

Sundown, sunrise: Technical Appendices

June 2015

Grattan Institute Support

Founding members



Australian Government



Program support

Higher Education



Affiliate Partners

Google

Origin Foundation

Senior Affiliates

EY

PwC

The Scanlon Foundation

Wesfarmers

Affiliates

Ashurst

Corrs

Deloitte

Jacobs

Mercy Health

Urbis

Westpac

Grattan Institute Report No. 2015-2, Technical Appendices

These technical appendices were prepared to accompany the Grattan Institute Report, *Sundown, Sunrise: How Australia can finally get solar power right*. The purpose is to present the data and methodology used in the analysis, with a discussion exploring robustness and sensitivity.

The opinions in this report and the technical appendix are those of the authors and do not necessarily represent the views of Grattan Institute's founding members, affiliates, individual board members reference group members or reviewers. Any remaining errors or omissions are the responsibility of the authors.

Grattan Institute is an independent think-tank focused on Australian public policy. Our work is independent, practical and rigorous. We aim to improve policy outcomes by engaging with both decision-makers and the community.

For further information on the Institute's programs, or to join our mailing list, please go to: <http://www.grattan.edu.au/>

The technical appendices may be cited as:

Wood, T., Blowers, D., and Chisholm, C., 2015, *Sundown, Sunrise, Technical Appendices*, Grattan Institute

All material published or otherwise created by Grattan Institute is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 3.0 Unported License

Overview

There were two major pieces of analysis in this report. The first aimed to quantify the aggregate costs and benefits to the Australian economy that have arisen and will arise due to the nearly 1.4 million solar PV systems that have been installed in Australia. This involved separately estimating each cost and benefit. Part of this analysis also involved calculating cross-subsidies that have gone from consumers without solar PV to those with solar PV, both due to government policy and due to the structure of electricity tariffs.

The second piece of analysis looked at the costs and benefits of solar PV from the perspective of a household. This analysis was undertaken for each state capital city. The costs and benefits were explored in terms of the current pricing structure of electricity, as well as under a change to more cost-reflective pricing, due to come in in 2017.

This piece of analysis was extended to assess the economics of battery storage for a household with a solar PV system already installed. This involved analysing how a small battery could be used for a grid-connected household, and also explored the required combination of solar PV and battery storage for a household to disconnect from the grid.

A number of data sources are used in both pieces of analysis. Appendix A outlines the data and simulation methods used across both pieces of analysis. Appendix B outlines the methodology for the economy-wide analysis, including a sensitivity analysis to examine the robustness of the results to different assumptions. Appendix C outlines the methodology used for the household-level analysis. All tables and figures supporting the analysis are displayed in Appendix D.

Table of contents

A Data and simulation	5
B Economy-wide analysis	11
C Household economics of solar PV and battery storage.....	20
D Tables and Figures	25

A Data and simulation

The analysis undertaken in this report utilises a number of data sources, including electricity consumption and associated survey data, weather data including temperature and solar radiation, pricing data from various sources and a range of other data. The consumption and weather data are used to simulate both household electricity consumption and solar PV output for every half-hour period over 15 years. These are simulated separately for different locations, different solar panel orientations, and different household sizes. Most analysis uses the simulated electricity consumption of an 'average' household, and the solar PV output of an optimally aligned system.¹

This Appendix outlines these data sources and the methodology used for the simulation in more detail.

A.1 Data sources

A.1.1 Electricity consumption data

Interval meter consumption data were provided by the Victorian Department of Economic Development, Jobs, Transport and Resources.² Electricity consumption of 673 households is recorded half-hourly over

¹Consumption of the 'average' household closely reflects average consumption across all households, but still takes into account variation in consumption across the day and across different days. It can be thought of as being the consumption profile of a 'typical' household. The optimally aligned solar PV system, in terms of maximising output, is north facing with a tilt of between 20 and 40 degrees to the horizontal.

²Victorian Government (2014).

a period extending from June 2010 until February 2013.³ Consumption data are linked with survey data from the same households, including information on household size, income, appliance use, and whether there were solar panels on the roof.

