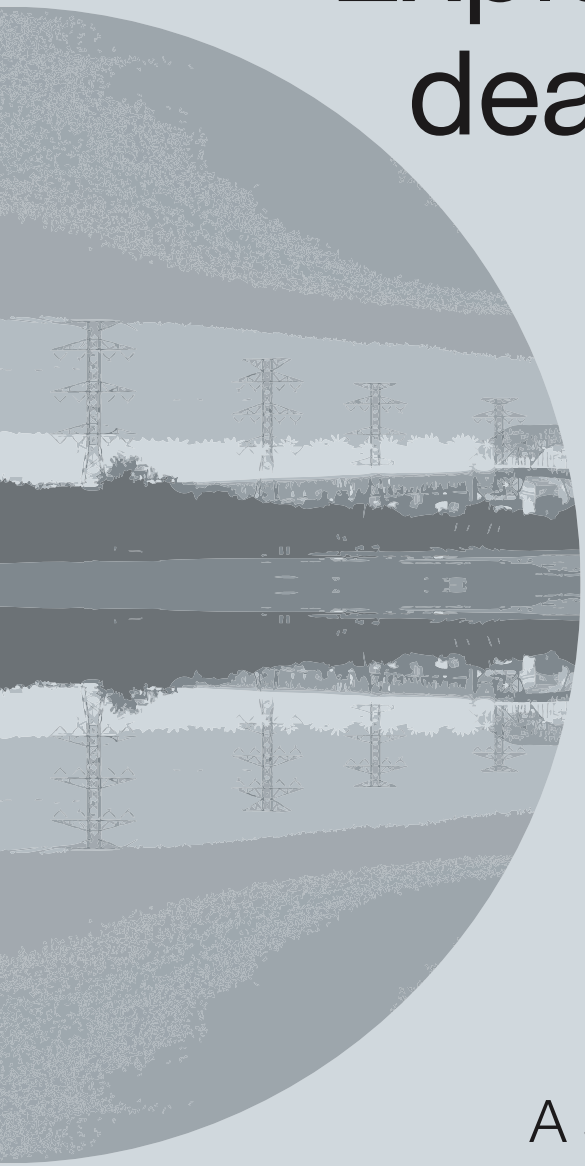
# Exploring the death spiral



**AUDRC** Laboratory[1414]

## A system dynamics model of the South West Interconnected System

William Grace

# Exploring the death spiral

**AUDRC** Laboratory **1414**

Australian Ubrna Design reseatch Centre **AUDRC**, October 2014

# Contents


/ Executive Summary

// Introduction

/// A Model of the SWIS

//// The Base Case

///// Case 1 – Expansion of Residential Solar & Storage

////// Case 2 – Growth of Commercial Solar & Storage

/////// Case 3 – Solar Growth Without Storage

//////// The Implications of the Model Results

/////////// Policy Response

Appendix A

Appendix B

# Figures


Figure 1 Causal loop diagram of model 11
Figure 2 and 3 - Solar PV Growth 13
Figure 4 - Solar Capacity 13
Figure 5 - Average hourly network loads (2025) 15
Figure 6 - Maximum hourly network loads (2025) 15
Figure 7 - Solar exports (March 2030) 15
Figure 8 - Duck Curve 16
Figure 9 and 10 - Energy Storage Growth 16
Figure 11 - Storage Capacity 18
Figure 12 - Maximum hourly network loads 18
Figure 13 - January day network loads (2034) 18
Figure 14 - IMO Solar penetration forecast 19
Figure 15 - Minimum hourly network loads 19
Figure 16 - Over-generation risk by 2025 19
Figure 17 - Over-generation risk by 2034 20
Figure 18 - Typical day over-generation 20
Figure 19 - Annual network energy 20
Figure 20 - Annual system costs 22
Figure 21 -System unit costs 22
Figure 22 - Private investment in solar / storage 22
Figure 23 - 20 year public and private expenditures on energy 23
Figure 24 - Greenhouse gas emissions 23
Figure 25 - The Death Spiral 27
Figure 26 - Gross State Product and Energy Intensity 30
Figure 27 - Recent Energy Demand 30
Figure 28 - Rooftop solar PV on the SWIS[8] 31
Figure 29 - Cost of solar PV in Australia ($/W) 31
Figure 30 - Projected Cost and Production - of Li-ion storage 31
Figure 31 - Causal loop diagram of model 33
Figure 32 - Electricity demand 36
Figure 33 - Impact of solar PV on network loads (1) 36
Figure 33 - Impact of solar PV on network loads (2) 37
Figure 34 - Uptake of solar PV 37
Figure 35 - Solar PV cost curve 37
Figure 36 - Solar and storage capacity 39
Figure 37- Optimum storage capacity 39
Figure 38 - Storage cost curve 45
Figure 39 - Base Case electrical energy demand scenarios 48
Figure 40 - Base Case A capacity scenario 48
Figure 41 Base Case B capacity scenario($/W) 48
Figure 42 - Base Case Network Peak Loads 49
Figure 43 - Maximum monthly spot price 49
Figure 44 - Average monthly spot price 49
Figure 45 - Base Case A system costs 51
Figure 46 - Base Case B system costs 51
Figure 47 - Base Case unit costs 51
Figure 48 - Case 1A Residential solar growth 54
Figure 49 - Case 1A Total residential solar capacity 54
Figure 50 - Case 1A Average hourly network loads (MW) 54
Figure 51 - Case 1A Maximum hourly network loads (MW)) 55
Figure 52 - Case 1A Monthly system costs 55
Figure 53 - Case 1A Annual network energy 55
Figure 54 - Case 1A System unit costs ($/MWh) 57
Figure 55 - Case 1B Residential storage growth 57
Figure 56 - Case 1B Residential storage capacity 57
Figure 57 - Case 1B Max hourly network loads (MW) 58
Figure 58 - Case 1B Annual system costs 58
Figure 59 - Case 1B System unit costs 58
Figure 60 - Case 2A Business solar growth 62
Figure 61 - Case 2A Total business solar capacity 62
Figure 62 - Case 2A Total residential and business solar capacity 62
Figure 63 - Case 2A Average hourly network loads (MW) 63
Figure 64 - Case 2A Maximum hourly network loads (MW) 63
Figure 65 - Case 2A Annual network energy 63
Figure 66 - Case 2A Annual system costs 64
Figure 67 - Case 2A System unit costs 64
Figure 68 - Case 2B Business storage growth 64
Figure 69 - Case 2B Business storage capacity 66
Figure 70 - Case 2B Average hourly network loads (MW) 66
Figure 71 - Case 2B Maximum hourly network loads (MW) 66
Figure 72 - Case 2B Annual network energy 67
Figure 73 - Case 2B Annual system costs 67
Figure 74 - Case 2B System Unit Costs 67
Figure 75 - Case 3 Maximum hourly network loads 69
Figure 76 - Case 3 Average hourly network loads 69
Figure 77 - Case 3 Annual network energy 70
Figure 78 - Case 3 Annual system costs 70
Figure 79 - Case 3 System unit costs 70
Figure 80 - IMO Solar penetration forecast 74
Figure 81 - Minimum hourly network loads 74
Figure 82 - Solar exports 74
Figure 83 - Case 2B SWIS Duck curve 75
Figure 84 - Over-generation risk by 2025 75
Figure 85 - Over-generation risk by 2034 75
Figure 86 - Typical day over-generation 77
Figure 87 - Annual network energy 77
Figure 88 - Annual system costs 77
Figure 89 - System unit costs 79
Figure 90 - Private investment in solar / storage 79
Figure 91 - 20 year public and private expenditures on energy 79
Figure 92 - Influence of tariffs on payback periods 80
Figure 93 - Influence of tariffs on solar capacity 80
Figure 94 - Greenhouse gas emissions 80

# / Executive Summary

The inevitable increase in the take up of private solar PV systems in WA homes and businesses will hasten a transformation of the electricity network during the coming decade that is needed anyway.

**Introduction**
The electricity industry worldwide is talking about the so-called death spiral. Under this scenario conventional electricity networks are undermined by customers reducing their energy demand through energy efficiency measures and / or private generation, mainly rooftop solar photovoltaic panels (PV). Both processes reduce the quantum of electricity purchased from the network, thereby reducing revenue to the network. As many of the network costs are fixed, this necessarily implies increasing unit costs and therefore increasing tariff charges for electricity. The tariff increases merely exacerbate the problem – hence the "spiral" reference.

In this study these issues are considered in the context of Western Australia's south-west interconnected system (SWIS). The SWIS serves the south-west portion of the state, some 900,000 dwellings and 100,000 businesses. The effect of increasing rooftop solar PV and the potential in the future for private electrical storage are modelled using the technique called system dynamics.

**The SWIS**
The SWIS currently has a generation capacity of nearly 6,000 MW. Despite a growing population and economy, both peak and average demand on the SWIS have plateaued in recent years. Part of this change can be attributed to general reductions in energy intensity in the economy (i.e. energy consumed per $ Gross State Product).

**Rooftop Solar PV**
Rooftop solar penetration has increased significantly in recent years on houses within the area served by the SWIS, and in Australia more generally. Some 15% of dwellings have solar PV with a total nameplate capacity of around 336 MW. Households and businesses that export energy to the SWIS (at times when solar generation exceeds electrical demand) are paid in accordance with the Renewable Energy Buyback Scheme (REBS).

**Model Structure**
The purpose of the model is to explore the influence of growing solar penetration on the SWIS network. The essential structure of the model is depicted in the causal loop diagram below. Causal loop diagrams identify the influences of variables on a system over time. (Refer to Fig. 1)

The dynamic hypothesis is that the reducing price of solar PV systems (an exogenous variable in the model) will increase private solar capacity which in turn will reduce the quantum of energy generated on the network, pushing up unit prices and further incentivising take-up of private solar PV (Loop R1). This is known as a reinforcing loop as increases or decreases in one variable are compounded. This reinforcing loop is the essence of the so-called death spiral. Other non-financial drivers are neglected.

However, this is only part of the story. An increase in private solar capacity also reduces network generation costs by reducing both the total amount of energy generated and peak demand (Loops B1 and B2). Reducing peak demand directly reduces the cost of generation (peaking plants have higher operational costs), and also reduces the

necessary network capacity, thus reducing capacity costs (Loop B3). Both factors will tend to offset otherwise increasing system costs. Accordingly these are known as balancing loops

The addition of private energy storage does not change the quantity of energy generated, but does reduce peak network demand, thus creating a further balancing loop (Loop B4). This suggests that increasing private storage will somewhat offset the impacts of private solar generation on the network.

The behavior of the real system over time is determined by the relative strengths of the reinforcing and balancing loops. The results of most interest are:

- network costs;
- network unit prices;
- the overall economic costs of supplying electricity to the community; and
- greenhouse emissions

Like all models, this one is a highly simplified depiction of reality. As the saying goes "All models are wrong – some are useful." The results reported here are therefore not predictions of the future – merely plausible scenarios based on the assumptions made.

**Electricity Demand**

The model determines the electricity demand arising from:

- residential houses; and
- commercial and industrial facilities.

The existing residential demand and commercial demand profiles have been determined from historical half hourly reports of total network load, and presentations of the IMO WA on residential and commercial loads. The annual residential demand has been derived from the reported network loads, modified to include the demand met by private solar.

| | GWh |
|---|---|
| Reported 2012-13 residential load | 5,035 |
| Energy produced by 336 kW private solar | 540 |
| Estimated total residential demand | 5,575 |
| Reported 2012-14 commercial load | 12,914 |
| Estimated total demand | 18,489 |

The model assumes the IMO base case forecast for population to grow at 2.1% per annum. The commercial and industrial demand is calculated in the model as the product of the state's Gross State Product (GSP) and the energy intensity (i.e. MWh per year per dollar of GSP). The recent data shows that energy intensity has been dropping by approximately 1% per annum and this is the default assumption in the model. GSP is forecast by the Treasury to grow at 3% per annum and this is the default figure used in the model.

**Solar PV**

The existing number of residences with solar systems (15.5%) and the average size of their solar array (2.4 kW) have been taken from the IMO data. It is assumed at the outset of the simulation period that there is no solar PV in business premises.

The model calculates the payback period for a household arising from:

- avoided electricity imports from the network at the residential tariff; plus
- electricity exports to the network at the residential feed-in tariff (renewable buyback scheme); and
- the installed cost of solar energy.

Both the size of the solar array and the fraction of houses and businesses with solar energy grow towards a maximum fraction as a function of the payback period.

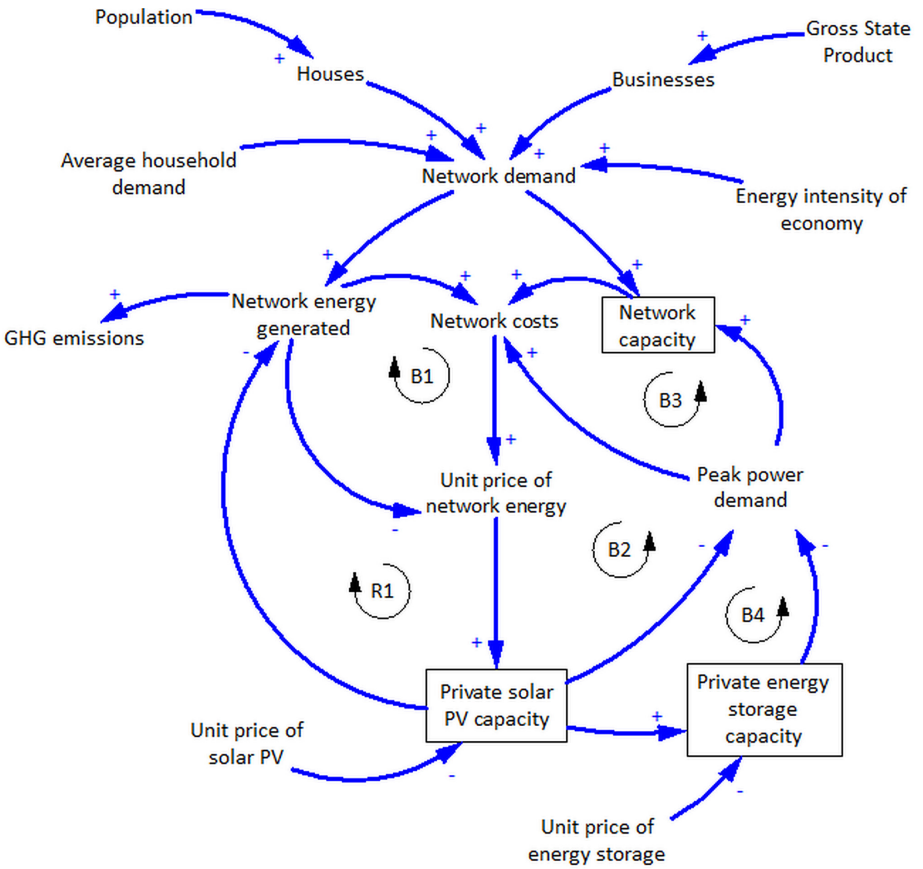



Figure 1 Causal loop diagram of model

**Energy Storage**

At the outset of the model period it is assumed there is no energy storage in either residential or business premises. The model calculates the additional benefit to the householder and business from adding storage to their solar array. It is assumed that storage operates simply on the basis that:

- solar generation in excess of demand is stored (up to the limit of the storage capacity);
- the storage discharges (to zero) to meet demand that cannot be met by solar generation; and
- remaining demand is met by the SWIS network.

The additional benefit of storage is therefore determined by:

• savings from the additional avoided network imports (at the normal tariff); plus
• the benefit of exports (at the feed in tariff).

The incentive to add storage is again determined by a payback period calculated from the benefits noted above, and the unit cost of solar storage.

### The Network

The network generation capacity is used to calculate the recurrent generation costs. The initial capacities of each type of generation are based on the existing capacity credits allocated by the IMO, and other information.
The model assumes there are no additions to the existing generation capacity (including wind). As the network is presently over capacity the model allows for retirements to each type of thermal generation. The default condition is for coal retirements at 20 MW / year throughout the simulation period, commencing in 2016.

### System Costs

The model calculates the total SWIS costs on the basis of the existing reported costs for the SWIS. These include the cost of government subsidy to calculate an approximate overall unit cost. The model assumes that tariffs change over time pro-rata to changing unit costs of network energy. All costs in the model are un-escalated and therefore quoted in 2014$.

| | |
|---|---|
| Capacity | 5,685 MW |
| Energy | 18,133,609 MWh |

### Scenarios Considered

The model has been used to investigate a number of scenarios related to the possible growth of private solar PV and storage and the impacts of this growth on the SWIS network. For comparison purposes a Base Case is included, which assumes growth in residential solar is restricted to the present penetration rates (15%).
The model calculates demand and generation hourly (assuming a typical hourly pattern for each day of each month) and runs for 20 years starting in 2015.

### Model Results - Solar Growth without Storage

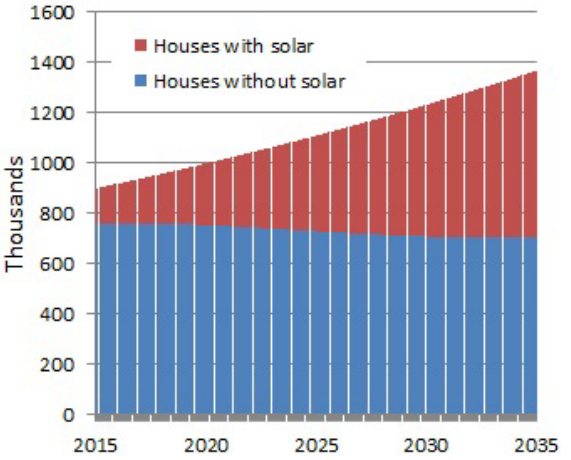
This case examines the implications of residential and business solar growth without storage, i.e.:

• growth in residential solar PV penetration continues; and
• growth in business solar PV penetration commences in 2015.

Under the model assumptions, payback periods continue to fall as system sizes grow and unit costs reduce. This results in rapid growth in both the residential and business sectors. By 2035 around 50% of houses and 40% of businesses have solar PV. (Refer to Fig. 2 and 3)

Reducing payback periods also lead to larger installed systems with average array sizes increasing to around 4.5 kW for residential systems and 90 kW for business systems. (Refer to Fig. 4)

There are significant implications for the



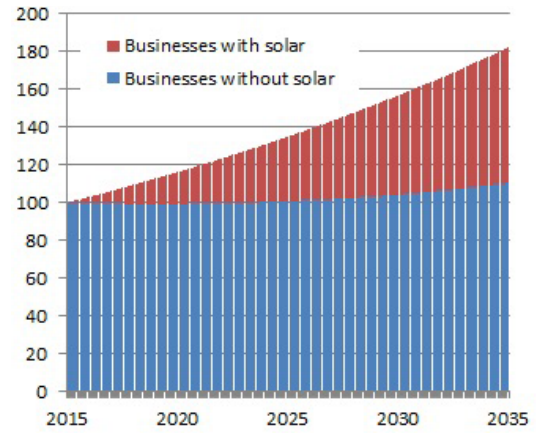




Figure 2 and 3 - Solar PV Growth

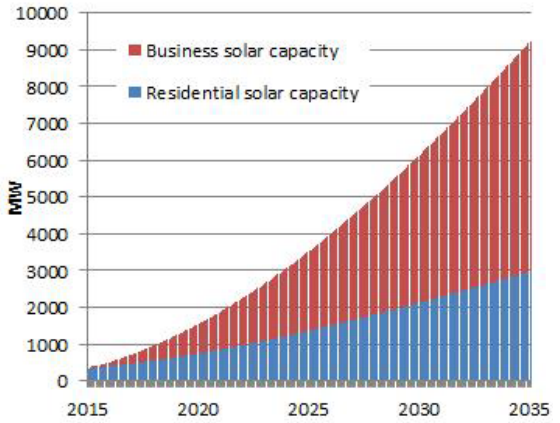



Figure 4 - Solar Capacity

SWIS if this scale of growth in private solar PV occurs. By 2025 average hourly loads on the network are significantly reduced from the Base Case, and this divergence grows thereafter. (Refer to Fig. 5)

However, maximum loads are only marginally reduced by daytime solar generation. Accordingly the maximum hourly loads by 2025 show only a minor reduction in comparison to the Base Case. (Refer to Fig. 6)

This means that the capacity of the network is required to be maintained at the levels of the Base Case, with consequent capacity based costs. However, the most significant implication of this scale of solar generation is on minimum network loads, i.e. when solar generation is at its maximum during the middle of the day in general and in the summer in particular. By March 2030 available solar exports exceed the total electricity demand in the middle of the day, and accordingly network loads fall to zero. (Refer to Fig. 7)

The lead up to this circumstance is shown in the following figure which depicts the so-called “duck curve”. This encapsulates the problem for networks of accommodating highly varying daytime solar generation. (Refer to Fig. 8)

This suggests that there could be an intermittent over-generation problem by 2020 when minimum network loads fall below the normal operating capacity of baseload coal generation, which is intended to run consistently, and cannot be readily cycled down and up in a matter of hours. Steep ramping of generation is required in the hours of declining solar generation. A similar situation has been identified by the California Independent System Operator[1].

**Model Results - Solar Growth with Storage**

This case examines the implications of residential and business solar growth with storage, i.e.:

- growth in residential solar PV penetration continues;
- growth in business solar PV penetration commences in 2015; and
- both are accompanied by growth in private storage.

Storage payback periods in the model are dependent on storage costs, savings and REBS income which are all a function of solar array size. Accordingly it takes some time for paybacks to drop to the level whereby take-up would be financially attractive. However, after around 2020 paybacks have dropped to the 10-15 year range.

