endeavour Energy's capital expenditure program is predominately driven by expenditure in areas dominated by residential loads, the benefit to the network of rooftop PV systems would be less than discussed above because the amount of energy being produced by a PV system drops significantly between late afternoon and early evening, resulting in a reduced impact on peak demand and a larger cross-subsidy from customers without PV systems to customers with them.

44 According to AEMO's 2014 NEFR, peak demand in NSW can be expected to occur at 5:00 PM in a 50% POE year (i.e., a year with average temperature conditions) and at 4:00 PM in a 10% POE year (i.e., a year with much hotter than normal temperatures). The use of 4:30 PM in this analysis as the time of peak demand provides a realistic but slightly optimistic assessment of the value of rooftop PV. It also makes the resulting estimate of the cross subsidy slightly conservative.

To illustrate this and to demonstrate the sensitivity of these financial outcomes to the timing of network system peak demand, the calculations above were re-done under the assumption that it is the demand at 5:30 PM AEST (instead of 4:30 PM) that drives Endeavour Energy's requirements to increase capacity. This single change in assumptions results in an increase in the cross-subsidy by more than 50% -- from the $98 reported above to $163 per annum. This is simply because the benefits accruing to the network business are smaller, because the PV system produces much less energy at 5:30 PM than it does at 4:30 PM[45]. However, because the PV system generates the same amount of electricity regardless of when peak demand occurs, and because customers are charged based on their total consumption and not when that consumption occurs, the fall in the revenue from customers with rooftop PV systems that needs to be recovered through higher charges remains the same regardless of when peak demand occurs[46].

In this regard it should be noted that, according to AEMO's *2014 National Electricity Forecasting Report*, the time of peak demand is tending to occur later in the day in many distribution areas, and this will be especially true where there has already been a significant level of penetration of rooftop PV systems.

45 If the time of peak demand were earlier, the impact of the PV system would produce more energy and its impact on peak demand would be greater and the cross-subsidy smaller. There are other factors that also affect these outcomes. In addition to the impact of reduced (or increased) impact of the PV system on network peak demand described above, the cost of augmentation is also important. Where augmentation costs are lower, the cross-subsidy will be higher – because the reduction in peak demand has a lower benefit. It must also be remembered that augmentation of the network is undertaken at the local area level. The time of peak demand may vary across these local areas, as will the cost of the augmentations required. The examples above have used average figures for simplicity.

46 An additional complicating factor is that there may already be sufficient capacity in the network. In such a case, the network will not experience an actual reduction in capital expenditure in that year. More generally, therefore, the actual value of the cross subsidy will change over time as the balance of the supply and demand of network capacity in the local area changes over time.

Appendix A: Estimating the electricity production of an average-sized rooftop PV system

The approach and data sources used in estimating the amount and value of the electricity required from the grid by a customer with a typical rooftop PV system in the Endeavour Energy distribution area is documented below.

Step 1: Quantify the load in each half-hour block by season:

1.1 Download the latest (2013) net system load profile (NSLP) from AEMO website.

1.2 Calculate the proportion of Endeavour Energy's overall NSLP that lies in each half-hour interval.

1.3 Aggregate those percentages by season, and by each of the 48 half-hour periods of the day.

1.4 Multiply those aggregated percentages (by season/half-hour period) by 5000kWh (the assumed average consumption of a residential customer without electric hot water) to work out the average aggregate consumption in each half-hour block, in each season.

Step 2: Calculate solar production in each half-hour block by season

2.1 Average representative days for each season were identified for the period May 2013* through to 2014 (*this time period was driven by the availability of data on the 'APVI Solar Map' website - see next step). These representative days were based on whether or not that day had 'average' temperature and solar exposure (for the season in question). Data on temperature and solar exposure was derived from the BOM website, and based on a representative inner Sydney weather station (NOTE: For a day to be considered representative of a season, it must reflect both average temperature *and* average solar exposure for that season).

2.2 We then extracted the estimated output of a PV cell in NSW as a percentage of its maximum capacity for each of those representative days from the APVI Solar Map website.

NOTE: Where multiple days met the 'representative day' criteria in any given season (temperature and solar exposure), we obtained data for all of those days, however, in our analysis, we used the maximum output in any given half-hour period from those representative days (so as to produce the most conservative estimate of the output of a PV cell in that season).

2.3 The capacity factor for each hour period across each of the four seasons (adjusted for the impact of daylight savings, in the case of the summer season) was then multiplied by the average solar panel size in NSW (2.6kW), which was derived from the CER website (up until May 2014 - based on postcodes starting with '2'), to estimate the amount of energy generated in each half-hour period in each season.

Step 3: Calculate the amount and value of the unserved energy

3.1 We then deducted the solar production in each half-hour block (by season) from the load in each half-hour block (by season) to determine the amount of unserved energy in each half-hour block (by season).

3.2 We then multiplied this unserved energy by Origin Energy's Regulated Retail Price - specifically, the first tier of its IBT tariff for residential customers in the Endeavour Energy area.