The Household Energy Consumption Survey (HECS), collected by the ABS in 2012 across all states, includes similar demographic and location variables to the Victorian interval meter data. This survey also includes information on household electricity consumption at different times of the year.

Aggregated state electricity demand data measured half-hourly are available from the Australian Energy Market Operator (AEMO) from 1999 to 2013.⁴ The same data are obtained from the Independent Market Operator (IMO) for Western Australia from 2006 to 2013.

A.1.2 Weather data

Temperature and humidity data from the Bureau of Meteorology (BOM) measured half-hourly from 17 weather stations across Victoria are linked with the interval meter consumption data. Each household is linked with the closest weather station by distance.

The simulation of consumption in other locations is based on temperature and humidity data from weather stations across the country, measured from 1999 to 2013. Global solar radiation data measured

³Households provided about one year of data on average.

⁴AEMO (2015b).

daily from the same weather stations across the same time period are used to simulate daily output from solar PV.

A.1.3 Miscellaneous data

The Clean Energy Regulator has publicly available data showing the number of solar PV systems and total capacity installed in every post-code Australia-wide for every month since the beginning of 2011. The total installations and capacity from 2001 to 2010 are also recorded by postcode.

Electricity price data are taken from the major retailers in each state and territory.⁵ Where competition exists between retailers, the best available electricity market offer is taken from Tier 1 retailers. Only single-rate tariff offers are considered, since these are the most common tariff structure across the country.

Solar PV total installation prices by system size are based on the Clean Energy Regulator's publication of the average out-of-pocket expense per kilowatt (reported quarterly), and on the Solar Choice publication of the average price per kilowatt (reported monthly and for various system sizes) where the CER data are not available.⁶

Independent regulators in each state determined a 'fair and reasonable' feed-in tariff for solar power exported to the grid, taking into account a weighted average of the wholesale price of the electricity displaced, as well as any benefit arising from the fact that solar energy

⁵Energy Australia (2015), Origin Energy (2015), AGL (2015), Aurora Energy (2015), Synergy (2015) and Power and Water Corporation (2014).

⁶CER (2015a) and Solar Choice (2015).

is generated much closer to where it is consumed than centralised generation.⁷

Emissions-intensity data of electricity produced in the National Electricity Market are available for each of the eastern states. This is reported half-hourly from 2011 until 2015.⁸

A.2 Simulation

A.2.1 Simulation of solar PV output

Solar PV output is simulated half-hourly across a year by calculating the amount of direct solar radiation falling on a one kilowatt solar PV system with an arbitrary orientation and tilt, taking into account latitude and longitude, and the elevation and azimuth angle of the sun, assuming perfectly sunny days.⁹ These calculations are then adjusted using daily global solar radiation data from 1999 to 2013.

It is possible to obtain greater accuracy of solar output using solar radiation data measured over more frequent intervals, where direct and diffuse radiation are separately measured.¹⁰ The approximate measure used in this analysis takes into account that solar output is highest in the middle of the day, but does not take into account natural

⁷IPART (2012), ESC (2014), QCA (2013), ESCOSA (2014), Synergy (2014) and OTTER (2015). Note that Synergy is the retailer in Western Australia, not the independent regulator.

⁸AEMO (2015a).

⁹The azimuth at a point in time is defined as the angle between the shadow cast by a vertical rod and due south.

¹⁰Direct radiation is the main form of energy captured by solar panels, which is the radiation direct from the sun to the earth's surface. Diffuse radiation is sunlight that has been scattered (such as by clouds) but still reaches the earth's surface.

variation in output across the day.¹¹ However, average daily output across different times of the year is accurately measured.

Solar PV output is simulated separately for each capital city, based on a weather station location in a middle suburb, and again for a regional weather station in each state or territory. Most analysis assumes that the solar panels are north-facing with a 30-degree tilt (essentially optimally aligned to maximise output), but orientation and tilt are easily adjusted for in the simulation, as is the efficiency of solar panels.

A.2.2 Simulation of household consumption

The purpose of this simulation is to obtain a household electricity consumption profile that is close to the average, but also looks like a typical consumption profile, taking into account variation across different times of the day and across different days.¹² Interval consumption data from Victoria are used to estimate a regression model of consumption, from which consumption profiles are simulated for each capital city and the balance of states and territories.