Penetration thereafter increases steadily in both residential and business facilities. By 2035 there is some 13,000 MWh of storage capacity and 405,000 houses and 45,000 businesses possess storage. However, this is still only about 1.5 hours of storage at the nameplate solar capacity. (Refer to Fig. 9, 10 and 11)

By observation the storage case has

1 http://www.caiso.com/documents/flexibleresourceshelprenewables_fastfacts.pdf

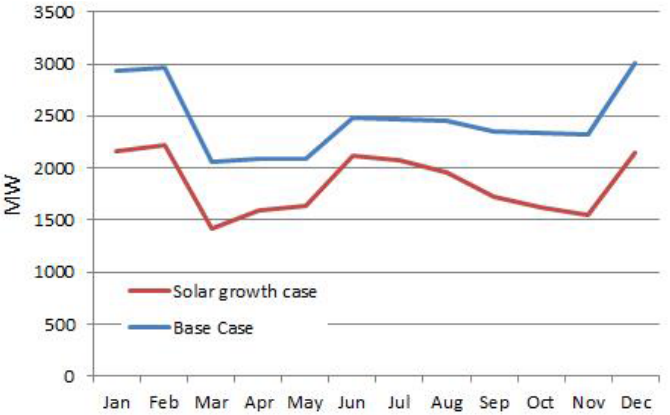



Figure 5 - Average hourly network loads (2025)

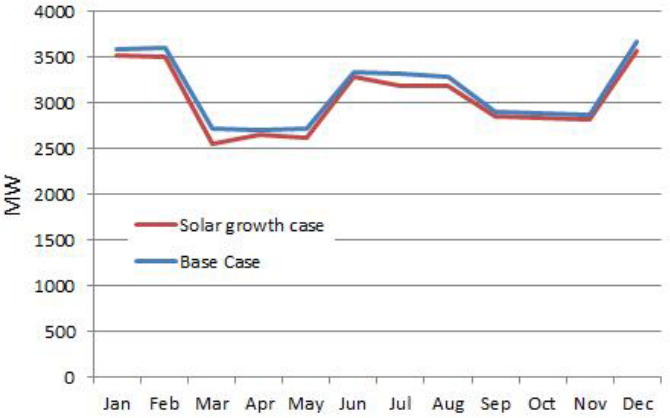



Figure 6 - Maximum hourly network loads (2025)

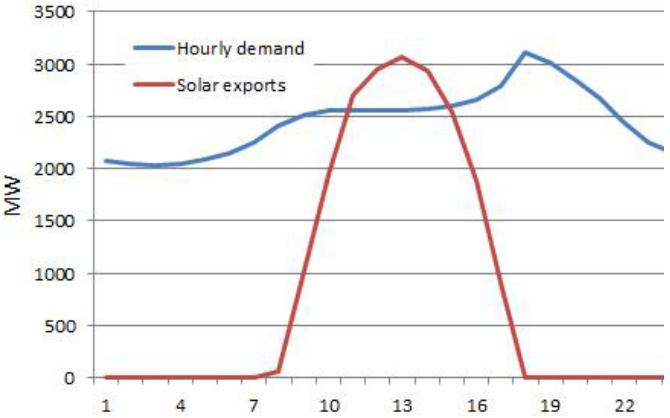



Figure 7 - Solar exports (March 2030)

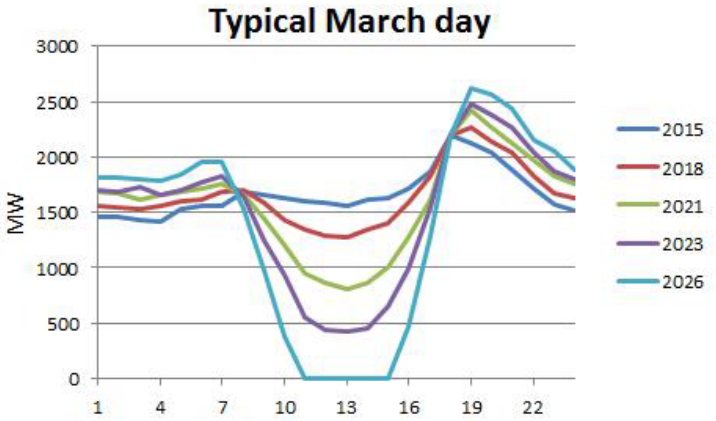



Figure 8 - Duck Curve

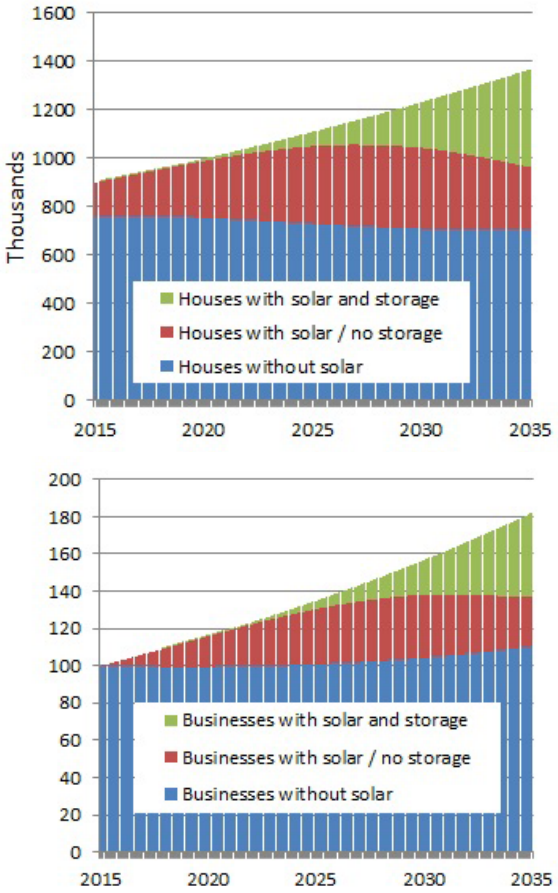



Figure 9 and 10 - Energy Storage Growth

little impact on the network for the first half of the simulation period. The duck curve up to 2025 is similar to that for the solar only case. It is only thereafter that the influences of storage are felt. By 2035 storage has reduced maximum network loads significantly from the solar only case. (Refer to Fig. 12)

The over generation problem is somewhat ameliorated in the storage case but minimum network loads will still fall to 0 under certain circumstances. (Refer to Fig. 13)

## The Implications of the Model Results

### Solar growth

In a recent report the IMO forecast the growth of private solar to grow linearly for the coming decade to reach approximately 1000 MW of nameplate capacity by 2024.(Refer to Fig. 14)
In contrast the model, which is based on an increasing take up as payback periods reduce, suggests that this figure could be as high as 3,000 MW by 2024 and 3 times that figure by 2035.
The IMO forecast is based on linear growth. Exponential growth is a more common phenomenon, and is usually observed in the time histories of innovative technologies, including solar PV take-up in Australia[2].
Although growth in the commercial sector has been slower than residential to date, as awareness grows and unit prices decline, this is potentially the largest contributor to growth by far.
Payback periods are lower for commercial systems because there is a better match between solar generation and demand, and time-of-use tariffs are higher during peak periods.

### Network loads

The most dramatic effect on the network of growth in solar penetration of this scale is seen in the impact on minimum loads on the network. This illustrates the impact of growing solar exports to the network during daytime periods in general and in summer in particular. (Refer to Fig. 15)
Figures 16 and 17 show the % of hours in each month that network loads may reach over-generation and zero generation points.

Over the longer term the “hollowing-out” of network load would likely require a different configuration of generation type on the network.
Private energy storage ameliorates the impacts of solar generation on the network as it reduces both the peak and average energy demands, thus lowering system costs.
With projected growth in storage lagging the growth in solar PV, storage only partially offsets the over-generation problem. By the end of the simulation period there is only around 1.5 hours of storage (at nameplate). This means that the amount of over-generation from solar will likely continue to increase, albeit to a lesser extent than without storage. (Refer to Fig. 18)

### Network Energy and System Costs

All of the cases considered result in lower annual energy required from the network than the Base Case. In the most likely case that business premises also adopt private solar and storage there would be a dramatic reduction in required energy, both in relative (45%)

2 http://apvi.org.au/wp-content/uploads/2014/07/PV-in-Australia-Report-2013.pdf

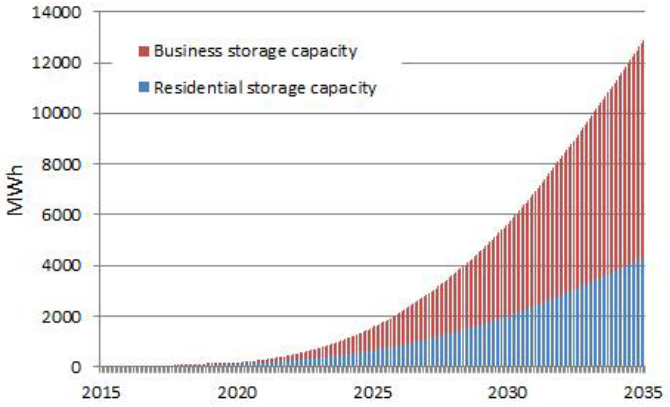



Figure 11 - Storage Capacity

Figure 12 - Maximum hourly network loads

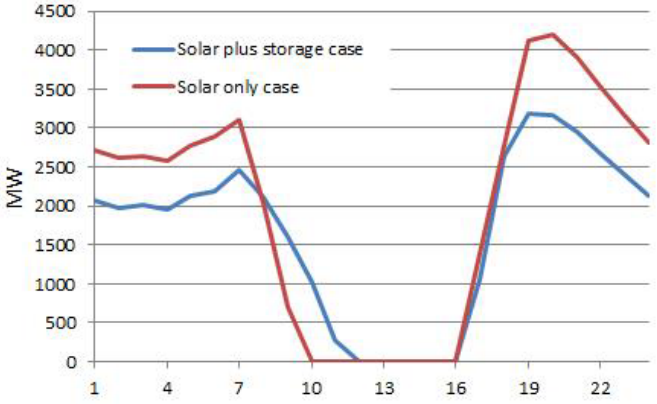
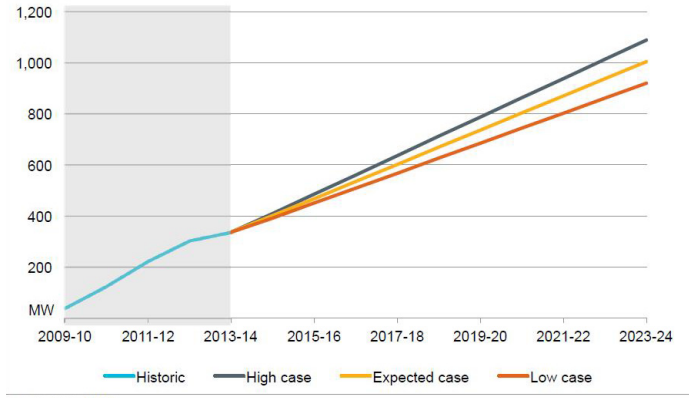



Figure 13 - January day network loads (2034)




*Source: IMO/NIEIR*

Figure 14 - IMO Solar penetration forecast

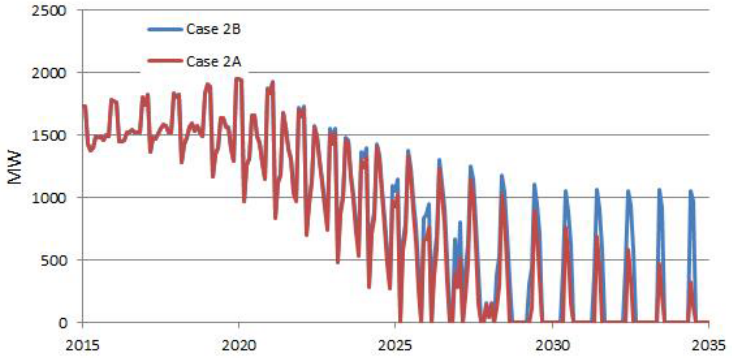



Figure 15 - Minimum hourly network loads

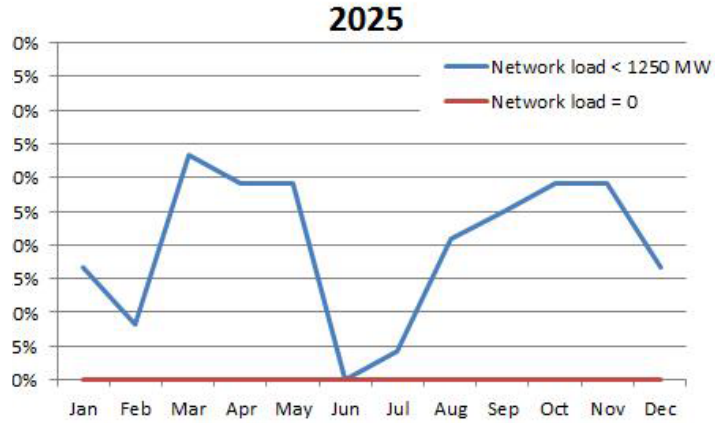



Figure 16 - Over-generation risk by 2025

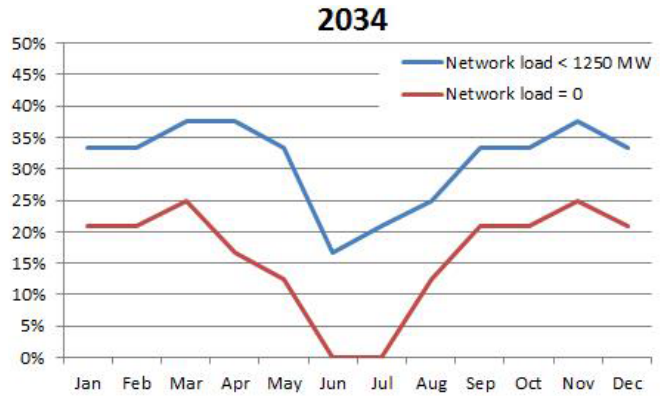



Figure 17 - Over-generation risk by 2034

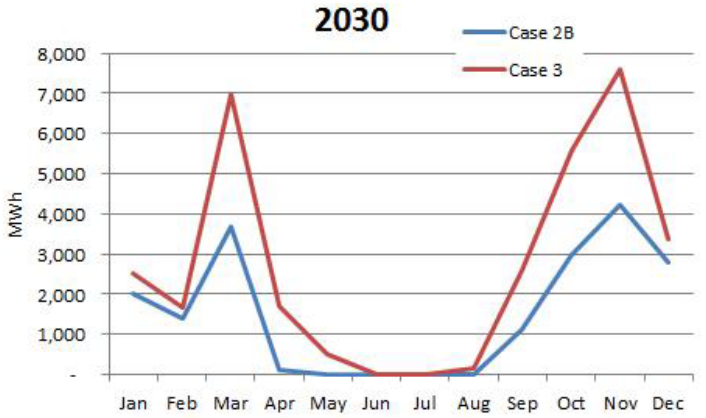



Figure 18 - Typical day over-generation

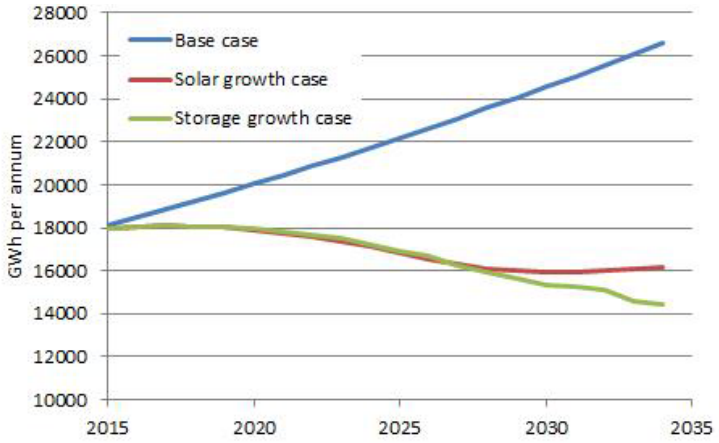



Figure 19 - Annual network energy

and absolute terms (15%). (Refer to Fig. 19)

A reduced energy demand translates to reduced system costs. Under the storage scenario (residential and business solar and storage), system costs would rise only slowly, and then potentially fall to near current costs. This occurs due partly to a reduction in the capacity of the network (assumed mainly related to coal generation), which induces savings in the cost of capacity credits. However, this neglects any ongoing debt obligations associated with this generation capacity which, while not a direct cost to the SWIS, is a cost to publicly owned entities and hence the taxpayer. The costs of writing off this debt are not included in this study. (Refer to Fig. 20)

If tariffs presently delivered $295 / MWh, the SWIS would recover all costs. The model suggests that unit costs will fall from this figure under the Base Case conditions. However, under the other cases it is likely that, although overall system costs will decrease, unit costs will increase substantially. (Refer to Fig. 21)

Although reduced system costs indicate that increased solar penetration will lead to an overall economic benefit, a rise in unit costs is still problematical. Individual consumers, who for one reason or other cannot reduce their network energy consumption sufficiently to offset tariff increases, will pay more for energy under this scenario. As this group will include those who are least able to absorb the additional cost, equity will become an important element of the policy response.

**A Broader Perspective on Costs**

Of course the SWIS costs do not represent all the costs incurred, as they do not take into account the private investments in solar PV and battery storage. The model tracks these costs and accrues them over time to enable a more complete cost comparison of the options. (Refer to Fig. 22)

These range between $11bn and $15bn for the most likely cases. As the net annual savings for the SWIS accrue to around $7.6 bn, the 20 year accumulation of private and SWIS costs are similar. (Refer to Fig. 23)

**The Influence of Tariff Increases**

Part of the death spiral metaphor is that increasing solar penetration will lead to higher tariffs which will only improve the cost-benefit equation further. By default the model increases existing household and business tariffs pro-rata to system unit cost increases. However, the influence of increasing tariffs is easily tested by “switching off” tariff increases in the model. Doing so demonstrates that the tariff increases are not the main driver of reduced paybacks. The reducing unit cost of solar PV has much more influence than increasing tariffs.

**Greenhouse Gas Emissions**

The Base Case indicates that greenhouse gas emissions could rise by around 20% by 2035. The most likely scenario, i.e. growth in private residential and business solar and storage would reverse this and deliver reductions of around 25%. However, even this contribution would be insufficient to meet the requirements of a credible emission reduction target for south west Western Australia. (Refer to Fig. 24)

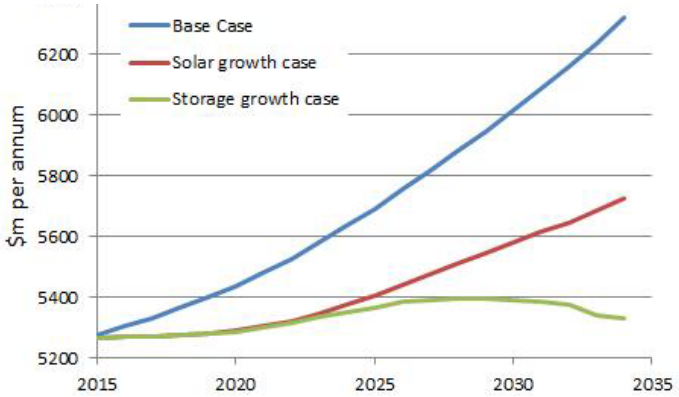



Figure 20 - Annual system costs

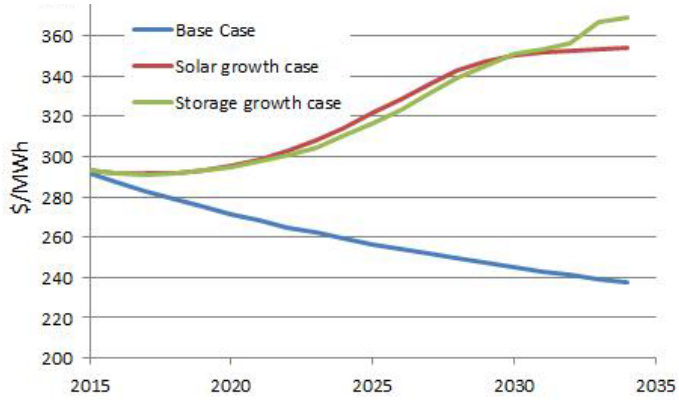



Figure 21 -System unit costs

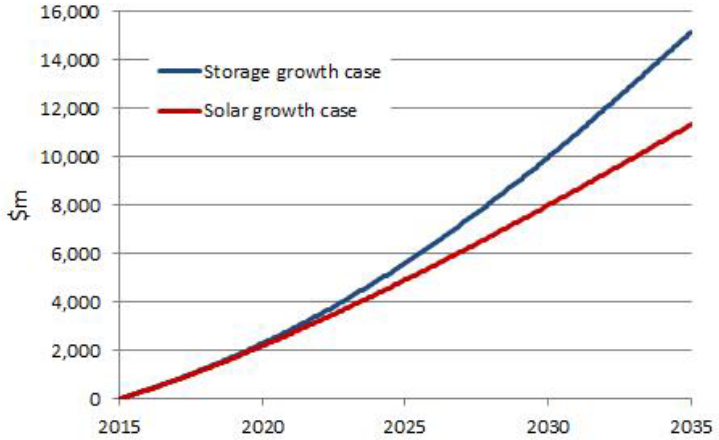



Figure 22 - Private investment in solar / storage

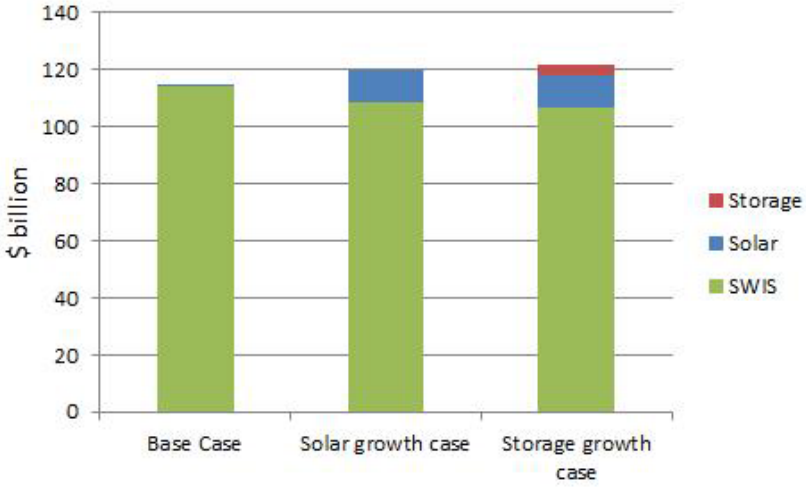



Figure 23 - 20 year public and private expenditures on energy

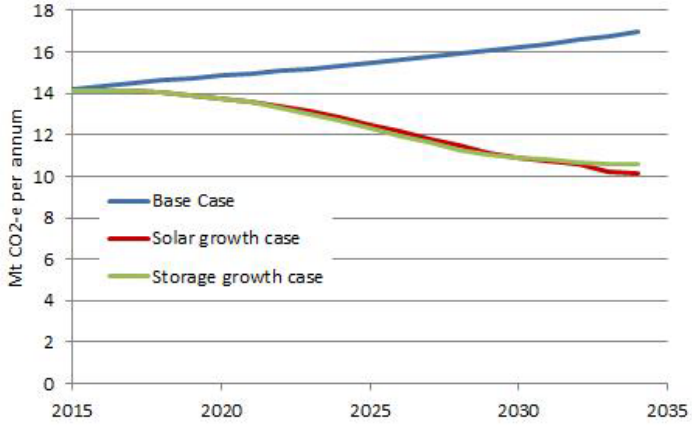



Figure 24 - Greenhouse gas emissions

## Policy Response

### Transition Strategy

The current review of the Wholesale Electricity Market (WEM) does not address the dependence of the SWIS on fossil fuel generation, a situation that cannot continue irrespective of the current political environment. Even if supply is not dampened through action on global warming, prices will inevitably and steadily rise forever after peak production in gas and coal later this century.

Electricity industry investments are made for decades and so it is essential that the future energy generation mix and network strategy is established now to ensure that new investments minimise the risk of stranded assets.

This study identifies that the growth of renewables in the form of private solar is inevitable and will have major implications for the network irrespective of any changes likely to arise from the WEM review. The energy system will change, and therefore the implications of this study should be considered in the context of this broader transition, for which a coherent long term energy strategy is required. The inevitable increase in the take up of private solar PV systems in WA homes and businesses will merely hasten a transformation of the electricity network during the coming decade that is needed anyway.

### An Integrated Energy Policy

The growth of private solar PV is being driven by global forces which are leading to lower unit costs for solar PV panels and economies of scale are driving down balance of system costs. Although it may be affected in the short term by various factors, Western Australia cannot escape the reality of this momentous technological shift.

The days of the electricity industry being the sole provider of energy services to consumers are over. They are now competing with their customers, and their response to this challenge will determine where the balance between network and private assets eventually lies. Policy must drive the most efficient economic outcome, not seek to "protect" the existing industry players. Lower emissions and lower total energy costs are positive outcomes for society and should be embraced, not resisted. While the fact that Synergy and Western Power are state owned enterprises obviously must influence policy, it should not cloud the fact that major change is inevitable. The future energy system must effectively and efficiently integrate private and network generation.

### Baseload Generation and Network Storage

This study identifies that excess solar generation in daytime hours will create an over-generation problem on the network in the coming decade, initially in the mid-seasons and then in the summer. This will require either network baseload generation to be intermittently reduced and / or private solar generation to be "floated". The former is problematical from the operational perspective and the latter wastes energy that has no marginal cost. Although private storage will ameliorate this situation somewhat, the capacity of private storage will not be sufficient to eliminate it.

The only way to avoid the steep ramping evident in the "duck curve" is to introduce network storage into the SWIS. This could potentially occur at existing substation sites which dispatch and receive electricity from the private systems in homes and businesses[1]. Storage at this "downstream" scale would logically be complemented by larger scale storage "upstream" aimed at smoothing supply and demand from network generation. This would be part of a strategy to transition generation from fossil fuels to renewables, many of which are intermittent in nature, e.g. wind.

The introduction of storage within the network itself, if commenced soon enough and with appropriate policy settings (e.g. in respect of the REBS rate), could potentially "head off" the growth in private storage modelled in this study. Economies of scale would mean lower costs per MWh for network scale storage, and if this was of sufficient scale to store all excess private solar generation, this could lead to the encouragement of private solar while dis-incentivising private storage.