Appendix B: SAPS specification and costs

B.1 Specification

Item	Description
Location:	Western suburbs of Sydney
House size:	'Typical' 3-4 bedroom
Family:	2 adults, 2 school-age kids
Annual electricity consumption:	5,000 kWh
End uses:	Electricity used for heating and air conditioning, refrigeration, lighting and plug loads that would characterise a typical family. Gas used for water heating and cooking and remains so after SPS installation
Siting:	Assume adequate roof space and no or minimal shading
Assumed SAPS configuration:	• Rooftop solar PV system - to serve as the primary generation system • Battery storage - to provide for electricity needs in non-daylight hours and expectable periods of low solar output • Back-up petrol- or diesel-fired inverter generator - to augment PV output during extended periods of low solar output and to substitute for it when the PV system is unavailable due to breakdown or scheduled maintenance • The components and quality of the components of the system should be selected to provide a level of service that is essentially equivalent to that provided by a grid connection.

B.2 SAPS system components and costs – 4 kW (constrained A/C) system

Quantity	Size	Cost
16	250 watt solar Panels	$4,800.00
24	1402 amps@ C100 [67.296kWhr storage	$23,520.00
1	5kW Constant, 15kW surge load sharing inverter/charger with data logging & Auto Generator start	$6,985.00
2	Midnite 80Amp MPPT Regulators	$2,100.00
4	Tilt on Roof Mounting Frames	$800.00
1	AC/DC control board pre wired	$1,500.00
1	9kVa 300RPM Petrol Generator with 2 wire auto start	$8,000.00
	Installation - Approximate Only	$6,500.00
	TOTAL (exclusive of GST)	$54,205.00
	GST	$5,420.50
	TOTAL (inclusive of GST)	$59,625.50
	STCs	$2,870.00[47]
	TOTAL after application of STCs	$56,825.50
2	Battery Box (optional)	$2,700.00

47 Based on 82 STCs in postcode zone 3 for Blacktown (from REC Registry STC calculator) and 14 November STC price of $35 from Greenbank Environmental.

B.3 SAPS system components and costs – 6 kW (moderate A/C capability) system

Quantity	Size		Cost
24	250 watt solar Panels		$7,200.00
24	2000 amps@ C100 [96kWhr storage		$33,552.00
1	7.5kW Constant, 21kW surge load sharing inverter/charger with data logging & Auto Generator start		$8,810.00
2	Midnite 80Amp MPPT Regulators		$2,100.00
5	Tilt on Roof Mounting Frames		$1,000.00
1	AC/DC control board pre wired		$1,500.00
1	12kVa 300RPM Petrol Generator with 2 wire auto start		$8,400.00
	Installation - Approximate Only		$7,200.00
		TOTAL (exclusive of GST)	$69,762.00
		GST	$6,976.20
		TOTAL (inclusive of GST)	$76,738.20
		STCs	4,340.00[48]
2		TOTAL after application of STCs	$72,398.20
24	Battery Box (optional)		$3,500.00

48 Based on 124 STCs in postcode zone 3 for Blacktown (from REC Registry STC calculator) and 14 November STC price of $35 from Greenbank Environmental.

Appendix C: Calculating the annual value the customer gets from being able to sell excess PV electricity generation

The approach and data sources used in estimating the amount and value of the electricity sold back to the grid by a customer with a typical rooftop PV system in the Endeavour Energy distribution area is documented below.

Step 1: Identify the price paid for electricity fed back into the grid

In relation to the case study presented here we used Origin Energy's feed-in tariff of $0.0545 /kWh, exclusive of GST, which applies to net metered solar installations.

Step 2: Estimate the amount of electricity to be fed back into the grid

In the case study example we estimated the amount of electricity to be exported to the grid annually by the average sized rooftop PV system to be 1,698 kWh. Multiplying that amount of electricity by the feed-in tariff price mentioned above (exclusive of GST) results in an annual value to the consumer of $93.

Appendix D: Methodology used to estimate the impact of rooftop PV on network costs and revenues and potential cross-subsidies

Step 1: Determine the average reduction in a solar customer's network bill, by multiplying:

1.1 the first tier of Endeavour Energy's residential increasing block NUoS tariff (N70), by

1.2 the average reduction in a customer's energy consumption stemming from them installing solar (2044kWh)

Step 2: Estimate the value that network businesses (distribution and transmission separately) receive from having a solar panel connected to a distribution network.

This is a function of the amount of energy that that solar panel produces at times when their network is expected to reach peak demand levels (which in turn drives their future augmentation program). This was estimated by:

2.1 extracting information from the APVI Solar Map website regarding the average production of a solar panel in NSW (with production being the percentage of its maximum capacity at each half-hourly interval) on peak days (being 3 days in December, 2013 - all of which were highlighted by the website as being peak days), and adjusting this to account for daylight savings.

2.2 extracting information from Endeavour Energy's Annual Pricing Proposal regarding its LRMC for LV connected customers, and converting this to a GST-exclusive amount.

2.3 averaging TransGrid's location based monthly demand tariffs for the Endeavour Energy region (from TransGrid's Transmission Price List for 1 July 2014 to 30 June 2015)

Step 3: Identify the impact on peak demand

The maximum capacity factor at the time of system peak at 4.30PM Eastern Standard Time (28.94%) from those 3 days (with 4.30pm Eastern Standard Time chosen as it is the time at which Endeavour Energy's NSLP records its maximum half-hourly demand), and multiplying this by the average size of a solar PV system in postcodes starting with a '2' (from the CER website, and based on information up until May 2014), by the values obtained in items (2.2) and (2.3) above.