Interval consumption data

Interval meter data for 673 households are measured half-hourly over a period of nearly three years, with households providing an average of one year of data. This results in almost 10 million observations. Unfortunately only net electricity consumption is measured, not the consumption and exports of energy produced by solar PV. Because of

¹¹For example, it does not take into account that cloud cover might be present in the morning, but not in the afternoon.

¹²A consumption profile is a measure of how a household's consumption of electricity changes at different times of the day and across the year.

this, the 168 households with solar PV are excluded from the analysis so that simulated consumption of the average household without solar PV is not biased downwards.¹³

Consumption data are likely to be correlated across different dimensions. For each particular household, there will be times of the day when consumption is usually higher and times of the day when it is usually lower. Also, if a household has a higher-than-average level of consumption in one half-hour period, this is more likely to be followed by another period of higher-than-average consumption. Correlations also exist across households. For instance, there are times of the day when aggregate consumption is usually high, and times when it is low. Likewise, aggregate consumption varies across the year. A consumption equation expressing this is written as follows:

$$\text{consumption}_{itd} = \alpha_{it} + \delta_{id} + \gamma_{td} + \varepsilon_{itd}$$

i: household id

t: time of day

d: date

That is, some consumption is determined by household-specific factors that may vary across different times of the day, or across different days (for example, if a household has an electric hot water system, this is likely to affect consumption at certain times of the day, but not at others), while some consumption is determined by factors not specific to the household (such as weather patterns).

¹³Around 25 per cent of households in the sample have solar PV, which is higher than the penetration rate in Victoria. This indicates a potential selection bias issue, with households surveyed more likely to be more concerned about their energy use than the average household. However, many demographic factors are controlled for, which is likely to minimise any selection bias in the simulation.

This equation is used to build a regression model from which electricity consumption is simulated.

Regression analysis

Some of the factors affecting consumption can be controlled for in a regression analysis. A survey of the same households includes demographic information such as the number of people in the household, dwelling structure, household income, age of the oldest resident, and household appliance use (including both gas and electric appliances). The postcode of each household is used to link it to the nearest weather station (17 are used across Victoria), from which half-hourly temperature and humidity data are added. Location type (urban, regional/rural or remote) is also controlled for.

In order to capture as much variation as possible, a separate regression is run for each half-hour period.¹⁴ In order to capture variation specific to households, the regression model contains a household-specific random effects term.¹⁵

In addition to demographic variables, the regressions include calendar effects by including an indicator variable for weekends and public holidays, and a smooth function that takes into account the day of the year, capturing seasonal variation in consumption.

Persistence in consumption (and correlation across time periods) is captured by including functions of lagged consumption for the three

¹⁴This is the approach taken by Hyndman and Fan (2010) in forecasting the density of peak demand for the electricity sector as a whole. Much of the approach described in that paper is utilised in this analysis.

¹⁵Without this term the regression model overestimates the variation in consumption. This is sometimes referred to as a multilevel regression model.

previous half-hour periods, and the same time period on the three previous days. Nonlinear functions of temperature and humidity are also included in the regression model. These include the temperature and humidity recorded by the nearest weather station in the same time period, the previous period, the same time period the previous day, and the maximum, minimum and average temperature over the previous 24 hours.¹⁶ A function of aggregate state demand (taken from AEMO) is also included.

Because electricity consumption is always positive and has a positive skew, the natural logarithm of consumption is used. The regression model takes the following form:

$$\begin{aligned} \ln(\text{consumption})_{itd} = & \beta_{0t} + \beta_{1t}\mathbf{X}_i + f_{1t}(d, \text{weekend}) \\ & + f_{2t} \left\{ \ln(\text{consumption})_{i,t-1,d}, \ln(\text{consumption})_{i,t-1,d-1}, \dots \right\} \\ & + f_{3t}(\text{temperature}_t, \text{humidity}_t, \text{temperature}_{t-1}, \dots) \\ & + f_{4t}(\text{AEMO}_t) + \lambda_{it} + \varepsilon_{itd} \\ & t = 1, \dots, 48 \end{aligned}$$