1 Although not covered in this study, storage at this scale could also facilitate decentralised micro-grids operating at the precinct / suburb scale.

# // Introduction

Conventional electricity networks are being undermined by customers reducing their energy demand through energy efficiency measures and / or private solar generation.

**The Death Spiral**

The electricity industry worldwide is talking about the so-called death spiral. The dynamics at play are summarised in Figure 25.

In this depiction conventional electricity networks are undermined by customers reducing their energy demand through energy efficiency measures and / or private generation, mainly rooftop solar photovoltaic panels (PV). Both processes reduce the quantum of electricity purchased from the network, thereby reducing revenue to the network. As many of the network costs are fixed, this necessarily implies increasing unit costs and therefore increasing tariff charges for electricity. The tariff increases merely exacerbate the problem – hence the "spiral" reference.

In this study these issues are considered in the context of Western Australia's south-west interconnected system (SWIS). The SWIS serves the south-west portion of the state, some 900,000 dwellings and 100,000 businesses. The effect of increasing rooftop solar PV and the potential in the future for private electrical storage are considered.

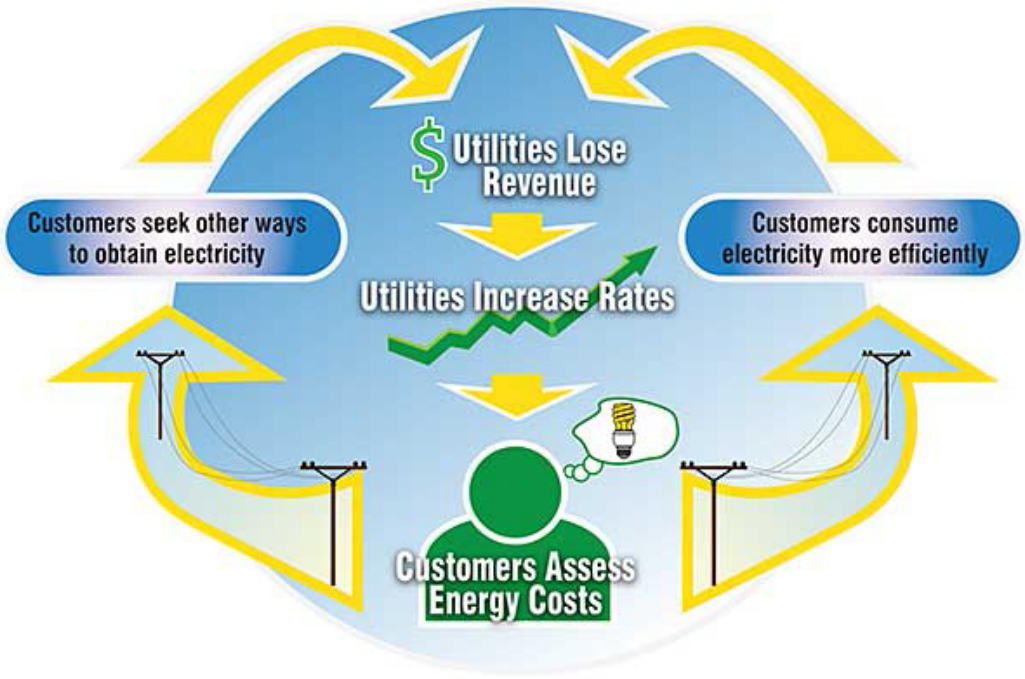



Figure 25 - The Death Spiral

**Characteristics of the SWIS**

The system currently has a generation capacity of nearly 6,000 MW. In 2006 the previously integrated system was split into three components: generation; transmission and distribution; and retail. Synergy (a state owned business enterprise) owns around half of the generation capacity and has a retail monopoly on accounts of less than 50 megawatt hours (MWh) per year (essentially covering residential dwellings). Private generators provide the balance of the energy source, and private retailers compete with Synergy for accounts of more than 50 MWh per year. Western Power (another State owned enterprise) operates the transmission and distribution elements of the system, operating as a regulated monopoly.

An independent market operator (IMOWA)[2] operates the Wholesale Electricity Market[3] (WEM) with the following objectives:

• to ensure there is sufficient capacity to meet demand from WA consumers via the Reserve Capacity Mechanism;
• to facilitate competition between power generators and retailers; and
• to encourage private sector investment in power generation and retailing.

2 The explanation of the IMO role is taken directly from their website http://www.imowa.com.au

3 A review of the WEM is underway at the time of writing.

Three mechanisms exist for trading energy in the WEM:

Bilateral Contracts: these are agreements between wholesale market suppliers and consumers for the provision of energy. The market has no role in how these contracts are formed or on the conditions contained within these contracts.

The Short Term Energy Market (STEM): the STEM is a daily forward market for energy that allows Market Participants to trade around their bilateral energy positions (established in 2006).

The Balancing Market: this market is used to determine actual dispatch in the WEM. Market Participants provide balancing submissions for each trading interval, specifying prices at which their facilities may be dispatched and by how much. The IMO uses these prices to construct the Balancing Merit Order, used by System Management for real time dispatch (established in July 2012).

A key component of the WEM is the Reserve Capacity Mechanism (RCM). The RCM was designed to incentivise investment to ensure that there is adequate generation and Demand Side Management (DSM) capacity available each year to meet peak system requirements.

The Economic Regulatory Authority (ERA)[4] has several regulatory functions in respect of electricity:

• approve access arrangements for Western Power's electricity transmission and distribution networks. An access arrangement sets out the prices, terms and conditions that a network owner can charge companies to use its infrastructure.
• administer the licensing regime. This involves issuing licences to entities generating, transmitting, distributing or retailing electricity, monitoring and enforcing compliance with licence conditions and approving customer protection measures.
• monitor the behaviour of participants in the wholesale electricity market (where retailers buy electricity from generators) to make sure that they are following the market rules and report to the Minister for Energy about the effectiveness of the market.

4 http://www.erawa.com.au/electricity

The ERA plays no role in setting retail electricity prices, which are set by Government for Synergy customers.

Despite a growing population and economy, both peak and average demand on the SWIS have plateaued in recent years. (Refer to Fig. 26 and 27) Part of this change can be attributed to general reductions in energy intensity in the economy (i.e. energy consumed per $ Gross State Product).

**Rooftop solar penetration**

Rooftop solar penetration has increased significantly in recent years on houses within the area served by the SWIS, and in Australia more generally .(Refer to Table 1[5]and Fig. 28[6])

Households and businesses that export energy to the SWIS (at times when solar generation exceeds electrical demand) are paid in accordance with the Renewable Energy Buyback Scheme (REBS) which has just been reduced from 8.85 to 7.13 c/kWh, about one-third of the household tariff. The government briefly introduced an additional feed-in tariff of 40c/kWh but this was withdrawn (due to high subscription) in 2011.

5 Source:Sunwiz

6 Source: IMOWA

The increase in take-up of private solar PV installations coincides with a significant drop in unit price in recent years.[7] (Refer to Fig. 29)

**Electrical Energy Storage**

The other innovation that is likely to follow the rapid take-up of household solar energy is energy storage. In the short term this will probably be battery storage and lithium-ion batteries appear most likely to lead the market. Development of lithium-ion batteries is being driven by both domestic scale renewable energy and the electric vehicle industry. (Refer to Fig. 30)

7 Source: cleantechnica.com

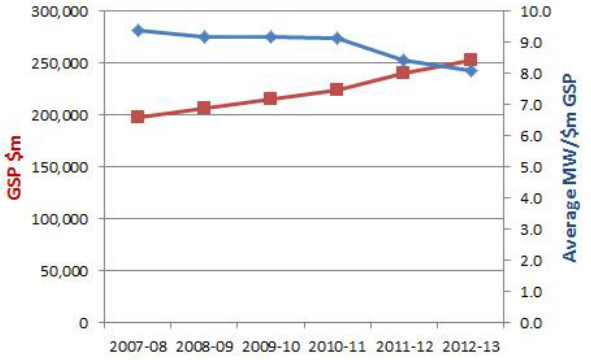



Figure 26 - Gross State Product and Energy Intensity

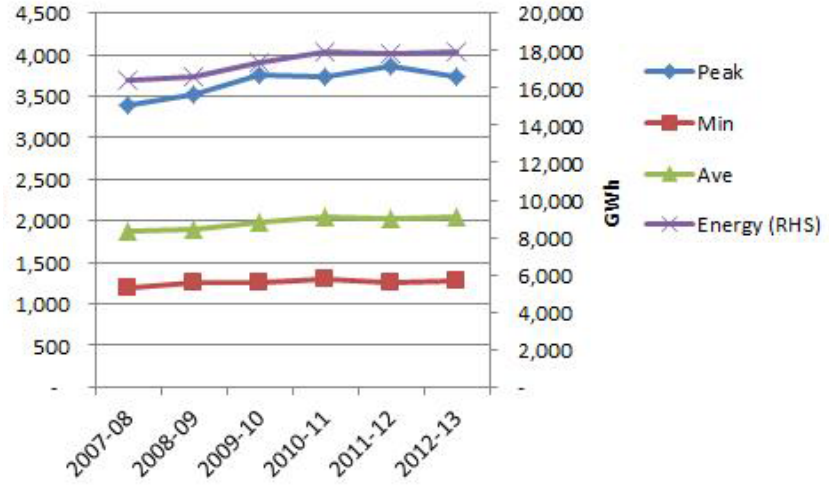



Figure 27 - Recent Energy Demand

| State | #systems | Capacity (MW) | Proportion of dwellings with Solar Power |
|---|---|---|---|
| ACT | 14,000 | 38 | 10% |
| NSW | 252,000 | 633 | 10% |
| NT | 3,000 | 11 | 4% |
| QLD | 360,000 | 986 | 22% |
| SA | 160,000 | 450 | 25% |
| TAS | 18,000 | 55 | 9% |
| VIC | 201,000 | 532 | 10% |
| WA | 149,000 | 334 | 18% |
| National | 1,157,000 | 3,039 | 14% |

Table 1 - Solar PV in Australia[7]

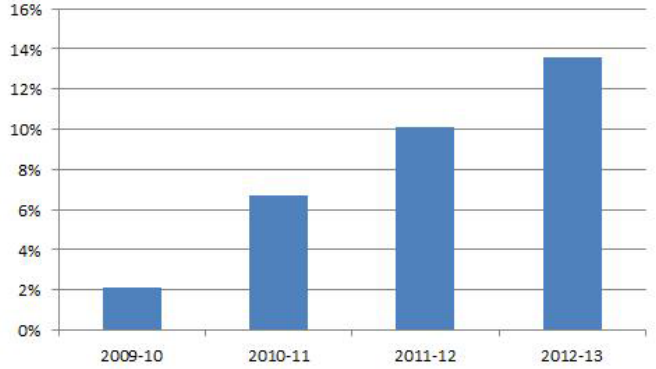



Figure 28 - Rooftop solar PV on the SWIS[8]

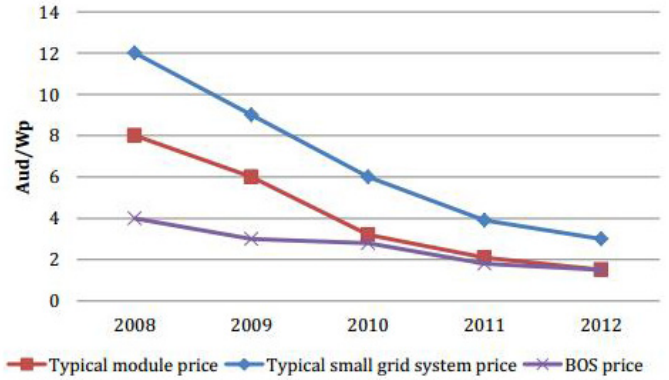



Figure 29 - Cost of solar PV in Australia ($/W)

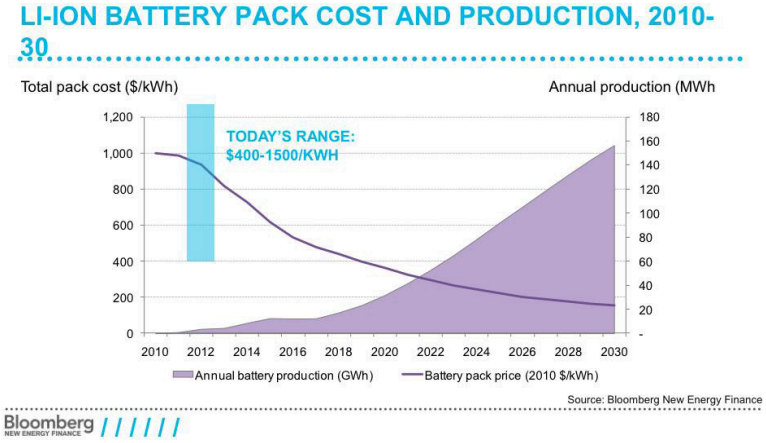



Figure 30 - Projected Cost and Production - of Li-ion storage

# /// A Model of the SWIS

The model uses the technique of system dynamics to explore the impact of private solar and storage on the SWIS to produce plausible scenarios in the period 2015-2035.

**Causal Structure**

The purpose of the model is to explore the influence of growing solar penetration on the SWIS network. The essential structure of the model is depicted in the causal loop diagram at Figure 31. Causal loop diagrams identify the influences of variables on a system over time, including feedback.

The dynamic hypothesis is that the reducing price of solar PV systems (an exogenous variable in the model) will increase private solar capacity which in turn will reduce the quantum of energy generated on the network, pushing up unit prices and further incentivising take-up of private solar PV[8] (Loop R1). This is known as a reinforcing loop as increases or decreases in one variable are compounded. This reinforcing loop is the essence of the so-called death spiral.

However, this is only part of the story. An increase in private solar capacity also reduces network generation costs by reducing both the total amount of energy generated and peak demand

8 Of course financial benefit is not the only driver behind the takeup of solar PV, including individual concern about global warming. Although these are difficult to characterise and have been neglected in this model, they will clearly only add to the momentum for growth.

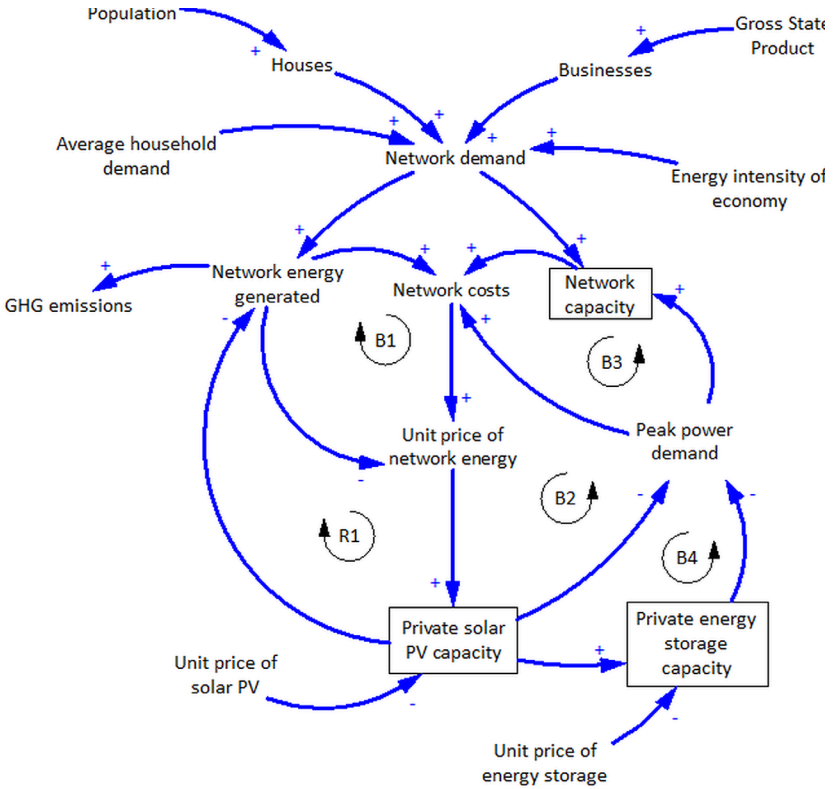



Figure 31 - Causal loop diagram of model

(Loops B1 and B2). Reducing peak demand directly reduces the cost of generation (peaking plants have higher operational costs), and also reduces the necessary network capacity, thus reducing capacity costs (Loop B3). Both factors will tend to offset otherwise increasing unit prices. Accordingly these are known as balancing loops.
The addition of private energy storage does not change the quantity of energy generated, but does reduce peak network demand, thus creating a further balancing loop (Loop B4). This suggests that increasing private storage will somewhat offset the impacts of private solar generation on the network.

Figure 31 identifies the causal structure of the system but the behavior of the real system over time is determined by the relative strengths of the reinforcing and balancing loops. The results of most interest are:

- network costs;
- network unit prices;
- the overall economic costs of supplying electricity to the community; and
- greenhouse emissions

The model uses the technique known as system dynamics[9], first developed at the Massachusetts Institute of Technology by Professor Jay Forrester. It applies to dynamic problems arising in complex systems, i.e. those characterized by interdependence, mutual interaction, information feedback, and circular causality. This particular model uses the Vensim[10] software.

Like all models, this one is a highly simplified depiction of reality. As the saying goes "All models are wrong – some are useful." The results reported here are therefore not predictions of the future – merely plausible scenarios based on the assumptions made.

**Electricity Demand**
The model determines the electricity demand arising from:

- residential houses; and
- commercial and industrial facilities.

The existing residential demand and commercial demand profiles have been determined from historical half hourly reports of total network load, and presentations of the IMO WA on residential and commercial loads. The annual residential demand has been derived from the reported network loads, modified to include the demand met by private solar. (Refer to Table 2)

| | GWh |
|---|---|
| Reported 2012-13 residential load | 5,035 |
| Energy produced by 336 kW private solar | 540 |
| Estimated total residential demand | 5,575 |
| Reported 2012-14 commercial load | 12,914 |
| Estimated total demand | 18,489 |

Table 2 - Estimated annual electricity demand

Hourly demands for a typical day of each month of the year are inputs to the model (Appendix A). The profiles for a typical January and June day are depicted in Figure 32. As these are typical days they do not reflect the absolute annual peak demand (around 3,700 MW in 2012/13).

The recent demand history for residential electricity indicates that the average per residence has not changed over the last five years if the growth in solar energy is taken into account. Accordingly the electricity demand per dwelling is a constant in the model. (Refer to Fig. 32)

The IMO base case forecast assumes population to grow at 2.1% per annum. The model assumes that the number of houses will grow at this rate as a default but can be readily varied.

The commercial and industrial demand is calculated in the model as the product of the state's Gross State Product (GSP) and the energy intensity (i.e. MWh per year per dollar of GSP). The recent data shows that energy intensity has been dropping by approximately 1% per annum and this is the default assumption in the model (again this can be readily varied). GSP is forecast by the Treasury to grow at 3% per annum and this is the default figure used in the model. It is assumed that the number of businesses grow by this amount. Again, these values can be readily varied.

**Residential solar**
The model calculates the contribution of household scale solar energy generation (see Appendix B). It incorporates the following elements:

- Solar energy without storage; and
- Solar energy with storage.

**Solar without storage**
The existing number of residences with solar systems (15.5%) and the average size of their solar array (2.4 kW) have been taken from the IMO data. The impact of a 2.4 kW array on network loads is shown in Figure 33 for typical January and June days.

It can be seen that solar has only a minor impact on reducing residential peak loads as these occur in the evenings. While significant energy is exported to the network in summer, exports are limited in the winter. Larger solar arrays maintain the shapes identified in Figure 33, but the troughs in network load become larger.

The model calculates the payback period for a household arising from:

- avoided electricity imports from the network at the residential tariff; plus
- electricity exports to the network at the residential feed-in tariff (renewable buyback scheme); and
- the installed cost of solar energy.

Both the size of the solar array, and the fraction of houses with solar energy grow towards a maximum fraction as a function of the payback period. (Refer to Fig. 34) The default value for the maximum fraction of houses with solar is 60%, and maximum solar array is 7.2kW (3 times the present average). At the commencement of the simulation period the payback period for residential solar is around 7 years, and so the model assumes that this will incentivise some 10% of remaining homes to purchase solar (spread over an adjustment time of 6.5 years). This percentage increases if and when payback decreases until at year 1 all remaining houses would be incentivised to install solar PV.

Avoided electricity imports are calculated in the model on an hourly

9 http://www.systemdynamics.org/what-is-s/au

10 http://vensim.com/

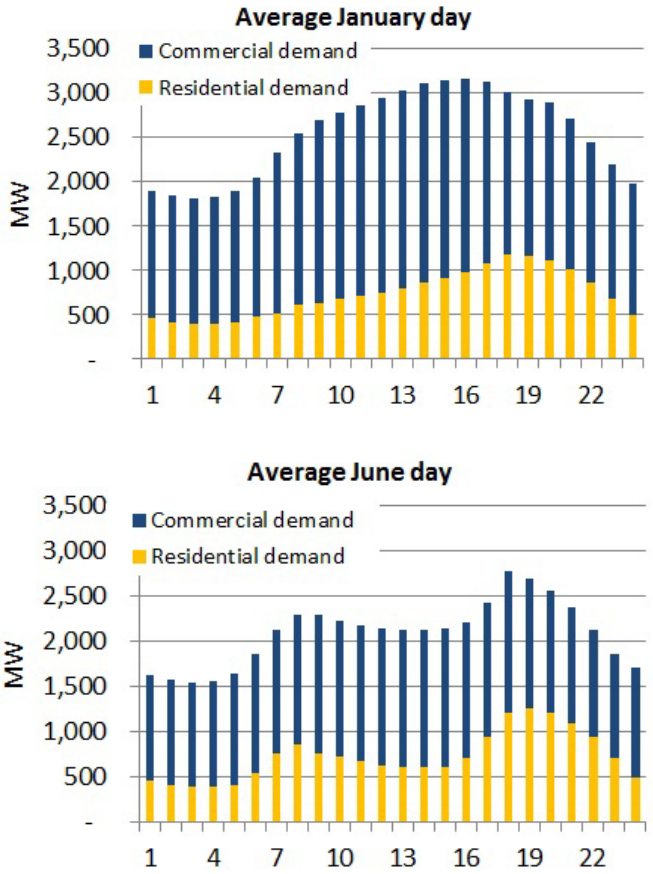



Figure 32 - Electricity demand

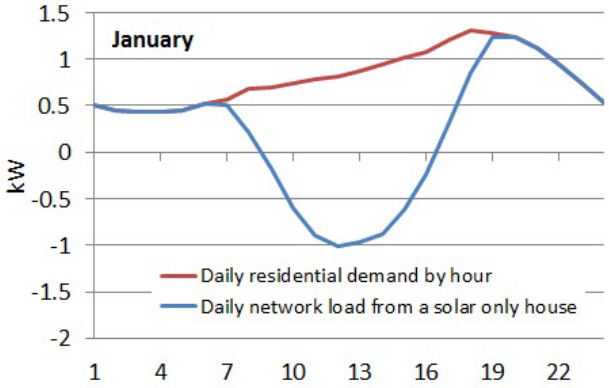



Figure 33 - Impact of solar PV on network loads (1)

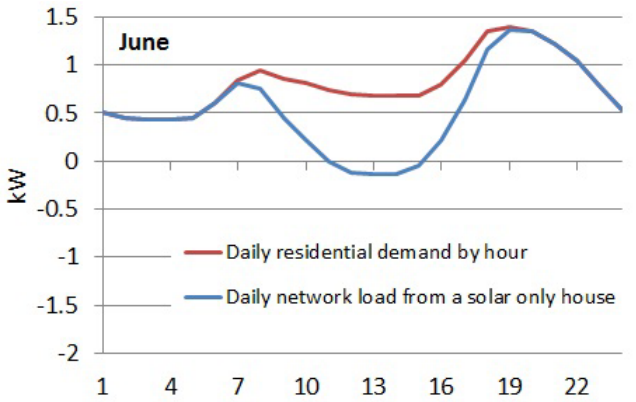



Figure 33 - Impact of solar PV on network loads (2)

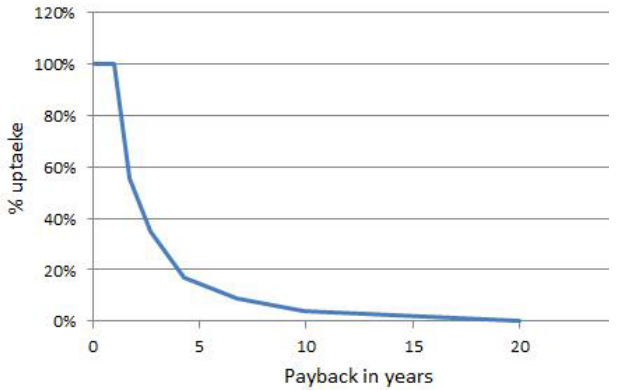



Figure 34 - Uptake of solar PV

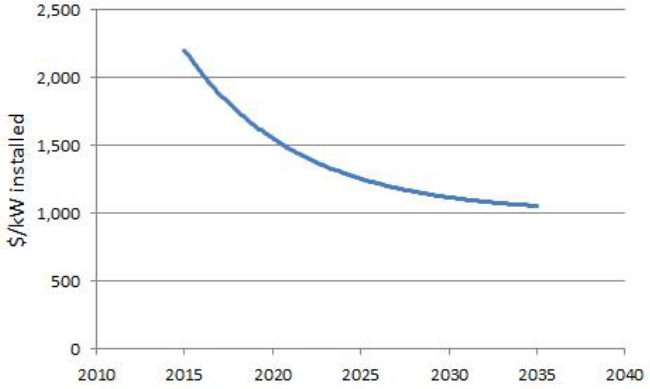



Figure 35 - Solar PV cost curve

basis in accordance with the profiles exemplified in Figure 33. Savings are determined as the product of the total avoided energy and the applicable network tariff. The existing residential time of use tariff (SM1) is used by the model to calculate normal hourly, monthly and annual charges. The model assumes that tariffs change over time pro-rata to changing unit costs of network energy.