$$\lambda_{it} \sim \mathcal{N}(0, \sigma_{\lambda_t}^2)$$

$$\varepsilon_{itd} \sim \mathcal{N}(0, \sigma_{\varepsilon_t}^2)$$

$$\text{corr}(\lambda_{it}, \varepsilon_{itd}) = 0$$

i : household ID t : time of day d : day of the year

Here, \mathbf{X}_i contains observed household-specific variables. The functions f_{1t} , f_{2t} , f_{3t} and f_{4t} are assumed to be smooth and additive in their components, and are estimated using cubic regression splines. Household-specific effects (λ_{it}) and the error term are assumed to

¹⁶This captures how demand for electricity responds to changes in temperature.

be normally distributed. This assumption is convenient for estimation, but it is useful to note that the natural logarithm of consumption has a skewness parameter of -0.196, and excess kurtosis of 0.277, so the normal distribution is a reasonable approximation.

The key parameters to estimate for each time period are β_{0t}, β_{1t} , the functional forms of f_{1t} to f_{4t} , $\sigma_{\lambda t}$ and $\sigma_{\varepsilon t}$. The parameters in the regression equation can be estimated by ordinary least squares, but estimating $\sigma_{\lambda t}$ and $\sigma_{\varepsilon t}$ separately requires the expectation-maximisation algorithm. This algorithm is extremely computationally intensive when run on the entire sample. Instead, the ratio of $\sigma_{\varepsilon t}^2$ to the overall variance, $\sigma_{\lambda t}^2 + \sigma_{\varepsilon t}^2$, is estimated on a much smaller subsample.¹⁷ The remaining parameters, and the overall variance, $\sigma_{\lambda t}^2 + \sigma_{\varepsilon t}^2$, are estimated using ordinary least squares. The estimates of the overall variance are then used to update the estimates of $\sigma_{\lambda t}$ and $\sigma_{\varepsilon t}$ taken from the smaller sample using the estimated variance ratio.¹⁸

Simulation

Having estimated a regression model for each time period, it is then possible to simulate consumption profiles for different households in different locations. These consumption profiles are simulated for an average household in each capital city (including Canberra), and for an average household in regional Victoria, New South Wales, Queensland, Western Australia and Northern Territory.¹⁹

¹⁷This subsample involved 20 per cent of households, and 20 per cent of observed consumption intervals for these households.

¹⁸That is, it is assumed that the variance ratio estimated in the smaller sample holds for the larger sample.

¹⁹The average household in Adelaide and Hobart are assumed to be representative of their respective states.

The key assumption for this is that the electricity consumption habits of households in Victoria are representative of those in other states, having controlled for household demographics, appliance use, temperature and humidity. This is a strong assumption, as there are likely to be state-specific factors not accounted for in the model.²⁰

It is possible to test some aspects of simulated consumption profiles in different areas, such as average daily consumption at different times of the year. However, without interval meter data for other states, it is not possible to test whether the simulated maximum monthly demand is representative.²¹

Each simulation is based on a household with ‘average’ characteristics of their respective location: usually this is a household with a median income, a working family with two or three children (oldest resident below 50), with a reverse-cycle air-conditioning unit, gas or electric hot water, depending on location, and a detached house as opposed to a unit or apartment.²² The household-specific effects, λ_{it} , are set to their mean value (zero) in each simulation.

For the simulated consumption profiles in each capital city, temperature and humidity data are taken from a representative weather station.

²⁰For instance, a household in Brisbane may be more likely to run a heating system on a cold day than a household in Melbourne on a day with the same temperatures.

²¹The maximum monthly household demand in summer and winter appear to be consistent with expectations. The representative household in each city has a higher maximum demand in summer than in winter, except for Sydney and Hobart. This reflects that Hobart households tend to use more electric heating in winter, and less air-conditioning in summer, while Sydney experiences fewer extreme heat days than other cities.

²²Households with these ‘average’ characteristics consume more than the median household, but this is because average consumption is greater than the median.