Electricity exports are merely the difference between the annual household solar generation and the avoided imports. The value of exports is derived from the existing solar feed in tariff ($0.0713 / kWh).

The unit cost of solar PV is modelled as a stock with an initial value reflecting present unit costs ($2,200 /kW). This is the approximate installed cost of systems in Australia presently, excluding the benefit of the small scale technology certificates (STCs) which are presently worth approximately $690 / kW in the SWIS area. As there is currently uncertainty about the continuation of the STC scheme, the model neglects that benefit. The model assumes that the unit cost transitions to a final unit cost ($1000 /kW) in accordance with Figure 35. The curve is based on a review of published forecast costs. Both the final unit cost and adjustment time can be easily varied in the model.

The quantity of residential solar electricity generated (in MW) is determined by the residential solar capacity (total number of houses x fraction of solar houses x the average residential array in kW) and the amount of solar energy generated annually per unit of capacity.

### Solar with storage

The effect that private solar and storage has on the network can be explained through observation of Figure 36 which depicts solar generation and demand over a single day.

Up to a certain threshold, a solar PV system without storage reduces network demand pro rata to the capacity of the system. When the system capacity becomes large enough, generation will exceed demand at certain times of the day and solar energy is exported to the network. This capacity is noted as A in Figure 36. Because the system cannot generate power overnight, the fraction of demand that can be met is limited to some fraction of the total. Increasing generation capacity beyond that figure contributes little to further avoided network imports and cannot exceed just over 50% in total (on an annual basis) based on local solar and electricity demand patterns. Because the unit price of energy from the network is around three times the unit value of exports, the additional financial benefits of increasing solar capacity diminish beyond Point A.

The second figure identifies the situation when storage is added to the household system. For systems with a solar capacity below Point A, storage is ineffective because there is insufficient energy generated to charge the storage. Beyond Point A, a proportion of the energy that would otherwise be exported is stored for later discharge,



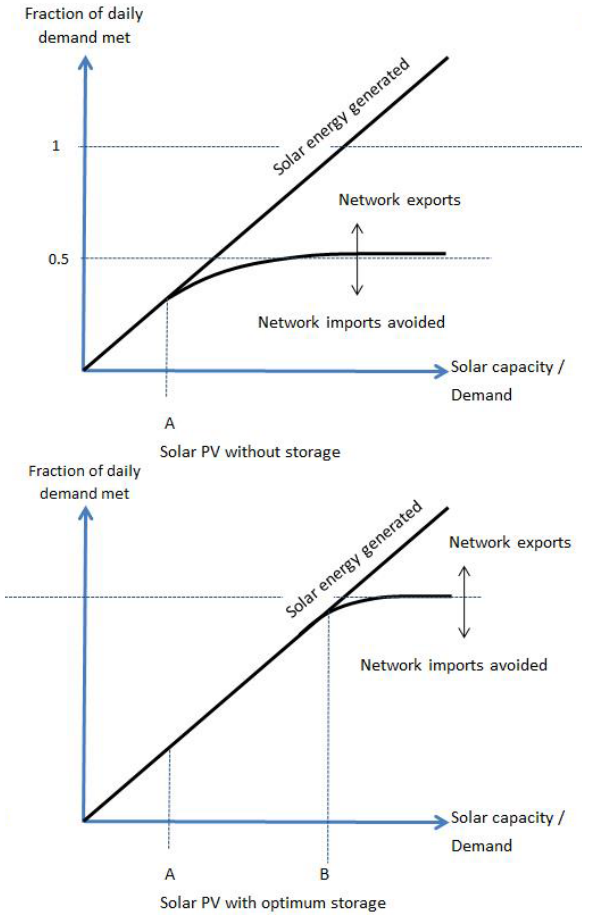



Figure 36 - Solar and storage capacity

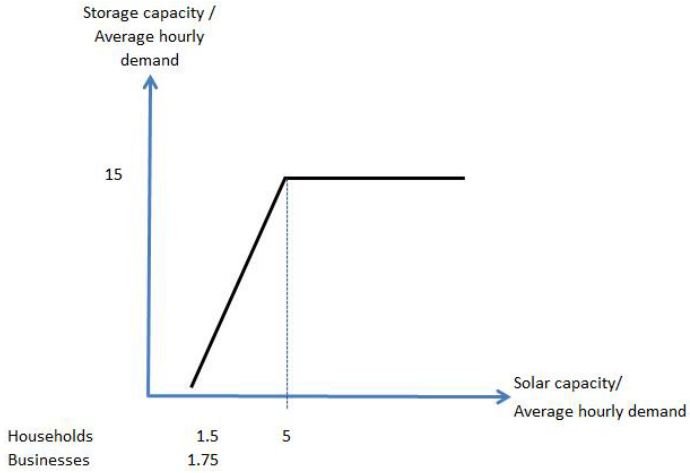



Figure 37- Optimum storage capacity

the extent to which of course depends on storage capacity and losses incurred. Consider first a system with optimum solar and storage capacity as depicted, i.e. a combined system that requires no electricity to be imported (energy independence). This is point B on the figure above. If the storage capacity is then capped, any further energy generated is exported to the network. Now consider the implications of increasing storage capacity above this optimum level. If there is no additional solar capacity added then the additional storage is redundant. If the solar capacity is increased then the energy that would otherwise be exported is now merely stored, offering no additional benefit in either avoided network imports or exports. Accordingly there is both a lower and upper limit for optimal storage capacity, and this is a function of both solar generation and demand. As both of these vary throughout the year, the curves are different for every day of the year. A system that achieves energy independence in the winter months, will necessarily export energy in the summer months.

Based on the hourly model of solar PV and household demand in Perth, the approximate optimum storage capacity for a given solar capacity was determined for both household and business systems. The difference between households and businesses in respect of the minimum value is due to the difference in demand patterns. (Refer to Fig. 37)

By adopting this approach to setting storage capacity, the model avoids multiple combinations of solar capacity and storage capacity. Solar capacity in the model is normalised as a fraction of average hourly demand.

The model calculates the additional benefit to the householder from adding storage to their solar array. It is assumed that storage operates simply on the basis that:

- solar generation in excess of demand is stored (up to the limit of the storage capacity);
- the storage discharges (to zero) to meet demand that cannot be met by solar generation; and
- remaining demand is met by the SWIS network.

The optimum storage capacity is 0 for solar arrays which are not sufficiently large to completely offset demand during the hours of generation (summer conditions determine this threshold which is about 1.1 kW for residential systems). For solar arrays above this capacity, there is increasing benefit in storing more energy to avoid network imports. However, there is an upper limit (about 10 kWh of storage for residential systems), above which there is excessive storage capacity for the amount of generation. This upper limit has been determined by selecting a storage capacity which discharges to (approximately) 0 on summer days.

By adopting this approach to selecting an optimum amount of storage, the model determines the fraction of energy imported on an hourly, daily and annual basis with the selected combination of solar array and storage.



Larger scale solar arrays will generate more electricity than can be optimally stored so there is also a component of generation that is exported (allowing for storage losses).

The additional benefit of storage is therefore determined by:

- savings from the additional avoided network imports (at the normal tariff); plus
- the benefit of exports (at the feed in tariff).

The incentive to add storage is again determined by a payback period calculated from the benefits noted above, and the unit cost of solar storage. The latter has been determined from the technical press and assumes the present storage costs of approximately $1,000 / kWh will drop to around $200 / kWh. (Refer to Fig.38) These values may be considered conservative given the curve set out in Figure 30.

The fraction of houses with storage trends towards the number of houses with solar energy in accordance with the same algorithm assumed for solar arrays. The fraction is assumed to be zero at the commencement of the simulation.

At any given time therefore the model predicts:

- the average residential solar array;
- the number of houses with solar arrays; and
- the number of houses with an optimal storage system

The impact of these combinations on the network at each time step is used to calculate the network load on an hourly basis for each month of the year from:

- A house without solar;
- A house with solar but no storage; and
- A house with solar and optimum storage.

The net impact is merely the product of these values and the number of houses in each category.

**Commercial Solar**

The model structure for the commercial solar is identical to the residential model in all respects, except for the initial conditions. The model assumes that at the outset there is no commercial solar or storage.

The maximum fraction of solar businesses defaults to 50% in the model but this is variable. Because the electrical demands of the business sector are much larger than for houses, and the available space (on average) for solar PV is greater, the model sets a much larger array size as the maximum average array – 150kW. However, unit costs for both solar and storage are assumed to be the same for residential and commercial systems.

It is important to note that paybacks for business PVs are marginally lower than for residential customers because the commercial peak is earlier in the day and is therefore served more effectively by solar generation, meaning that more of the generated energy goes to import avoidance (at the normal tariff) rather than export (at the lower REBS tariff).

The functions controlling takeup of both

solar and storage are the same as for the residential sector, as is the payback function. Payback again is determined by the savings and benefits arising from avoided electricity imports and exports. In this case the business tariff R1 is read into the model and is used in this calculation. The model simplistically assumes that tariffs change over time pro-rata to changing unit costs of network energy.

**Utility Network**

The network generation capacity is used to calculate the recurrent generation costs and spot price arising from the Short Term Energy Market (STEM). The initial capacities of each type of generation are based on the existing capacity credits allocated by the IMO, and other information.

| | |
|---|---|
| Coal | 1,777 MW |
| Gas combined cycle (Gas CC) | 715 MW |
| Gas combustion turbines (Gas CT) | 2,609 MW |
| Diesel | 210 MW |
| Wind | 169 MW |
| Total | 5,480 MW |

For the purposes of the model the 210MW of diesel generation capacity has been allocated to Gas CT. The figures above include some 390MW of Gas CT generation that is slated for retirement in the coming year, which the model takes into account. Demand side management (DSM) capacity has been ignored.

Information on the capital and operating (including fuel) costs and other characteristics of each type of generation has been derived from the Australian Energy Technology Assessment (AETA) 2012 by the Australian government's Bureau of Resources and Energy Economics.

The model assumes there are no additions to the existing generation capacity (including wind). As the network is presently over capacity the model allows for retirements to each type of thermal generation. The default condition is for coal retirements at 20 MW / year throughout the simulation period, commencing in 2016.

The network loads arising from residential and business premises are aggregated, and these figures together with the generation capacity are used to determine the hourly spot price on the network. Under the present arrangements only a small proportion of energy is purchased via the STEM. The vast majority is traded bilaterally by generators and retailers. As information on these trades is not publicly available the model assumes all generation is dispatched via a spot price mechanism. Accordingly the spot prices in the model are not directly comparable to the actual STEM prices on the SWIS.

The spot price mechanism applies only to the thermal network, assuming that both private solar and network wind generation "must-run".

Average bid prices for each type of thermal generation are assumed to approximate the fuel and variable operating costs prices associated with each type of generation, together with a 10% markup. This yields the following average bid prices:

| | |
|---|---|
| Coal | $35.10 / MWh |
| Gas CC | $98.22 / MWh |
| Gas CT | $143.15 / MWh |

The model assumes that each generation type will bid these figures ± 20% depending on demand. This model structure derives an hourly spot price on the assumption that the lowest cost available generation is deployed. A ceiling price of $200 is assumed. Wind generation in the model is derived from random function that assumes a capacity factor of 0.38 on average is achieved (a figure normally assumed for the SWIS).

The model also calculates the hourly and monthly costs of generation, assuming that each type of generation costs its average bid price per hour to operate. These calculations derive a unit cost ($/MWh) for the generation component of system costs.

**System Costs**

The model calculates the total SWIS costs. The monthly fixed cost of generation is added to the generation component described above. The fixed costs are again derived from the AETA report. Guidance for the calculation has been derived from the IMO report outlining the calculation for the reserve capacity credit cost per MW (which assumes that gas combustion turbines will determine this figure).

The annual fixed cost of generation has been taken to be the annualised cost of capital and fixed operations and maintenance costs amortised over 30 years using the weighted average cost of capital of 7.01%. These calculations yield the following costs for each generation type:

| | |
|---|---|
| Coal | $464,000 / MW pa |
| Gas CC | $144,500 / MW pa |
| Gas CT | $ 91,500 / MW pa |
| Wind | $366,000 / MW pa |

The capital costs per MW[11] are derived from the AETA report for each type of generation.

The monthly costs of transmission, distribution and retail (TDR) are added to the generation costs to give a total system cost figure per month. The costs for these items have been calculated on the basis of the existing reported costs for the SWIS[12]. The following includes the cost of government subsidy to calculate an approximate overall unit cost.

| | |
|---|---|
| Capacity | 5,685 MW |
| Energy | 18,133,609 MWh |

| | $/MWh | $m pa | $/MW |
|---|---|---|---|
| Generation costs | 127.69 | 2,315 | |
| Transmission & distribution | 105.67 | 1,916 | 337,064 |
| Other costs | 61.64 | 1,118 | 196,621 |
| Assume total unit cost | 295.00 | 5,349 | |

The model assumes the cost of transmission and distribution is $337,000 per MW pa if the capacity of the system remains the same or grows. If capacity falls below the initial value the costs are assumed to remain at their current figure on the basis that this infrastructure will continue to be in place and cost approximately the same to operate.

11 A markup of 50% has been applied to the capital costs set out in the AETA to allow for legal, financing and other costs associated with purchase of the asset.

12 http://www.westernpower.com.au/aboutus/save_electricity/The_price_of_power_.html

Other system costs are assumed to vary in accordance with capacity, i.e. at the rate of $197,000 / MW pa.

The total system unit cost is simply the addition of the generation costs and the transmission, distribution and other costs (including retail) divided by the quantity of network electricity generated. The average system unit cost is simply the average of the previous year's monthly values. The model assumes that changes to tariffs are pro-rata to unit cost increases and applied as a multiplier to the existing household and business hourly tariff regime (one year in arrears).
The model includes the cost of the REBS as a system cost, although the REBS tariff is assumed to remain constant at the current rate.

The present network is heavily dominated by fossil fuel generation. At the time of writing, a carbon price has been removed in Australia and hence no cost has been accrued in this study to account for greenhouse gas emissions. Given the global impetus for pricing carbon, it is unlikely that this situation will persist for the duration of the simulation period.
All costs in the model are un-escalated and therefore quoted in 2014$.

### Greenhouse Gas Emissions

The greenhouse emissions arising from the thermal network are also calculated. The emission intensities of each type of generator have been taken from the AETA report and the Account Factors from the National Greenhouse and Energy Reporting scheme[13].

| | |
|---|---|
| Coal | 0.88 $tCO_2$-e / MWh |
| Gas CC | 0.37 $tCO_2$-e / MWh |
| Gas CT | 0.515 $tCO_2$-e / MWh |

These figures combined with the monthly generation regime, determine the emission intensity of the network as a whole.

### Solar Costs

The model calculates the incremental solar and storage investment costs from the inflows to the stocks of houses and businesses and multiplies those flows by the fraction of premises that have solar or storage at that time step, and the unit cost of solar and storage. This identifies the total private investment in solar and storage at each time step.

### Public and Private Expenditures

The solar and storage investments are added to the recurrent network generation costs to give an indication of the total private and network expenditures throughout the simulation period. The calculation neglects the operations and maintenance costs associated with private solar and storage systems.

This calculation also neglects the investment in both private solar and the existing thermal network generation prior to the simulation period.

### Scenarios Considered

The model has been used to investigate a number of scenarios related to the possible growth of private solar PV and storage and the impacts of this growth on the SWIS network. These are summarised in the table below.

The model calculates demand and generation hourly (assuming a typical hourly pattern for each day of each month) and runs for 20 years starting in 2015. (Refer to Table 3)

The purpose of the model is to explore the underlying dynamics of the SWIS over the medium term. It does not seek to precisely simulate the short term dynamics such as the backlog of works like pole replacements and undergrounding works. It assumes that the essential nature of the existing system (including transmission and distribution costs) is sufficiently representative to explore systemic changes over the 20 year time horizon of the model.

13 http://www.environment.gov.au/climate-change/greenhouse-gas-measurement/publications/national-greenhouse-accounts-factors-july-2014

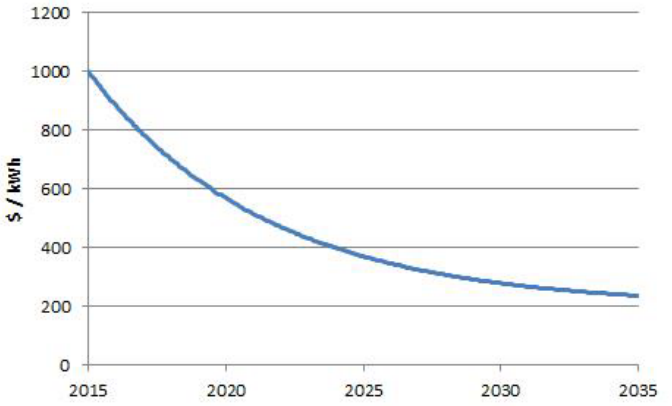



Figure 38 - Storage cost curve

| | Base case A | Base case B | Case 1 A | Case 1 B | Case 2 A | Case 2 B | Case 3 |
|---|---|---|---|---|---|---|---|
| **Demand** | | | | | | | |
| 3% pa growth in GSP | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 2.1% pa growth in population | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 1% pa reduction in emission intensity | | ■ | ■ | ■ | ■ | ■ | ■ |
| **Thermal network capacity** | | | | | | | |
| Existing capacity retained | ■ | | | | | | |
| 20 MW reduction per annum in coal generation capacity | | ■ | ■ | ■ | ■ | ■ | ■ |
| **Households** | | | | | | | |
| 15.5% of solar houses / 2.4kW array / no storage | ■ | ■ | | | | | |
| Growth in solar houses with improving payback / no storage | | | ■ | | | | ■ |
| Growth in solar & storage with improving payback | | | | ■ | ■ | ■ | |
| **Businesses** | | | | | | | |
| 0% of solar businesses | ■ | ■ | ■ | ■ | | | |
| Growth in solar houses with improving payback / no storage | | | | | ■ | | ■ |
| Growth in solar & storage with improving payback | | | | | | ■ | |

Table 3 - Modelled scenarios

# //// The Base Case

The Base Case assumes the penetration of private residential solar remains at the present levels, there is no residential storage; and there is no business solar PV or storage.

**Assumptions**
Two versions of the base case are reported here, representing interpretations of the status quo. In both cases the following are assumed:

- Economic growth of 3% pa;
- Population growth (represented by housing growth) of 2.1% pa;
- The penetration of private residential solar remains at the present value of 15.5%;
- The average size of arrays remain at 2.4MW;
- There is no residential storage; and
- There is no business solar PV or storage.

Base Case A assumes:

- There is no further reduction in energy intensity (i.e. energy consumed per unit of GSP); and
- The existing thermal capacity on the network is retained throughout the simulation period.

Base Case B assumes:

- The recent reductions in energy intensity (approximately 1% pa) continue; and
- The network thermal capacity is reduced by 20MW pa from 2016.

The differences in these cases affect the annual electrical energy demand over time as shown in Figure 39. These assumptions see the annual demand grow to between 27,000 and 32,000 GWh per annum over the simulation period from the current figure of around 18,000 GWh.

The variations in generation capacity are depicted in Figure 40 and Figure 41.

In these scenarios the capacity of the residential solar PV systems increases modestly from around 336 MW to 510 MW over the simulation period.

**Network Peak Loads**
Annual peak loads increase from just over 3,000 MW to around 5,100 MW for Base Case A and 4,500 MW for Base Case B. (Refer to Fig. 42)

**Spot prices**
Both maximum and average monthly spot prices are similar for the two base cases:

- Maximum monthly prices rise from around $120 to $175 / MWh; and
- Average monthly prices rise from $80 to $160 / MWh.

As noted above, the model assumes the spot price is used to dispatch all energy on the SWIS and so these figures are not directly comparable to the IMO's STEM price. (Refer to Fig. 43 and 44)

**System Costs**
Total system costs for Base Case B reflect the lower capacity and generation costs than assumed for Base Case A but are likely to increase substantially under either scenario. (Fig. 45 and 46)

**Unit Costs**
As in both cases, the relative increases in annual energy demand exceed the increases in system costs and the unit cost of energy falls 20-25% for these scenarios over the simulation period. This essentially reflects the fact that the network is operating more efficiently, i.e. a higher percentage of its overall capacity is utilised and generating revenue to recover costs. (Refer to Fig.47)

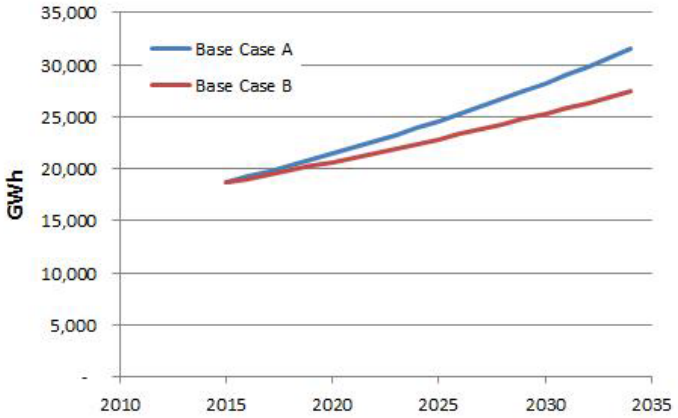



Figure 39 - Base Case electrical energy demand scenarios

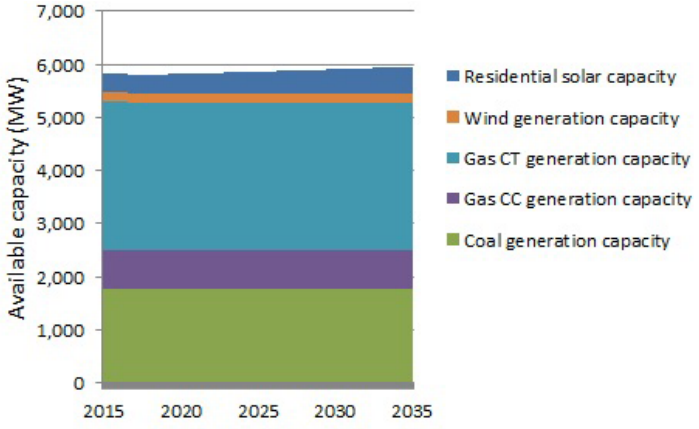



Figure 40 - Base Case A capacity scenario

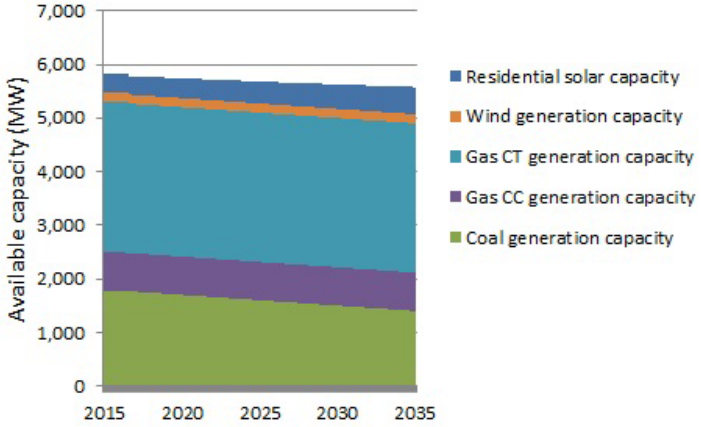



Figure 41 Base Case B capacity scenario($/W)



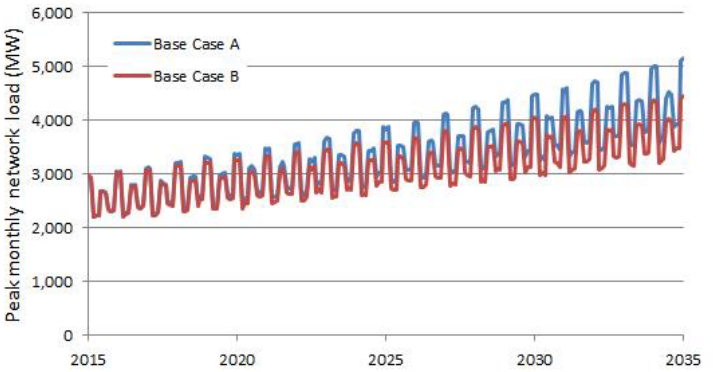



Figure 42 - Base Case Network Peak Loads

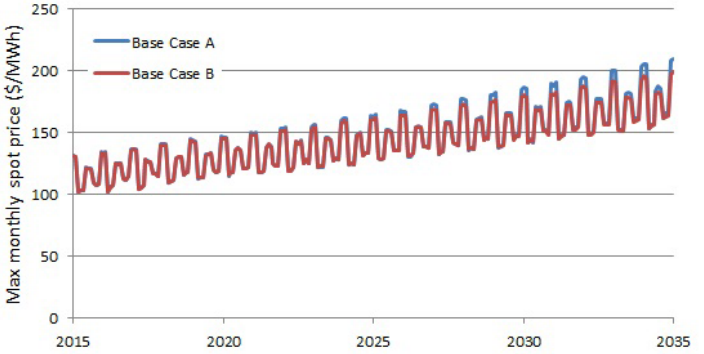



Figure 43 - Maximum monthly spot price

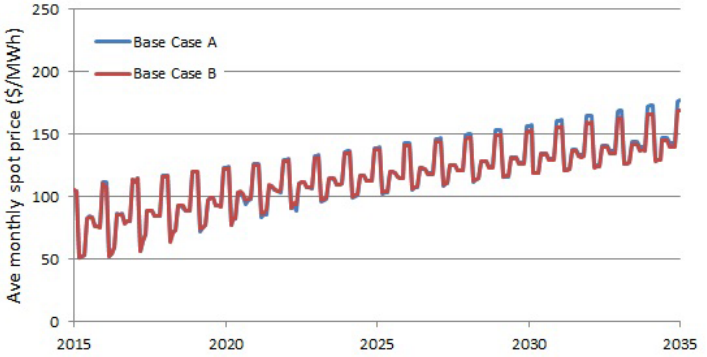



Figure 44 - Average monthly spot price

**Selected Base Case for Scenario Comparisons**

Base Case A assumes that energy intensities have reached their low point and will stabilise at present levels. This is considered unlikely due both to the continuing changes in the nature of the economy and in advances in energy efficiency. Accordingly Base Case B is adopted as the point of comparison for the other scenarios considered in the following sections; i.e.:

- Energy intensity will continue to reduce by 1% per annum; and
- This will enable the thermal capacity of the SWIS to be slowly reduced (by retiring 20 MW of coal capacity per year).

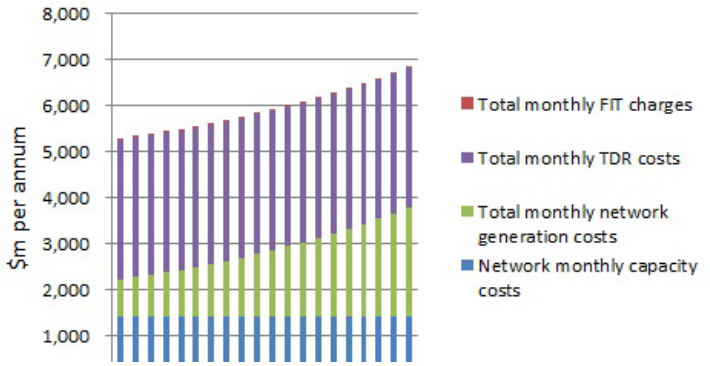



Figure 45 - Base Case A system costs

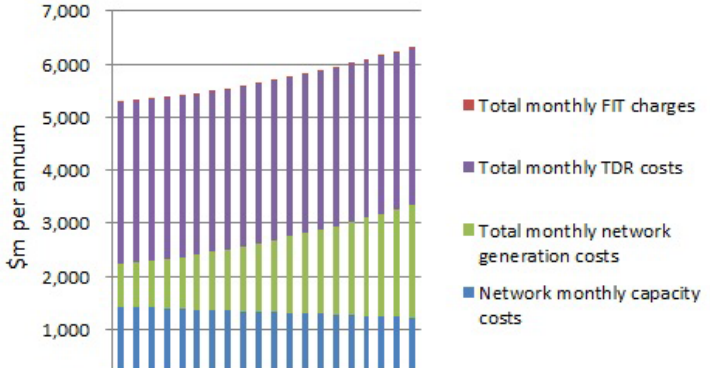



Figure 46 - Base Case B system costs

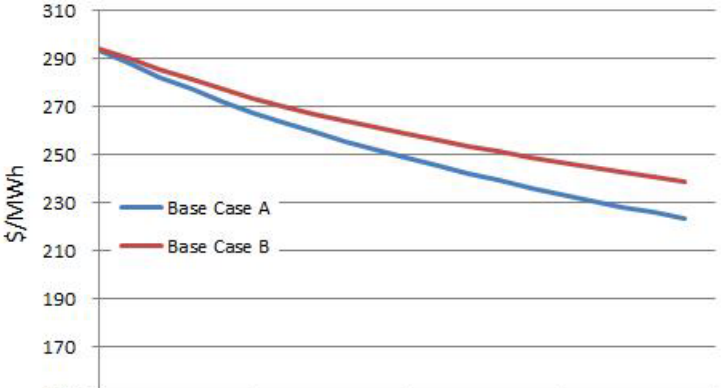



Figure 47 - Base Case unit costs

# ///// Case 1 - Expansion of Residential Solar & Storage

This case assumes penetration of private residential solar PV and energy storage grows in response to decreasing unit costs and rising tariffs.

**Assumptions**
This scenario assumes that continuing growth in private solar capacity is limited to the residential sector, i.e. that electricity demand from the commercial sector continues to be met solely from the SWIS. Two versions of this case are considered:

- Case 1A - growth in solar PV penetration continues; and
- Case 1B - growth in solar PV is accompanied by future growth in private energy storage.

The growth mechanisms and assumptions are described in heading Residential solar in Chapter //. In both cases the growth in overall electricity demand, and network configuration is as described above for Base Case B.

**Growth in Solar PV**
As the unit costs of solar PV drop as described in heading *Residential solar* in chapter //, the payback period also reduces. This process incentivises the further penetration of private generation. This reduces the amount of energy purchased from the network (relative to the Base Case) at the times of day in which solar generation occurs, and more so at the times of year at which generation is greatest (Refer to Fig. 33). However, the increasing penetration of solar has only a small effect on peak network loads, and accordingly the capacity of the network cannot be significantly reduced. Similarly, as many of the network costs are fixed to capacity, the overall system costs cannot be significantly reduced either. This inevitably leads to higher network unit costs, i.e. costs per MWh of energy produced.

As unit costs rise, tariffs inevitably must rise, further improving payback periods and hence further incentivising the purchase of private solar PV. This process is the essence of the death spiral concept, and is simulated by the model.
Low payback periods lead to an increase in both the proportion of houses with solar and size of arrays. By 2035 the model suggests that nearly half of all houses will have solar (Refer to Fig. 48) and the average array size will have grown to around 4.5kW.

The aggregate private solar capacity in the SWIS catchment under these assumptions rises from the present 340MW to nearly 3,000 MW by 2035. (Refer to Fig. 49)

**Network Impacts from residential solar growth**
This growth has an increasing effect on the amount of energy generated on the SWIS at times of day and year in which the solar energy is being generated. This is reflected in significant reductions in average network load but only minor reductions in maximum network load compared to the Base Case. (Refer to Fig. 50 and 51)

The net result is a reduction in generation and hence system costs, with the effect more pronounced in the summer months than the winter months. (Refer to Fig. 52)

Although generation costs are reduced in comparison to the Base Case, energy produced is reduced more in proportional terms, leading to a smaller reduction in unit costs over time than for the base case. (Refer to Fig. 53 and 54)

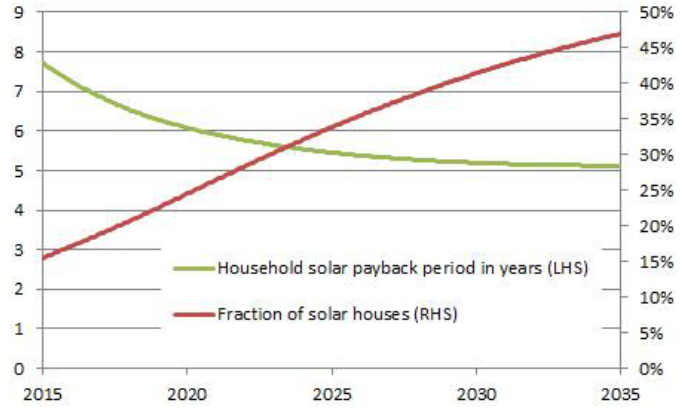



Figure 48 - Case 1A Residential solar growth

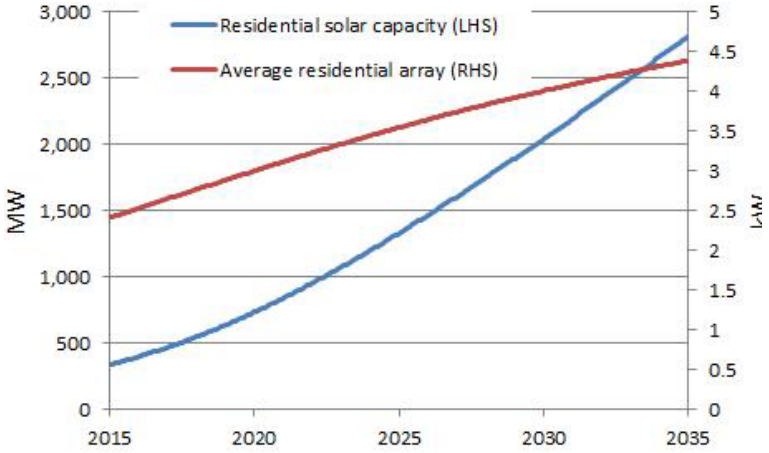



Figure 49 - Case 1A Total residential solar capacity

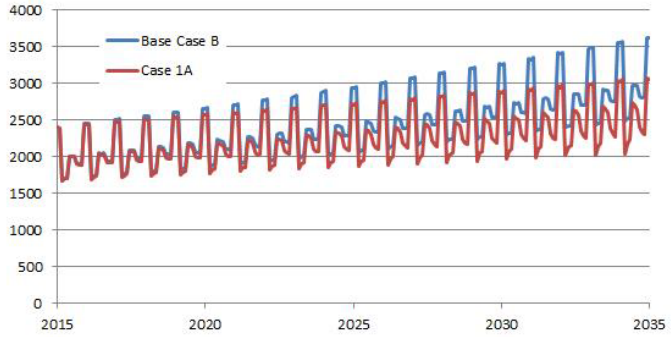



Figure 50 - Case 1A Average hourly network loads (MW)

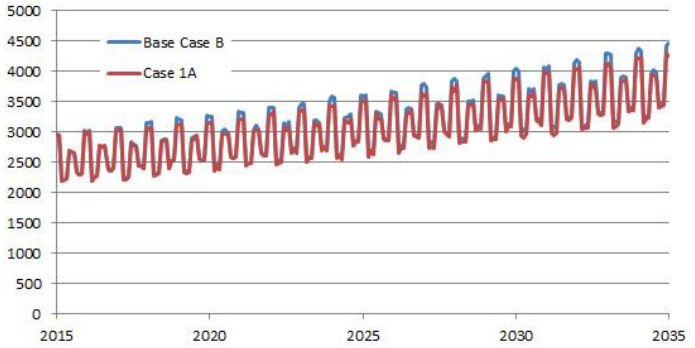



Figure 51 - Case 1A Maximum hourly network loads (MW))

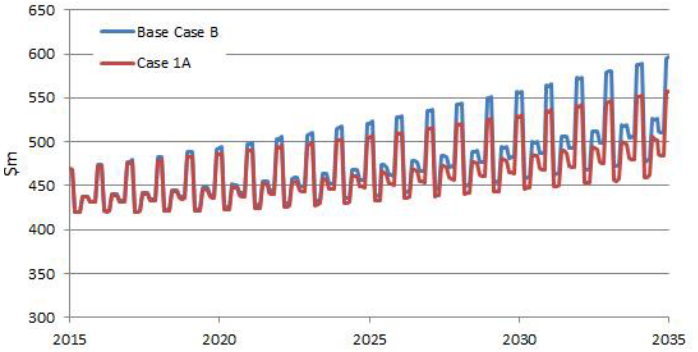



Figure 52 - Case 1A Monthly system costs

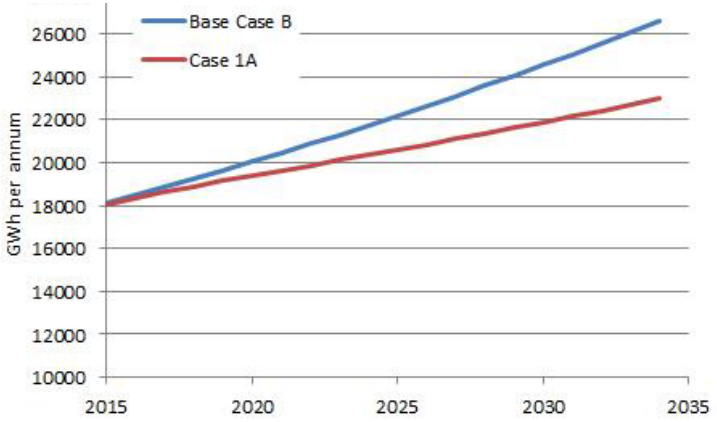



Figure 53 - Case 1A Annual network energy

The model assumes that tariffs will change proportionally to unit costs so reducing tariffs also reduce the savings benefit of solar, which is one component of the payback period. However, this is more than offset by the reducing unit cost, resulting in the net payback period shown in Figure 48.

**Residential Energy Storage**

In Case 1B residential energy storage is introduced to the model, in the manner explained in heading *Residential solar* in chapter //. By adding energy storage to the solar array, the householder obtains the benefit of avoiding the importation of energy at the normal tariff rather than exporting energy at the REBS rate. This benefit accrues an additional payback for an investment in storage.

At the commencement of the simulation the cost of storage is taken to be $1,000 / kWh but this is expected to reduce markedly in coming years (Refer to Fig. 30). The payback period will reduce accordingly. (Refer to Fig. 55)

With the adopted assumptions about costs, benefits and investment behaviour (Refer to Fig. 34) the growth of private energy storage is unlikely to begin until the early 2020s, but could then rise rapidly to around 20% of all houses by 2035, i.e. about 45% of solar houses (Refer to Fig. 55). By that time some 3,000 MWh of storage could be present in the SWIS catchment. (Refer to Fig. 56)

**Network impacts from residential solar and storage growth**

The effect of adding storage on the network is to:

- reduce the amount of energy exported during the normal solar generation periods (increasing minimum loads on the grid); and
- release the stored energy after daylight hours (reducing the peak demands on the grid).

There is no net effect on the average hourly network loads (as the same amount of energy is produced) but maximum hourly loads are marginally reduced towards the end of the simulation period in comparison to the solar-only case. As the penetration of residential storage is modest, the influence is not significant. (Refer to Fig. 57)

The reduced maximum loads translate to slightly lower spot prices being paid at peak hours. The reduced solar exports reduce the REBS costs and these factors combine to deliver slightly lower system costs (Refer to Fig. 58). As the total energy generated is the same, unit costs are slightly lower than for the solar only case (Refer to Fig. 59).

This scenario indicates that private storage will be beneficial to the network, although with the scale envisaged in the model, the impacts are minor.

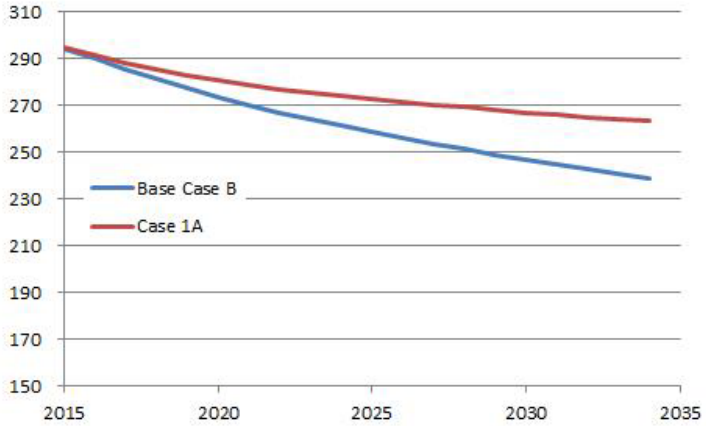



Figure 54 - Case 1A System unit costs ($/MWh)

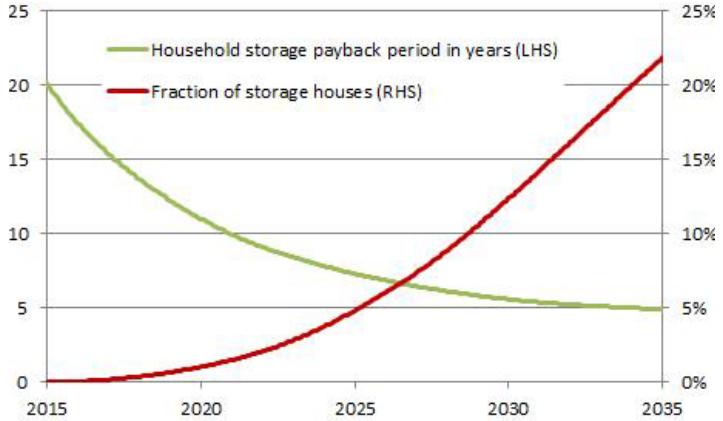



Figure 55 - Case 1B Residential storage growth

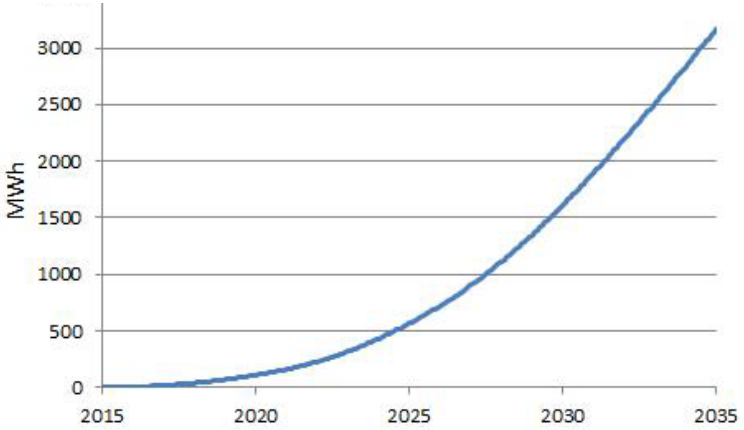



Figure 56 - Case 1B Residential storage capacity

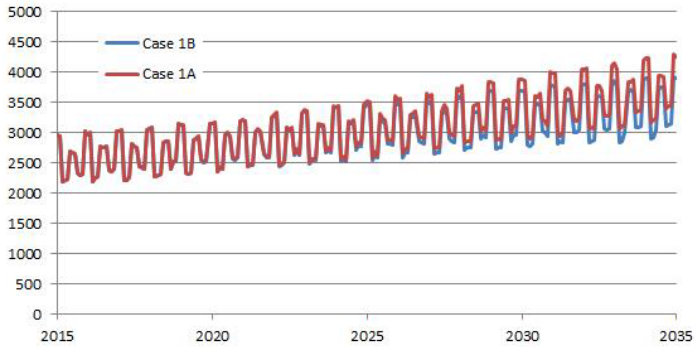



Figure 57 - Case 1B Max hourly network loads (MW)

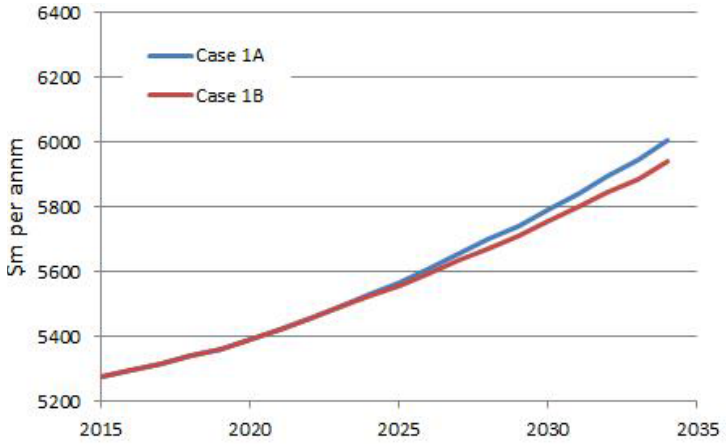



Figure 58 - Case 1B Annual system costs

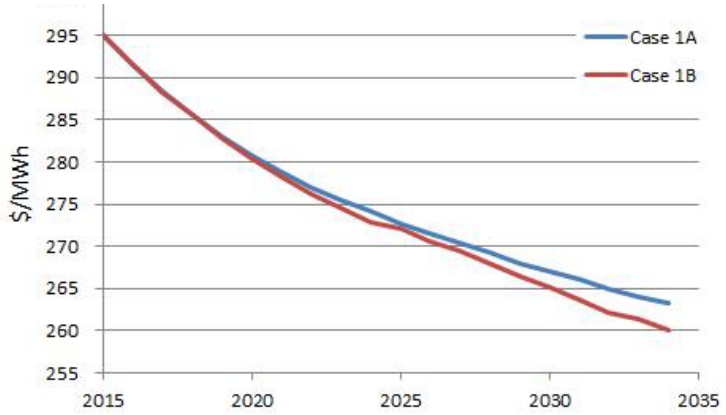
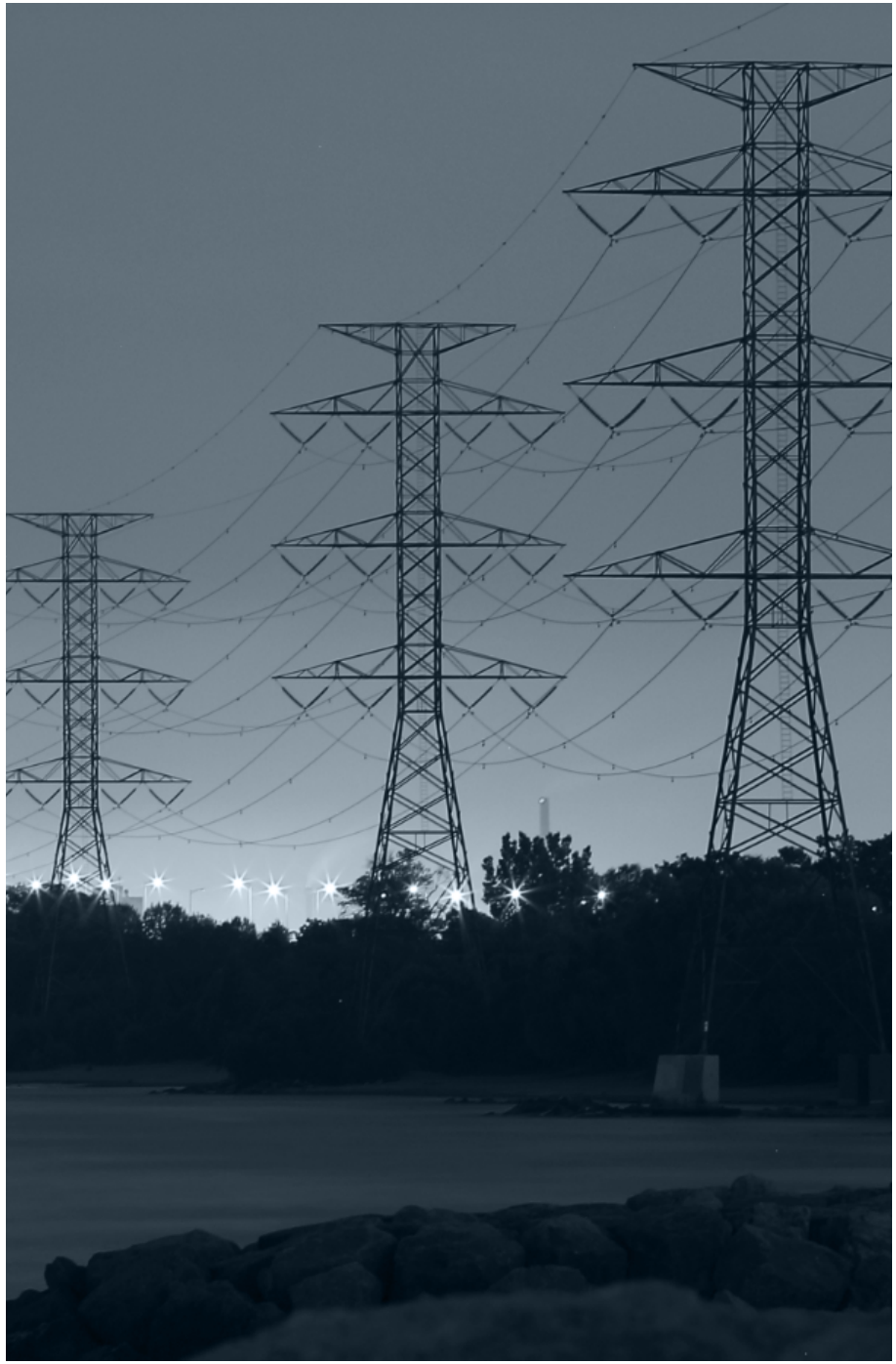



Figure 59 - Case 1B System unit costs





# ///// Case 2 - Growth of Comercial Solar & Storage

This case assumes penetration of commercial solar PV and energy storage also grows in response to decreasing unit costs and rising tariffs, and combines with residential solar to impact the network.

**Assumptions**

This scenario assumes that growth in private residential solar and storage capacity is augmented by growth in the commercial sector. Two versions of this case are considered:

- Case 2A - growth in business solar PV penetration commences in 2015; and
- Case 2B - growth in business solar PV is accompanied by future growth in private energy storage.

The growth mechanisms and assumptions are described in headings *Residential solar and Commercial Solar* in Chapter //. In both cases the growth in overall electricity demand, and network configuration is as described for Base Case B.

**Growth in Solar PV**

The payback periods for solar PV in the commercial sector are somewhat lower[14] than for the residential sector because the peak demand occurs earlier in the day. (Refer to Fig. 32) Therefore, the takeup is rapid, leading to over 40% of businesses having solar PV by 2035. (Refer to Fig. 60)

By 2035 there could be nearly 6000 MW of business solar capacity and average array sizes could approach 90 kW.

Over the longer term this growth will have a knock-on effect in the growth of residential solar and storage as it will lead to increased unit costs on the SWIS (see Chapter /////) and therefore further improve payback periods. By 2035 this increases the residential solar capacity by around 5% and increases the storage capacity penetration in comparison to the previous case (from 22% to 29% of houses).

When combined with the residential solar capacity, the model suggests that some 9,000 MW (nameplate) of private solar capacity could exist in the SWIS catchment by 2035. This is over 1.5 times the capacity of the SWIS network, although operating at a much lower capacity factor of about 0.18. (Refer to Fig. 61 and 62)

**Network impacts from business solar growth**

The combined impact of business solar on top of residential solar and storage has a significant impact on average network loads but much less impact on maximum loads. (Refer to 63 and 64)

By 2027 there is over 3,000 MW of solar capacity in businesses. At peak this will generate some 2,550 MW of power, exceeding the network demand at some hours of the day and times of year[15]. The model assumes that this excess power is “floated”, i.e. is not exported to the network (nor subject to REBS payments). This energy is therefore essentially lost. Never the less the addition of this quantity of solar decreases system costs (Refer to Fig.66) but reduces energy demand more significantly. (Refer to Fig. 65) The combined effect reverses the trend in

14 Payback periods increase slightly when the array size reaches the point where so much energy is generated that it is exported at the lower REBS rate. Eventually the reducing unit cost offsets and then reverses this trend. This phenomenon is not evident in the residential model as average array sizes are beyond this point at the outset of the simulation.

15 There are significant implications for the network arising from this which are discussed in Section 7 of the Report

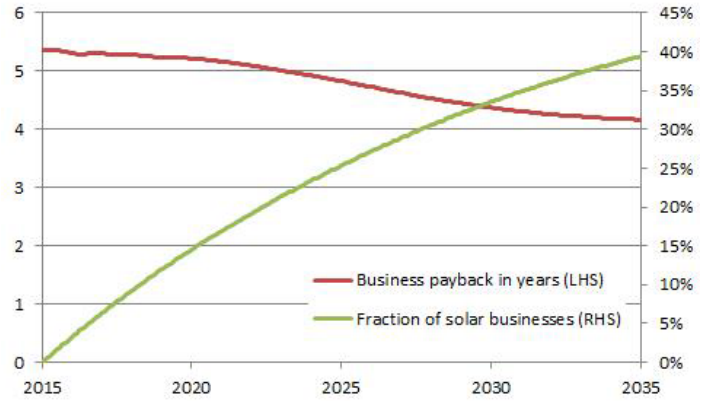



Figure 60 - Case 2A Business solar growth

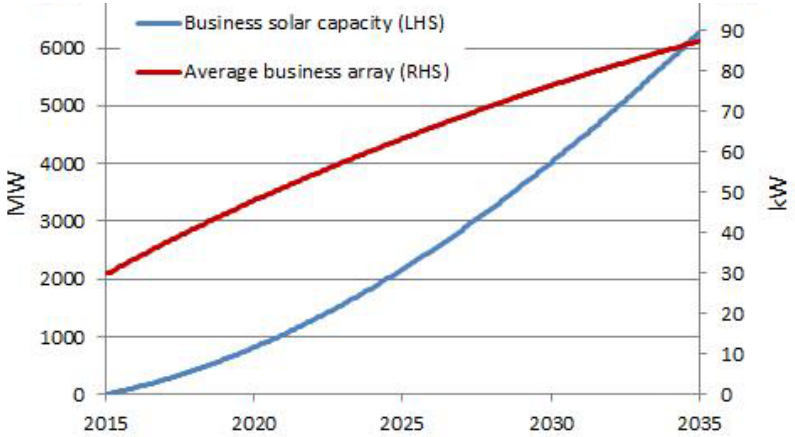



Figure 61 - Case 2A Total business solar capacity

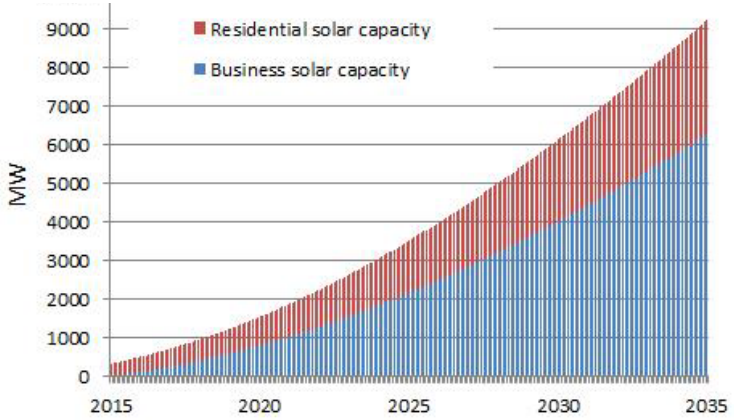



Figure 62 - Case 2A Total residential and business solar capacity

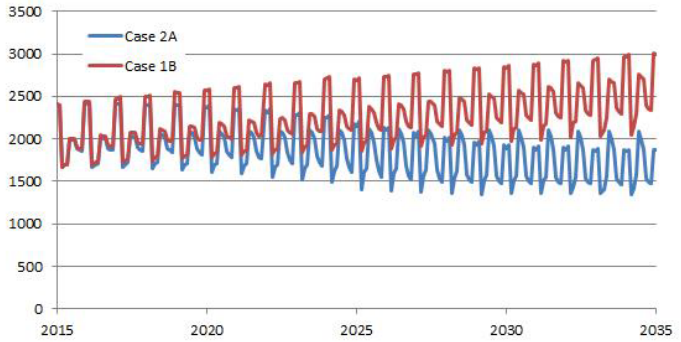



Figure 63 - Case 2A Average hourly network loads (MW)

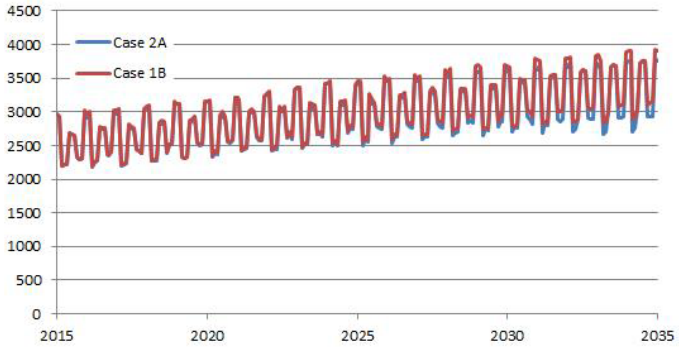



Figure 64 - Case 2A Maximum hourly network loads (MW)

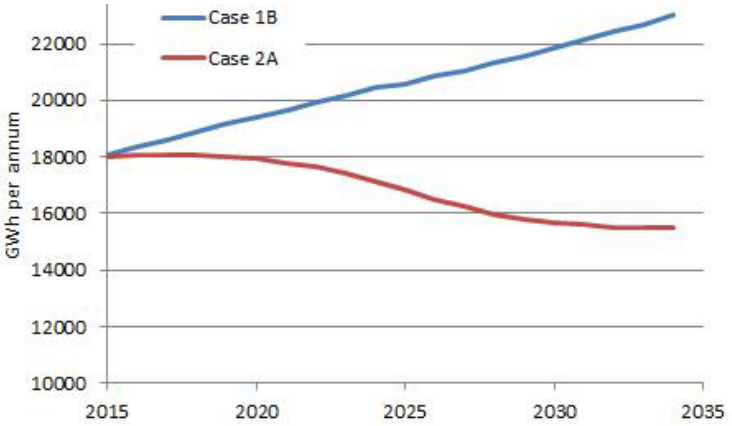



Figure 65 - Case 2A Annual network energy

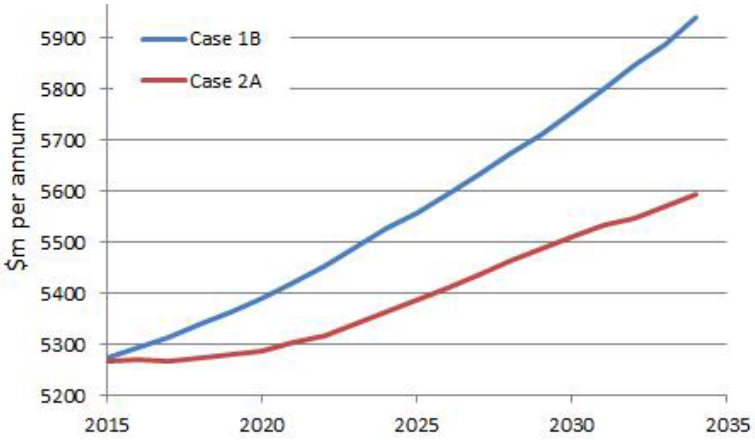


Figure 66 - Case 2A Annual system costs

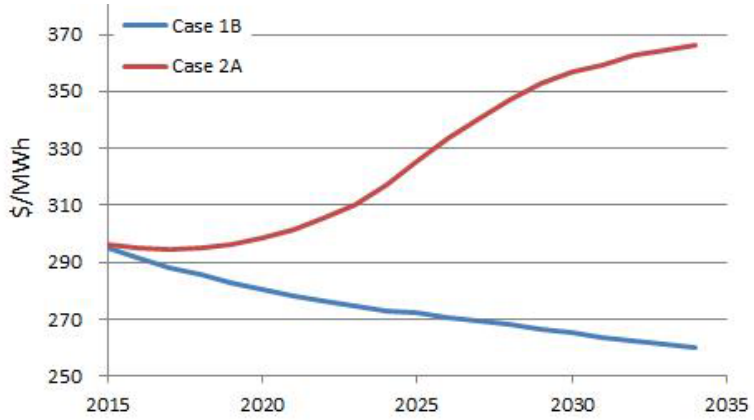


Figure 67 - Case 2A System unit costs

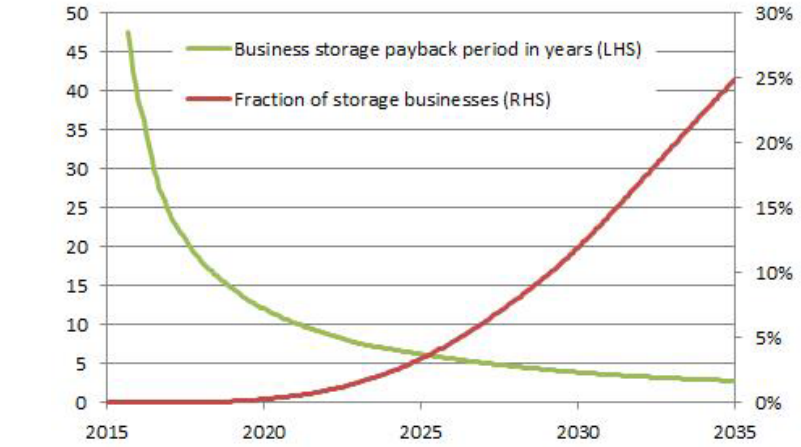


Figure 68 - Case 2B Business storage growth



unit cost reductions seen in previous case, and they now rise markedly (20%) over the simulation period. (Refer to Fig. 67)

**Business Energy Storage**

In Case 2B business energy storage is added to the model. The model suggests that by 2035 some 25% of businesses could have storage, which is over half of all those with solar PV. (Refer to Fig. 68)

This growth would see some 8,500 MWh of private business storage by 2035, complementing the 3,000 MWh of residential storage. (Refer to Fig. 69)

**Network impacts from business solar and storage growth**

Case 2B represents the combined effects of residential and business solar PV and storage on the SWIS. This case represents the most likely trajectory in the market for the combination of solar PV and storage, i.e. that the present growth of solar PV in the residential market will be replicated in the commercial sector, and that storage will complement these systems over time as unit costs and payback periods reduce.

As expected, the addition of storage to the model has little impact on average hourly network loads. Maximum network load are reduced as energy released from storage offsets peak demands. (Refer to Fig. 70 and 71)

Storage ameliorates the excess generation problem somewhat and accordingly the net energy consumed in Case 2B is marginally lower than Case 2A. System costs are reduced due to lower overall and peak generation but there is still a slight increase in unit costs towards the end of the simulation period. (Refer to Fig. 72, 73 and 74)

In the case of residential solar, the introduction of storage did not change the total quantity of energy generated on the SWIS, but reduced system costs so that unit costs were reduced. However, this phenomenon is not apparent in the case of business storage.

In the no-storage case for businesses, (Case 2A) there is substantial over-generation and this energy is lost and must be replaced by energy from the SWIS. In the storage case, the over-generation is reduced, meaning less energy in total is required from the SWIS. So, even though system costs fall under this scenario, unit costs rise. There is simply not sufficient storage to take full advantage of the amount of solar energy generated.

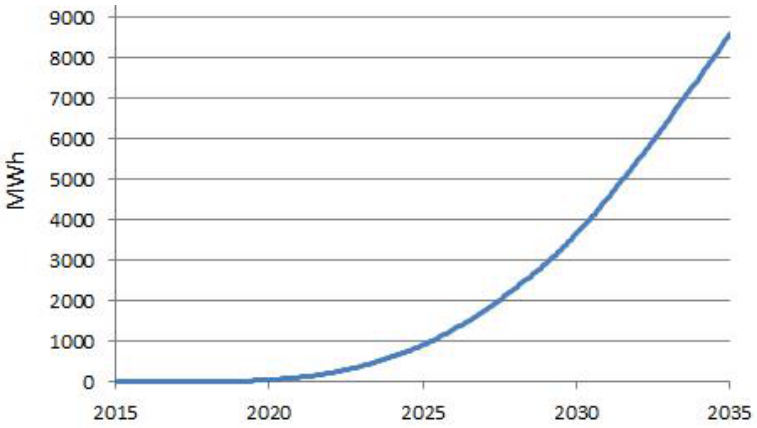



Figure 69 - Case 2B Business storage capacity

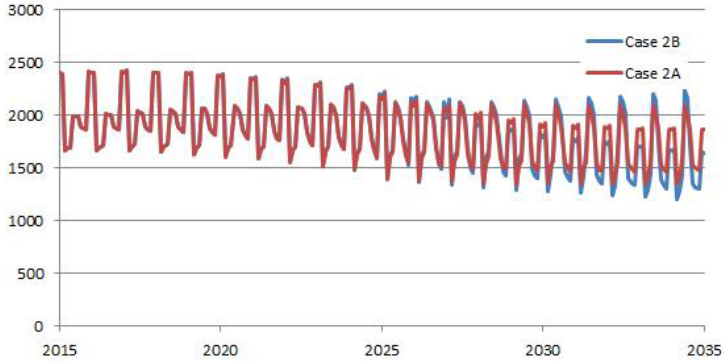



Figure 70 - Case 2B Average hourly network loads (MW)

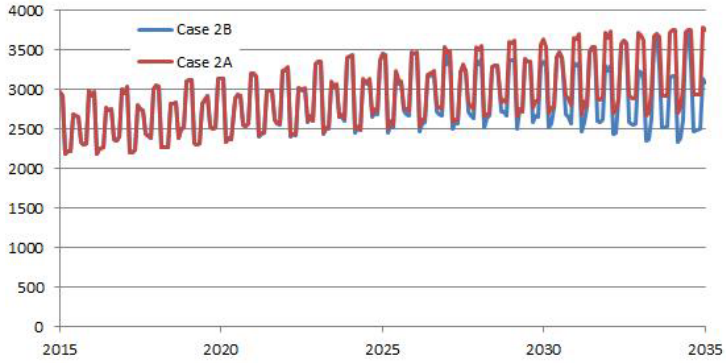



Figure 71 - Case 2B Maximum hourly network loads (MW)



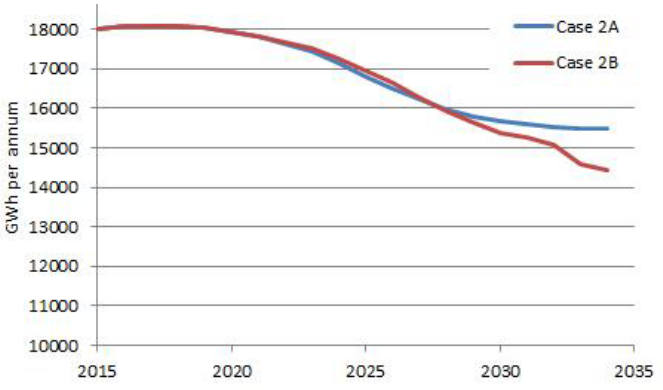



Figure 72 - Case 2B Annual network energy

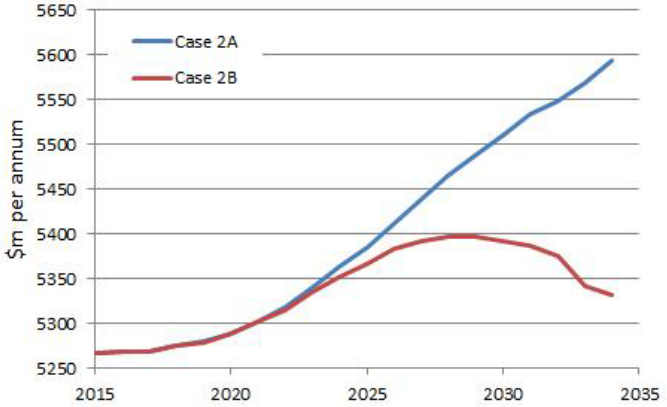



Figure 73 - Case 2B Annual system costs

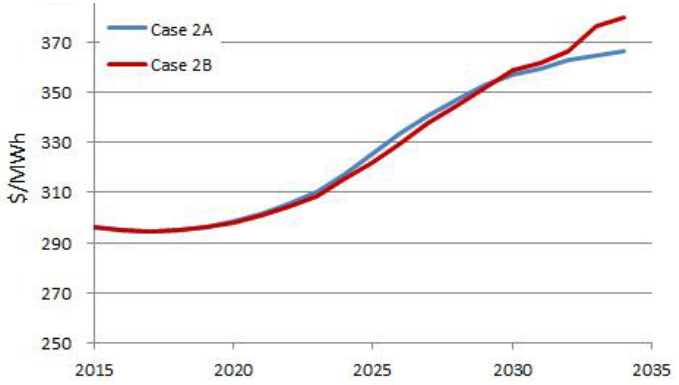



Figure 74 - Case 2B System Unit Costs

# /////// Case 3 - Solar Growth Without Storage

This case assumes growth in private solar in both residential and commercial premises as in the previous case but without storage.

**Assumptions**
To complete the range of scenarios considered, Case 3 examines the implications of residential and business solar growth considered in Case 2 but without storage.

**Network Implications**
Without storage, less solar energy is available to reduce the network peaks and accordingly maximum network loads are higher. Minimum network loads are lower than the storage case but the average network loads and annual energy are somewhat higher. (Refer to Fig. 75, 76 and 77)

As more network energy is required without storage, system costs are higher and unit costs are somewhat lower. (Refer to Fig. 78 and 79)

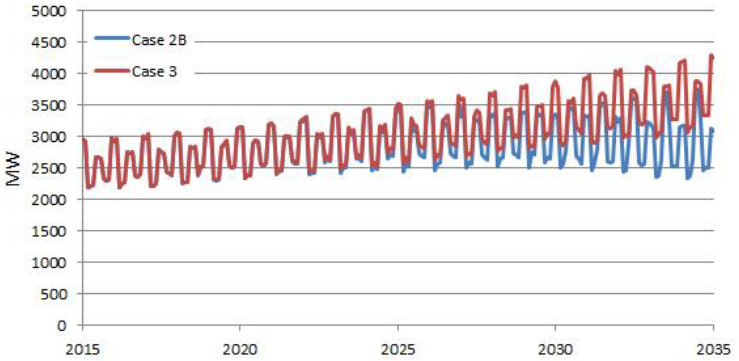



Figure 75 - Case 3 Maximum hourly network loads

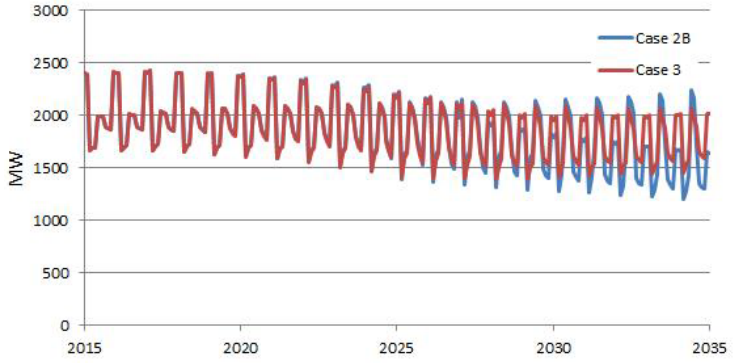



Figure 76 - Case 3 Average hourly network loads

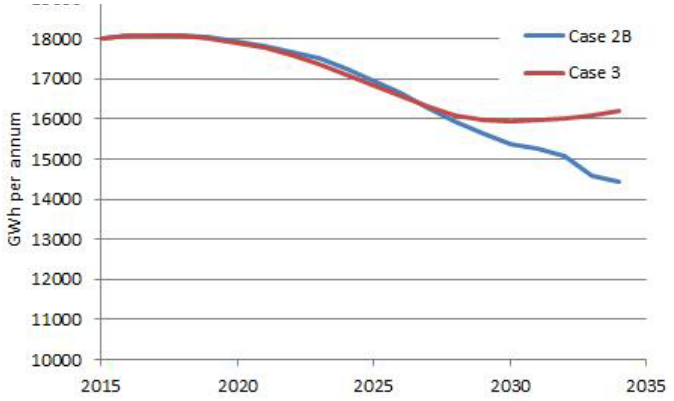



Figure 77 - Case 3 Annual network energy

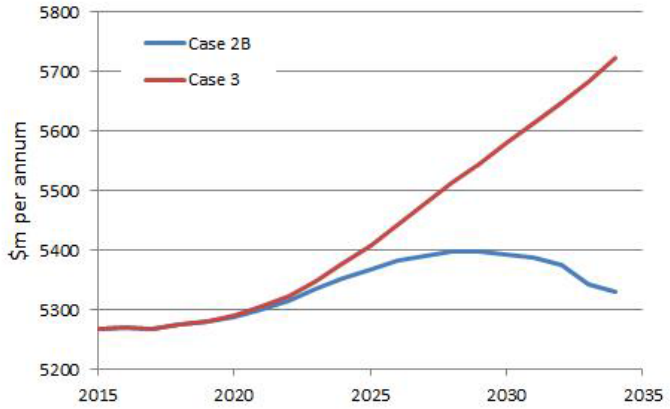



Figure 78 - Case 3 Annual system costs

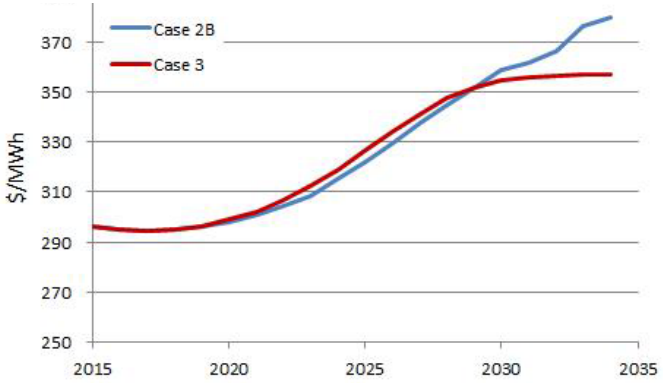



Figure 79 - Case 3 System unit costs

# //////// The Implications of the Model Results

Private solar capacity could be as high as 3,000 MW by 2024 and 9,000 MW by 2035 causing intermittent over-generation on the SWIS by 2020 when minimum network loads fall below the normal operating capacity of baseload coal generation.

**Limitations**
It needs to be stressed that the model results are not "predictions". They are plausible scenarios based on well-established principles of system dynamics but dependent on the inherent assumptions (as is the case for all models). The most important implications are to be drawn from the system trajectory (i.e. behaviour over time) rather than the precise magnitude of the values or the dates at which they occur.

The model seeks to replicate the essential systemic behaviour only, and accordingly does not attempt to portray any short term issues affecting the network such as maintenance backlogs or delayed tariff increases. These of course may result in substantial variation from the model results, particularly in the short term.

**Likely Growth of Solar PV**
In a recent report the IMO forecast the growth of private solar to grow linearly for the coming decade to reach approximately 1000 MW of nameplate capacity by 2024. (Refer to Fig. 80)

In contrast the model, which is based on an increasing takeup as payback periods reduce, suggests that this figure could be as high as 3,000 MW by 2024 and 3 times that figure by 2035. (Refer to Fig. 62)

Linear growth in dynamic systems is in fact unusual as it requires growth rates to decrease on an annual basis. Exponential growth is a more common phenomenon, and is usually observed in the time histories of innovative technologies, including solar PV takeup in Australia[16].

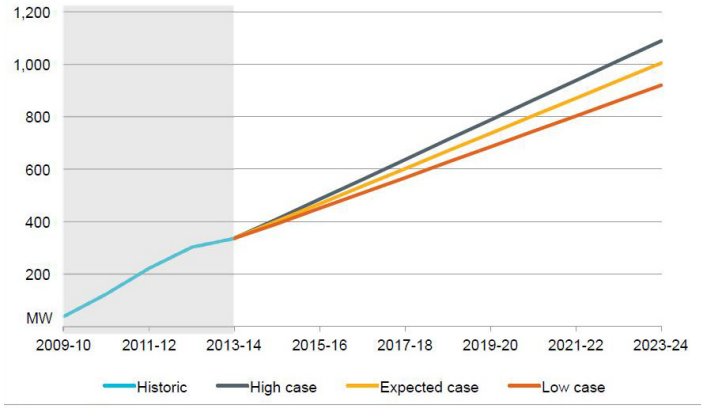
Although growth in the commercial sector has been slower than residential to date, as awareness grows and unit prices decline, this is potentially the largest contributor to growth by far. As noted previously, payback periods are lower for commercial systems because there is a better match between solar generation and demand, and time of use tariffs are higher during peak periods.

**Network loads**
The most dramatic effect on the network of growth in solar penetration of this scale is seen in the impact on minimum loads on the network. (Refer to Fig. 81) This illustrates the impact of growing solar exports to the network during daytime periods in general and in summer in particular.

This situation arises from the modelled growth in solar generation which, by early 2031 results in solar energy available for export from private systems beginning to exceed total electricity demand during daytime hours[17]. (Refer to Fig. 82)

The lead up to this circumstance is shown in Figure 83, which depicts the so-called "duck curve". This encapsulates the problem for networks of accommodating highly varying daytime solar generation.

16 http://apvi.org.au/wp-content/uploads/2014/07/PV-in-Australia-Report-2013.pdf
17 Exports are highest in spring and autumn when solar generation is substantial and electricity demands are modest. The figure represents the situation with private storage. Without storage, this situation would occur several years earlier.




Source: IMO/NIEIR

Figure 80 - IMO Solar penetration forecast

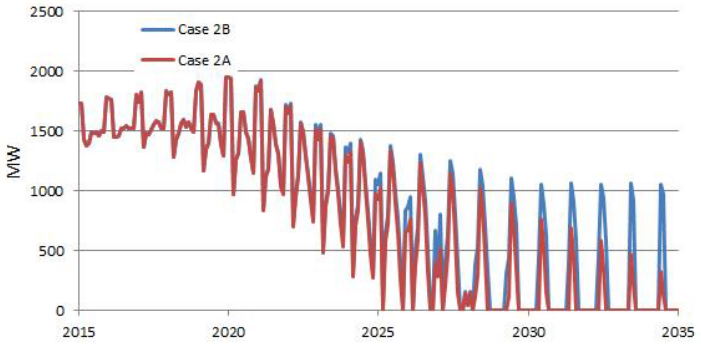



Figure 81 - Minimum hourly network loads

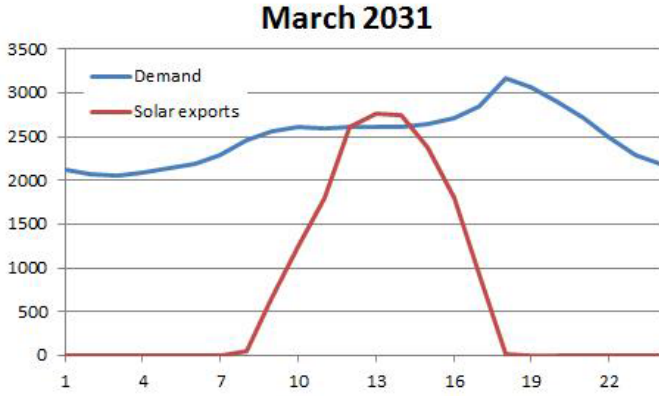



Figure 82 - Solar exports

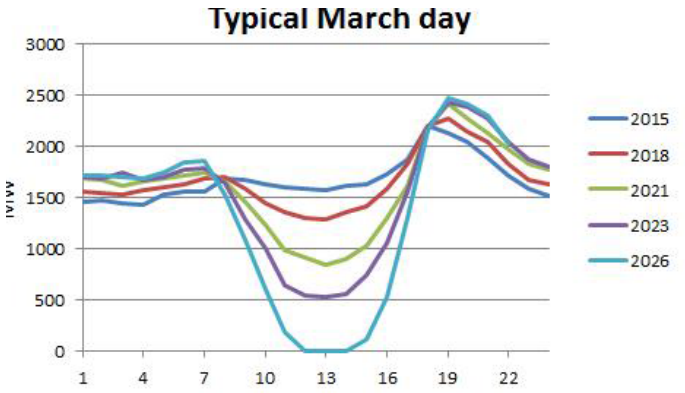



Figure 83 - Case 2B SWIS Duck curve

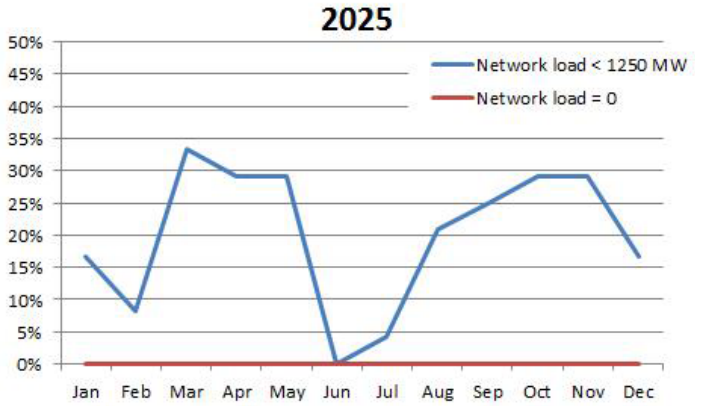



Figure 84 - Over-generation risk by 2025

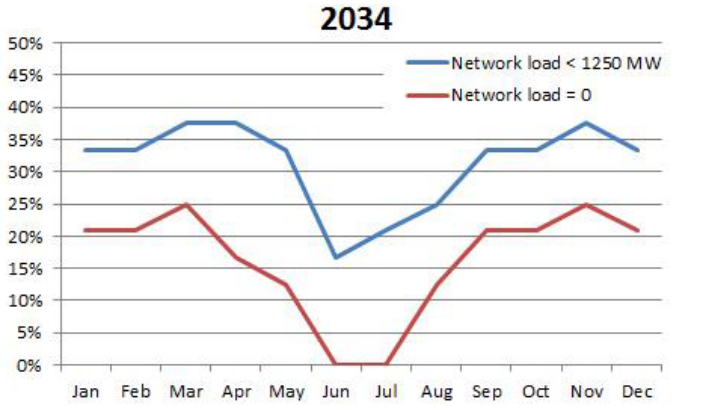



Figure 85 - Over-generation risk by 2034

This suggests that there could be an intermittent over-generation problem by 2020 when minimum network loads fall below the normal operating capacity of baseload coal generation, which is intended to run consistently, and cannot be readily cycled down and up in a matter of hours. Steep ramping of generation is required in the hours of declining solar generation. A similar situation has been identified by the California Independent System Operator[18].

Figure 84 and Figure 85 show the % of hours in each month that network loads may reach over-generation and zero generation points.

Over the longer term the "hollowing-out" of network load would likely require a different configuration of generation type on the network.

Private energy storage ameliorates the impacts of solar generation on the network as it reduces both the peak and average energy demands (Fig. 75 and 76), thus lowering system costs in total and in per MWh terms.

With projected growth in storage lagging the growth in solar PV, storage only partially offsets the over-generation problem. By the end of the simulation period there is only around 1.4 hours of storage (at nameplate). This means that the amount of over-generation from solar will likely continue to increase, albeit to a lesser extent than without storage. (Refer to Fig. 86)

**Network Energy and System Costs**

All of the cases considered result in lower annual energy required from the network than the Base Case. (Refer to Fig. 87) In the unlikely case that solar and storage growth is restricted to residential premises some 15% less energy will be needed from the SWIS to meet electricity demand. If the more likely case that business premises also adopt private solar and storage there would be a dramatic reduction in required energy, both in relative (45%) and absolute terms (15%).

A reduced energy demand translates to reduced system costs. (Refer to Fig. 88) Under Case 2B (residential and business solar and storage) system costs would rise only slowly, and then potentially fall to near current costs. This occurs due partly to a 450 MW reduction in the capacity of the network (assumed mainly related to coal generation), which induces savings in the cost of capacity credits. However, this neglects any ongoing debt obligations associated with this generation capacity which, while not a direct cost to the SWIS, is a cost to publicly owned entities and hence the taxpayer. The costs of writing off this debt are not included in this study.

If tariffs presently delivered $295 / MWh the SWIS would recover all costs. The model suggests that unit costs will fall from this figure under the Base Case conditions, and for modest residential only growth in solar and storage. However, under the cases that consider the business takeup of this technology, it is likely that although overall system

18 http://www.caiso.com/documents/flexibleresourceshelprenewables_fastfacts.pdf



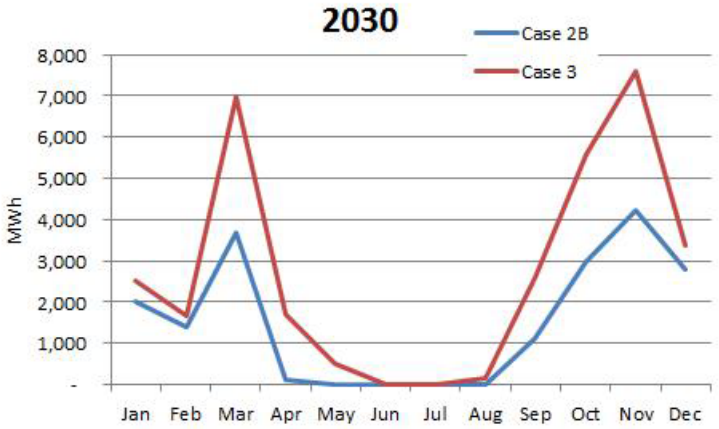



Figure 86 - Typical day over-generation

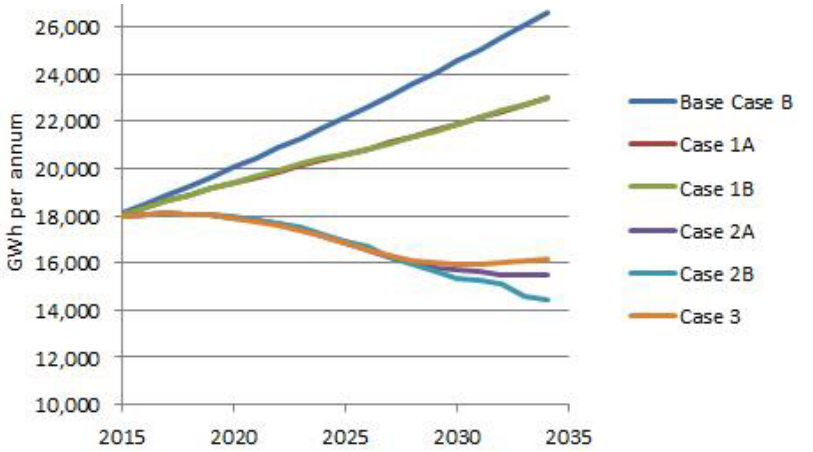



Figure 87 - Annual network energy

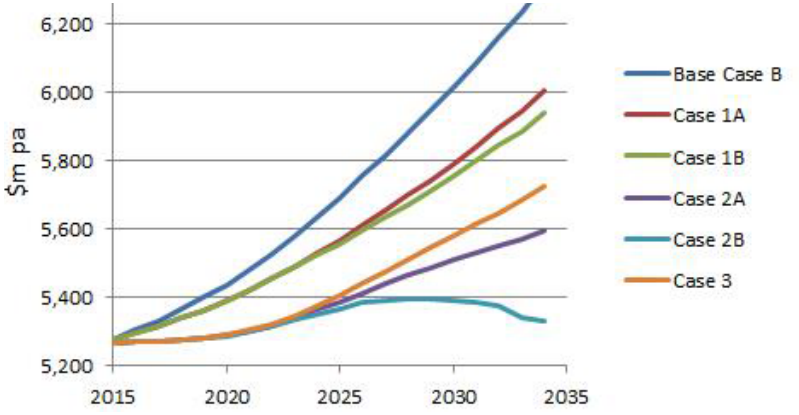



Figure 88 - Annual system costs

costs will decrease, unit costs will increase substantially. (Refer to Fig. 89)

Although reduced system costs indicate that increased solar penetration will lead to an overall economic benefit, a rise in unit costs is still problematical. Individual consumers, who for one reason or other cannot reduce their network energy consumption sufficiently to offset tariff increases, will pay more for energy under this scenario. As this group will include those who are least able to absorb the additional cost, equity will become an important element of the policy response.

### A Broader Perspective on Costs

Of course the SWIS costs do not represent all the costs incurred, as they do not take into account the private investments in solar PV and battery storage. The model tracks these costs and accrues them over time to enable a more complete cost comparison of the options. (Refer to Fig. 90)

These range between $3bn and $15bn for the various cases. The highest is for Case 2B that envisages residential and business solar and storage[19]. The net annual savings for the SWIS identified in Figure 88 accrue to around $7.6 bn so the 20 year accumulation of private and SWIS costs are almost the same. (Refer to Fig. 91)

### The Influence of Tariff Increases

Part of the death spiral metaphor is that increasing solar penetration will lead to higher tariffs which will only improve the cost-benefit equation further. By default the model increases existing household and business tariffs pro-rata to system unit cost increases. However, the influence of increasing tariffs is easily tested by "switching off" tariff increases in the model. As identified by Figure 92, the tariff increases are not the main driver of reduced paybacks. The reducing unit cost of solar PV has much more influence than increasing tariffs.

Accordingly restricting tariff increases have almost no influence on the capacity of private solar. (Refer to Fig. 93)

### Greenhouse Gas Emissions

The Base Case indicates that greenhouse gas emissions could rise by around 20%. The most likely scenario, i.e. growth in private residential and business solar and storage would reverse this and deliver reductions of around 25%. However, even this contribution would be insufficient to meet the requirements of a credible emission reduction target for south west Western Australia. (Refer to Fig. 94)

19 These figures ignore operating and maintenance costs and replacement accruals.



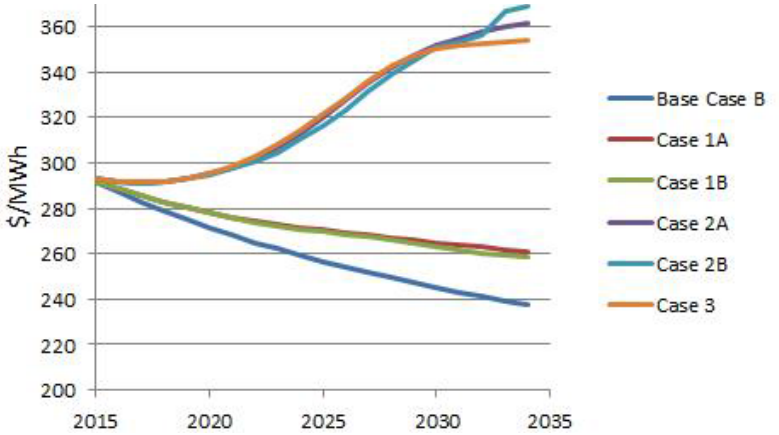



Figure 89 - System unit costs

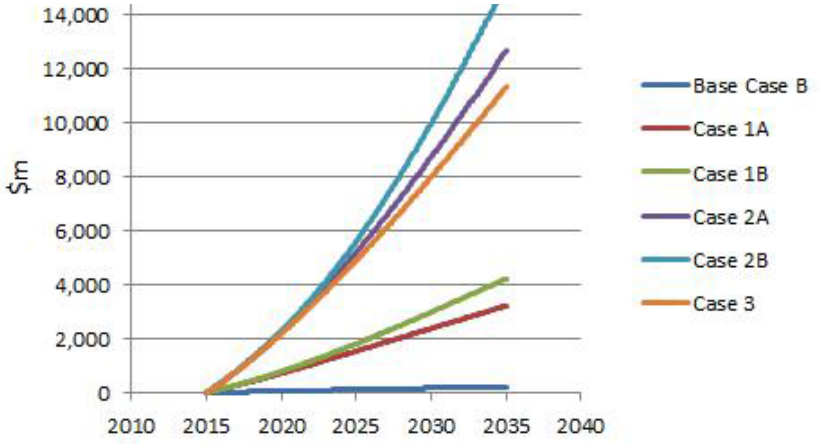



Figure 90 - Private investment in solar / storage

Figure 91 - 20 year public and private expenditures on energy

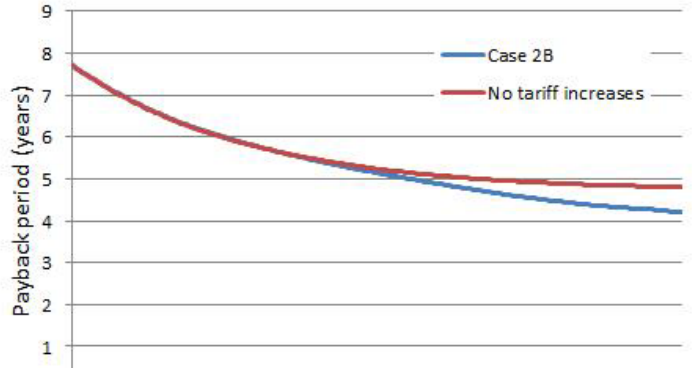



Figure 92 - Influence of tariffs on payback periods

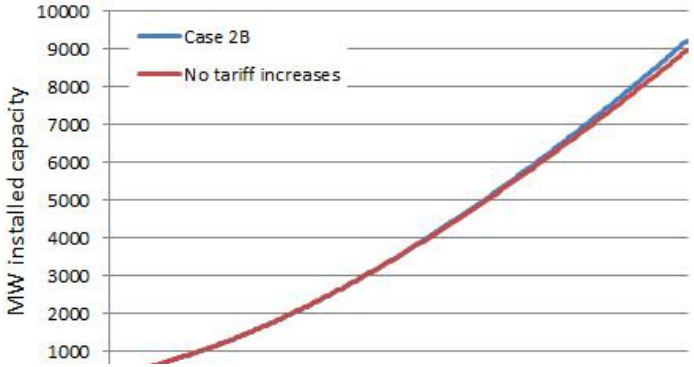



Figure 93 - Influence of tariffs on solar capacity

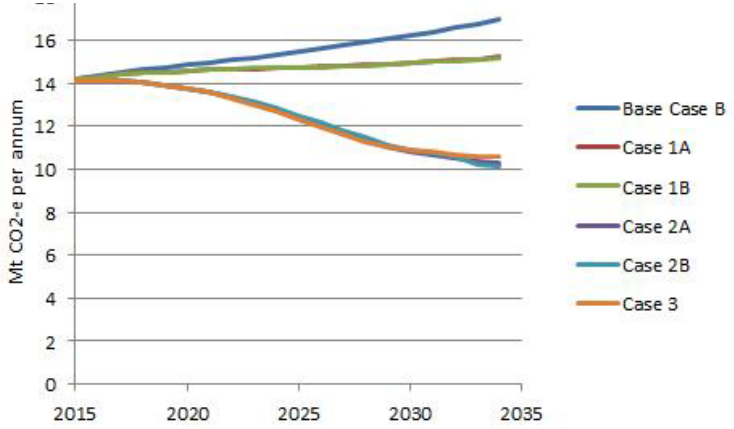



Figure 94 - Greenhouse gas emissions

# //////// Policy Response

A coherent long term energy strategy is required to address the major implications for the network arising from the inevitable consumer-led growth of private solar, and the public policy need for renewable energy at the network scale to replace fossil fuels.

**Transition Strategy**

The current review of the Wholesale Electricity Market (WEM) is mostly focussed on understanding the reasons for recent major increases in electricity prices and exploring market and tariff structures that will contain future cost increases on the assumption that the system will continue to operate as in the past. Unfortunately, the review does not address the obvious need for a much more fundamental transition to a completely different energy future.

This need arises from the dependence of the SWIS on fossil fuel generation, a situation that cannot continue irrespective of the current political environment. One of two eventualities will trigger a transition away from fossil fuels:

- Restrictions on their use arising from concerted action to reduce global greenhouse gas emissions; and / or
- Rising fuel costs associated with global demand and diminishing economically viable reserves.

Although WA's reserves of both coal and gas may seem large in comparison to local demand, it is the global supply and demand equation that will determine local availability and cost, and these pressures are already being felt in respect of the price of natural gas. Recent modelling of "peak" fossil fuels[20] suggests that peak years will be 2024–2046 for gas, and 2042–2062 for coal. Even if supply is not dampened through action on global warming, prices will inevitably and steadily rise forever thereafter.

Electricity industry investments are made for decades and so it is essential that the future energy generation mix and network strategy is established now to ensure that new investments minimise the risk of stranded assets.

It is argued by some that the current overcapacity on the SWIS means there is no room for more renewables on the network. However, as this study identifies, the growth of renewables in the form of private solar is inevitable and will have major implications for the network irrespective of changes likely to arise from the WEM review. The energy system will change and, therefore, the implications of this study should be considered in the context of this broader transition for which a coherent long term energy strategy is required. The inevitable increase in the take up of private solar PV systems in WA homes and businesses will merely hasten a transformation of the electricity network during the coming decade that is needed anyway.

**An Integrated Energy Policy**

The growth of private solar PV is being driven by global forces which are leading to lower unit costs for solar PV panels and economies of scale are driving down balance of system costs. Although it may be affected in the short term by various factors, Western Australia cannot escape the reality of this momentous technological shift.

The days of the electricity industry being the sole provider of energy services to consumers are over. The industry must necessarily re-envision itself as a part

20 Maggio, G., Cacciola, G. When will oil, natural gas, and coal peak? Fuel 98 (2012) 111-113

provider of a service that (many) customers already partly have. In other words, they are competing with their customers and their response to this challenge will determine where the balance between network and private assets eventually lies. Policy must drive the most efficient economic outcome, not seek to "protect" the existing industry players[21]. Lower emissions and lower total energy costs are positive outcomes for society and should be embraced, not resisted. While the fact that Synergy and Western Power are state owned enterprises obviously must influence policy, it should not cloud the fact that major change is inevitable. The future energy system must effectively and efficiently integrate private and network generation.

**Baseload Generation and Network Storage**

This study identifies that excess solar generation in daytime hours will create an over-generation problem on the network in the coming decade, initially in the mid-seasons and then in the summer. This will require either network baseload generation to be intermittently reduced and / or private solar generation to be "floated". The former is problematical from the operational perspective and the latter wastes energy that has no marginal cost. Although private storage will ameliorate this situation somewhat, the capacity of private storage will not be sufficient to eliminate it.

The only way to avoid the steep ramping evident in Figure 83 is to introduce network storage into the SWIS. This could potentially occur at existing substation sites which dispatch and receive electricity from the private systems in homes and businesses[22]. Storage at this "downstream" scale would logically be complemented by larger scale storage "upstream" aimed at smoothing supply and demand from network generation. This would be part of a strategy to transition generation from fossil fuels to renewables, many of which are intermittent in nature, e.g. wind.

The introduction of storage within the network itself, if commenced soon enough and with appropriate policy settings (e.g. a higher REBS rate), could potentially "head off" the growth in private storage modelled in this study. Economies of scale will mean lower costs per MWh for network scale storage, and if this was of sufficient scale to store all excess private solar generation, this could lead to the encouragement of solar while disincentivising private storage.

21 http://www.businessspectator.com.au/article/2014/10/15/energy-markets/how-electricity-industry-blocking-solar-australia?utm_source=exact&utm_medium=email&utm_content=954503&utm_campaign=cs_daily&modapt=

22 Although not covered in this study, storage at this scale could also facilitate decentralised micro-grids operating at the precinct / suburb scale.

# Appendix A - Modelled initial electricity demand

**Annual residential demand in MW (Total = 5.572 GWh)**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 461 | 461 | 364 | 364 | 364 | 461 | 461 | 461 | 364 | 364 | 364 | 461 |
| 2 | 401 | 401 | 304 | 304 | 304 | 401 | 401 | 401 | 304 | 304 | 304 | 401 |
| 3 | 389 | 389 | 291 | 291 | 291 | 389 | 389 | 389 | 291 | 291 | 291 | 389 |
| 4 | 389 | 389 | 291 | 291 | 291 | 389 | 389 | 389 | 291 | 291 | 291 | 389 |
| 5 | 401 | 401 | 304 | 304 | 304 | 401 | 401 | 401 | 304 | 304 | 304 | 401 |
| 6 | 474 | 474 | 364 | 364 | 364 | 546 | 546 | 546 | 461 | 461 | 461 | 474 |
| 7 | 510 | 510 | 486 | 486 | 486 | 753 | 753 | 753 | 583 | 583 | 583 | 510 |
| 8 | 607 | 607 | 522 | 522 | 522 | 850 | 850 | 850 | 619 | 619 | 619 | 607 |
| 9 | 631 | 631 | 510 | 510 | 510 | 765 | 765 | 765 | 571 | 571 | 571 | 631 |
| 10 | 668 | 668 | 504 | 504 | 504 | 729 | 729 | 729 | 534 | 534 | 534 | 668 |
| 11 | 704 | 704 | 486 | 486 | 486 | 668 | 668 | 668 | 510 | 510 | 510 | 704 |
| 12 | 735 | 735 | 498 | 498 | 498 | 631 | 631 | 631 | 510 | 510 | 510 | 735 |
| 13 | 789 | 789 | 510 | 510 | 510 | 607 | 607 | 607 | 510 | 510 | 510 | 789 |
| 14 | 850 | 850 | 522 | 522 | 522 | 607 | 607 | 607 | 510 | 510 | 510 | 850 |
| 15 | 911 | 911 | 595 | 595 | 595 | 607 | 607 | 607 | 516 | 516 | 516 | 911 |
| 16 | 972 | 972 | 680 | 680 | 680 | 716 | 716 | 716 | 607 | 607 | 607 | 972 |
| 17 | 1,081 | 1,081 | 741 | 741 | 741 | 935 | 935 | 935 | 729 | 729 | 729 | 1,081 |
| 18 | 1,178 | 1,178 | 947 | 947 | 947 | 1,214 | 1,214 | 1,214 | 874 | 874 | 874 | 1,178 |
| 19 | 1,154 | 1,154 | 959 | 959 | 959 | 1,251 | 1,251 | 1,251 | 972 | 972 | 972 | 1,154 |
| 20 | 1,105 | 1,105 | 862 | 862 | 862 | 1,214 | 1,214 | 1,214 | 935 | 935 | 935 | 1,105 |
| 21 | 1,008 | 1,008 | 735 | 735 | 735 | 1,093 | 1,093 | 1,093 | 826 | 826 | 826 | 1,008 |
| 22 | 850 | 850 | 631 | 631 | 631 | 935 | 935 | 935 | 704 | 704 | 704 | 850 |
| 23 | 668 | 668 | 486 | 486 | 486 | 704 | 704 | 704 | 486 | 486 | 486 | 668 |
| 24 | 486 | 486 | 340 | 340 | 340 | 486 | 486 | 486 | 340 | 340 | 340 | 486 |
| per day (MWh) | 17,421 | 17,421 | 12,933 | 12,933 | 12,933 | 17,354 | 17,354 | 17,354 | 13,352 | 13,352 | 13,352 | 17,421 |
| per month (GWh) | 530 | 530 | 393 | 393 | 393 | 528 | 528 | 528 | 406 | 406 | 406 | 530 |

Annual commercial/ industrial demand in MW (Total = 12.912 GWh)

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1,423 | 1,423 | 1,164 | 1,164 | 1,164 | 1,167 | 1,167 | 1,167 | 1,197 | 1,197 | 1,197 | 1,423 |
| 2 | 1,438 | 1,438 | 1,198 | 1,198 | 1,198 | 1,173 | 1,173 | 1,173 | 1,238 | 1,238 | 1,238 | 1,438 |
| 3 | 1,425 | 1,425 | 1,199 | 1,199 | 1,199 | 1,156 | 1,156 | 1,156 | 1,255 | 1,255 | 1,255 | 1,425 |
| 4 | 1,427 | 1,427 | 1,212 | 1,212 | 1,212 | 1,169 | 1,169 | 1,169 | 1,280 | 1,280 | 1,280 | 1,427 |
| 5 | 1,497 | 1,497 | 1,237 | 1,237 | 1,237 | 1,244 | 1,244 | 1,244 | 1,352 | 1,352 | 1,352 | 1,497 |
| 6 | 1,569 | 1,569 | 1,219 | 1,219 | 1,219 | 1,304 | 1,304 | 1,304 | 1,366 | 1,366 | 1,366 | 1,569 |
| 7 | 1,815 | 1,815 | 1,165 | 1,165 | 1,165 | 1,375 | 1,375 | 1,375 | 1,517 | 1,517 | 1,517 | 1,815 |
| 8 | 1,935 | 1,935 | 1,249 | 1,249 | 1,249 | 1,442 | 1,442 | 1,442 | 1,562 | 1,562 | 1,562 | 1,935 |
| 9 | 2,059 | 2,059 | 1,338 | 1,338 | 1,338 | 1,527 | 1,527 | 1,527 | 1,612 | 1,612 | 1,612 | 2,059 |
| 10 | 2,105 | 2,105 | 1,375 | 1,375 | 1,375 | 1,498 | 1,498 | 1,498 | 1,640 | 1,640 | 1,640 | 2,105 |
| 11 | 2,154 | 2,154 | 1,389 | 1,389 | 1,389 | 1,505 | 1,505 | 1,505 | 1,669 | 1,669 | 1,669 | 2,154 |
| 12 | 2,206 | 2,206 | 1,386 | 1,386 | 1,386 | 1,513 | 1,513 | 1,513 | 1,676 | 1,676 | 1,676 | 2,206 |
| 13 | 2,237 | 2,237 | 1,369 | 1,369 | 1,369 | 1,523 | 1,523 | 1,523 | 1,695 | 1,695 | 1,695 | 2,237 |
| 14 | 2,247 | 2,247 | 1,365 | 1,365 | 1,365 | 1,510 | 1,510 | 1,510 | 1,710 | 1,710 | 1,710 | 2,247 |
| 15 | 2,221 | 2,221 | 1,312 | 1,312 | 1,312 | 1,525 | 1,525 | 1,525 | 1,719 | 1,719 | 1,719 | 2,221 |
| 16 | 2,188 | 2,188 | 1,268 | 1,268 | 1,268 | 1,487 | 1,487 | 1,487 | 1,649 | 1,649 | 1,649 | 2,188 |
| 17 | 2,039 | 2,039 | 1,311 | 1,311 | 1,311 | 1,486 | 1,486 | 1,486 | 1,553 | 1,553 | 1,553 | 2,039 |
| 18 | 1,826 | 1,826 | 1,331 | 1,331 | 1,331 | 1,549 | 1,549 | 1,549 | 1,425 | 1,425 | 1,425 | 1,826 |
| 19 | 1,771 | 1,771 | 1,250 | 1,250 | 1,250 | 1,442 | 1,442 | 1,442 | 1,395 | 1,395 | 1,395 | 1,771 |
| 20 | 1,785 | 1,785 | 1,224 | 1,224 | 1,224 | 1,340 | 1,340 | 1,340 | 1,310 | 1,310 | 1,310 | 1,785 |
| 21 | 1,690 | 1,690 | 1,224 | 1,224 | 1,224 | 1,279 | 1,279 | 1,279 | 1,248 | 1,248 | 1,248 | 1,690 |
| 22 | 1,587 | 1,587 | 1,161 | 1,161 | 1,161 | 1,194 | 1,194 | 1,194 | 1,171 | 1,171 | 1,171 | 1,587 |
| 23 | 1,523 | 1,523 | 1,167 | 1,167 | 1,167 | 1,148 | 1,148 | 1,148 | 1,230 | 1,230 | 1,230 | 1,523 |
| 24 | 1,479 | 1,479 | 1,246 | 1,246 | 1,246 | 1,220 | 1,220 | 1,220 | 1,255 | 1,255 | 1,255 | 1,479 |
| per day (MWh) | 43,646 | 43,646 | 30,357 | 30,357 | 30,357 | 32,778 | 32,778 | 32,778 | 34,724 | 34,724 | 34,724 | 43,646 |
| per month (GWh) | 1,328 | 1,328 | 923 | 923 | 923 | 997 | 997 | 997 | 1,056 | 1,056 | 1,056 | 1,328 |

Total annual electricity demand in MW (Total = 18.484 GWh)

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1,885 | 1,885 | 1,528 | 1,528 | 1,528 | 1,628 | 1,628 | 1,628 | 1,561 | 1,561 | 1,561 | 1,885 |
| 2 | 1,839 | 1,839 | 1,502 | 1,502 | 1,502 | 1,574 | 1,574 | 1,574 | 1,541 | 1,541 | 1,541 | 1,839 |
| 3 | 1,813 | 1,813 | 1,490 | 1,490 | 1,490 | 1,545 | 1,545 | 1,545 | 1,547 | 1,547 | 1,547 | 1,813 |
| 4 | 1,815 | 1,815 | 1,503 | 1,503 | 1,503 | 1,558 | 1,558 | 1,558 | 1,572 | 1,572 | 1,572 | 1,815 |
| 5 | 1,897 | 1,897 | 1,540 | 1,540 | 1,540 | 1,645 | 1,645 | 1,645 | 1,656 | 1,656 | 1,656 | 1,897 |
| 6 | 2,043 | 2,043 | 1,583 | 1,583 | 1,583 | 1,851 | 1,851 | 1,851 | 1,827 | 1,827 | 1,827 | 2,043 |
| 7 | 2,326 | 2,326 | 1,650 | 1,650 | 1,650 | 2,128 | 2,128 | 2,128 | 2,100 | 2,100 | 2,100 | 2,326 |
| 8 | 2,542 | 2,542 | 1,771 | 1,771 | 1,771 | 2,292 | 2,292 | 2,292 | 2,182 | 2,182 | 2,182 | 2,542 |
| 9 | 2,690 | 2,690 | 1,848 | 1,848 | 1,848 | 2,293 | 2,293 | 2,293 | 2,182 | 2,182 | 2,182 | 2,690 |
| 10 | 2,773 | 2,773 | 1,879 | 1,879 | 1,879 | 2,226 | 2,226 | 2,226 | 2,175 | 2,175 | 2,175 | 2,773 |
| 11 | 2,859 | 2,859 | 1,875 | 1,875 | 1,875 | 2,173 | 2,173 | 2,173 | 2,179 | 2,179 | 2,179 | 2,859 |
| 12 | 2,941 | 2,941 | 1,884 | 1,884 | 1,884 | 2,145 | 2,145 | 2,145 | 2,186 | 2,186 | 2,186 | 2,941 |
| 13 | 3,027 | 3,027 | 1,879 | 1,879 | 1,879 | 2,130 | 2,130 | 2,130 | 2,205 | 2,205 | 2,205 | 3,027 |
| 14 | 3,097 | 3,097 | 1,887 | 1,887 | 1,887 | 2,117 | 2,117 | 2,117 | 2,220 | 2,220 | 2,220 | 3,097 |
| 15 | 3,132 | 3,132 | 1,907 | 1,907 | 1,907 | 2,132 | 2,132 | 2,132 | 2,235 | 2,235 | 2,235 | 3,132 |
| 16 | 3,159 | 3,159 | 1,948 | 1,948 | 1,948 | 2,204 | 2,204 | 2,204 | 2,256 | 2,256 | 2,256 | 3,159 |
| 17 | 3,120 | 3,120 | 2,052 | 2,052 | 2,052 | 2,421 | 2,421 | 2,421 | 2,282 | 2,282 | 2,282 | 3,120 |
| 18 | 3,004 | 3,004 | 2,278 | 2,278 | 2,278 | 2,764 | 2,764 | 2,764 | 2,300 | 2,300 | 2,300 | 3,004 |
| 19 | 2,924 | 2,924 | 2,210 | 2,210 | 2,210 | 2,693 | 2,693 | 2,693 | 2,367 | 2,367 | 2,367 | 2,924 |
| 20 | 2,890 | 2,890 | 2,087 | 2,087 | 2,087 | 2,555 | 2,555 | 2,555 | 2,245 | 2,245 | 2,245 | 2,890 |
| 21 | 2,698 | 2,698 | 1,959 | 1,959 | 1,959 | 2,372 | 2,372 | 2,372 | 2,074 | 2,074 | 2,074 | 2,698 |
| 22 | 2,437 | 2,437 | 1,792 | 1,792 | 1,792 | 2,129 | 2,129 | 2,129 | 1,875 | 1,875 | 1,875 | 2,437 |
| 23 | 2,191 | 2,191 | 1,653 | 1,653 | 1,653 | 1,852 | 1,852 | 1,852 | 1,716 | 1,716 | 1,716 | 2,191 |
| 24 | 1,965 | 1,965 | 1,586 | 1,586 | 1,586 | 1,706 | 1,706 | 1,706 | 1,595 | 1,595 | 1,595 | 1,965 |
| per day (MWh) | 61,066 | 61,066 | 43,290 | 43,290 | 43,290 | 50,132 | 50,132 | 50,132 | 48,076 | 48,076 | 48,076 | 61,066 |
| per month (MWh) | 1,857 | 1,857 | 1,317 | 1,317 | 1,317 | 1,525 | 1,525 | 1,525 | 1,462 | 1,462 | 1,462 | 1,857 |

# Appendix B - Modelled solar generation

**kW generated/ kW capacity**

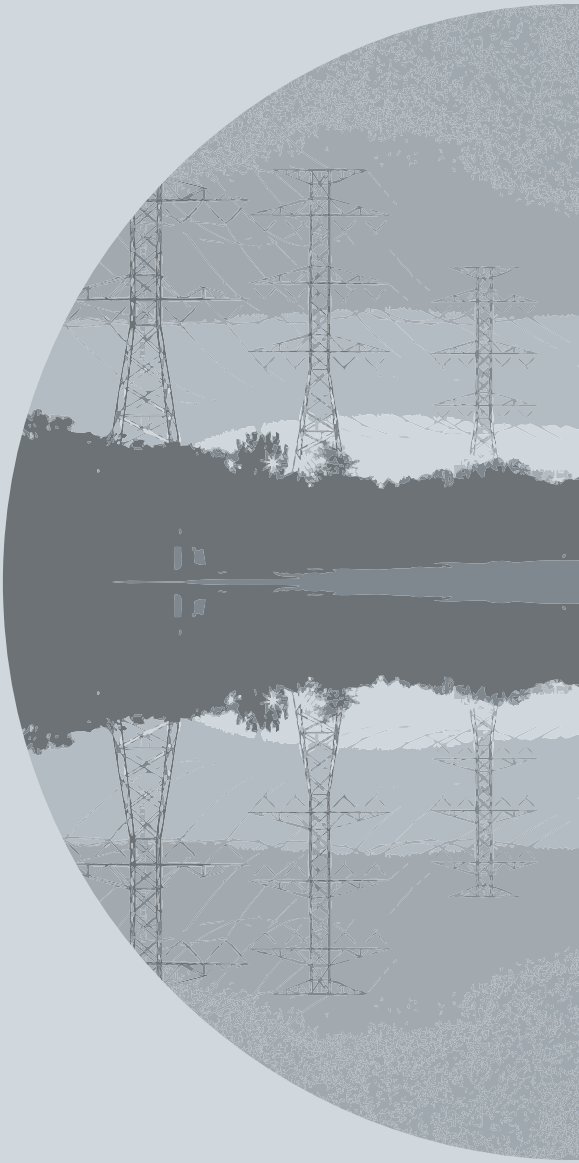
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 7 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 |
| 8 | 0.19 | 0.18 | 0.15 | 0.12 | 0.10 | 0.08 | 0.09 | 0.11 | 0.14 | 0.16 | 0.17 | 0.18 |
| 9 | 0.37 | 0.35 | 0.31 | 0.23 | 0.21 | 0.17 | 0.18 | 0.22 | 0.27 | 0.31 | 0.34 | 0.36 |
| 10 | 0.56 | 0.53 | 0.46 | 0.35 | 0.31 | 0.25 | 0.28 | 0.33 | 0.41 | 0.47 | 0.50 | 0.55 |
| 11 | 0.70 | 0.66 | 0.58 | 0.43 | 0.39 | 0.31 | 0.35 | 0.41 | 0.51 | 0.59 | 0.63 | 0.68 |
| 12 | 0.76 | 0.72 | 0.62 | 0.47 | 0.42 | 0.34 | 0.37 | 0.45 | 0.55 | 0.63 | 0.68 | 0.74 |
| 13 | 0.77 | 0.74 | 0.64 | 0.48 | 0.43 | 0.34 | 0.38 | 0.46 | 0.56 | 0.65 | 0.70 | 0.75 |
| 14 | 0.76 | 0.72 | 0.62 | 0.47 | 0.42 | 0.34 | 0.37 | 0.45 | 0.55 | 0.63 | 0.68 | 0.74 |
| 15 | 0.68 | 0.65 | 0.56 | 0.42 | 0.38 | 0.30 | 0.34 | 0.40 | 0.50 | 0.57 | 0.61 | 0.66 |
| 16 | 0.55 | 0.52 | 0.46 | 0.34 | 0.31 | 0.24 | 0.27 | 0.33 | 0.40 | 0.46 | 0.50 | 0.54 |
| 17 | 0.37 | 0.35 | 0.31 | 0.23 | 0.21 | 0.17 | 0.18 | 0.22 | 0.27 | 0.31 | 0.34 | 0.36 |
| 18 | 0.19 | 0.18 | 0.15 | 0.12 | 0.10 | 0.08 | 0.09 | 0.11 | 0.14 | 0.16 | 0.17 | 0.18 |
| 19 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 |
| 20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

# Contributor

**Adjunct Professor Bill Grace**
Urban sustainability specialist

The electricity industry worldwide is talking about the so-called death spiral. Under this scenario conventional electricity networks are undermined by customers reducing their energy demand through energy efficiency measures and / or private generation, mainly rooftop solar photovoltaic panels (PV). Both processes reduce the quantum of electricity purchased from the network, thereby reducing revenue to the network. As many of the network costs are fixed, this necessarily implies increasing unit costs and therefore increasing tariff charges for electricity. The tariff increases merely exacerbate the problem – hence the “spiral” reference.

In this study these issues are considered in the context of Western Australia’s south-west interconnected system (SWIS).



© Australian Urban Design Research Centre **AUDRC** 2014