A regional weather station is used to simulate a representative consumption profile for rural and regional areas in each state. 15 years of half-hourly weather data (temperature and humidity) are used in the simulation to account for natural variation across years: from 1999 until 2013. These are matched with aggregate demand data from AEMO over the same time period.²³

Initial values are chosen for lagged consumption based on the long-term average. The simulation then takes place iteratively, with consumption simulated over 15 years. Data from the Australia-wide Household Energy Consumption Survey are used to test whether the simulated consumption profiles closely correspond to average daily consumption in different locations and different times of the year. In most cases the simulated consumption profiles were close to the average, but where there were discrepancies, consumption profiles were re-simulated using slightly different characteristics to obtain a profile closer to the average (usually this was achieved by modifying the gas appliances in the household, reflecting that the proportion of gas-connected households differs across states and in urban and rural areas).

A.2.3 Simulation results

Table A.1 shows the average simulated consumption in each capital city, the average maximum demand in both summer (December to March) and non-summer (April to November), and the average out-

Table A.1: Simulation results

Averages

City	Consumption (kWh/day)	Max. demand (kW)		Solar output (kWh/kW/day)
		Summer	Non-summer	
Sydney	16.2	4.4	5.3	4.0
Melbourne	13.5	5.4	4.8	3.8
Brisbane	16.0	6.0	5.4	4.2
Adelaide	14.3	5.7	4.4	4.2
Perth	14.6	6.8	4.9	4.4
Hobart	20.5	4.3	7.3	3.5

put of a solar PV system with an optimal tilt, assuming 80 per cent efficiency.

²³AEMO (2015b). AEMO data do not exist before 2005 for Tasmania, while the equivalent data in Western Australia, from IMO, do not exist before 2006. Thus, these states are simulated over a shorter time frame. No aggregate demand data exist for Northern Territory, so the aggregate demand variable is excluded from the regressions used to simulate NT.

B Economy-wide analysis

B.1 Summary

The economy-wide analysis seeks to determine the aggregate costs and benefits to society from the installation of nearly 1.4 million solar PV systems since 2009, including all costs and benefits that have accrued to date, and all costs and benefits that will accrue out to 2030. In addition, the analysis seeks to calculate cross-subsidies from electricity consumers without solar PV to those with solar PV. The costs, benefits and cross-subsidies are reported in 2015 dollars assuming a nominal interest rate of 5 per cent, reflecting the cost of borrowing. Electricity prices are assumed to increase by 3.5 per cent each year in nominal terms.¹

The two main benefits of solar PV have been the avoided cost of electricity generation that solar has displaced, and the avoided carbon emissions in the electricity sector as a result.² The avoided generation benefit is calculated as the total amount of solar PV produced multiplied by the fair and reasonable feed-in tariffs determined in each state. Likewise, the emissions abatement is calculated using the average emissions-intensity of the avoided generation and a carbon price of \$30 a tonne.

¹ Assuming an inflation rate of 2.5 per cent, this is equivalent to a one per cent real increase.

² Households with solar PV have received private benefits greater than the cost of avoided generation, but much of these have come as a result of cross-subsidies from other consumers.

The capital cost of installing these systems is calculated using the average installation price at the time of installation, with the available subsidy under the Small-Scale Renewable Energy Scheme (SRES) added on. Maintenance costs are calculated as \$20 per kilowatt per year, and includes an additional cost for inverter replacement after 10 years (equal to 15 per cent of the out-of-pocket costs).

Cross-subsidies include those paid under the SRES, calculated as the total number of Small-Scale Technology Certificates (STCs) generated multiplied by the average certificate price in each month, and those paid through premium feed-in tariff schemes, calculated as the total amount paid over the life of the scheme less the total benefit of electricity fed back into the grid.³ In both cases the total cross-subsidy is adjusted to reflect the amount from consumers without solar PV to consumers with solar PV (noting that some cross-subsidies are from consumers with solar PV to other consumers with solar PV). Finally, cross-subsidies due to network tariffs are calculated as the amount households with solar PV would pay if they faced a cost-reflective demand tariff instead of the current tariff structure, assuming consumption is the same and that electricity networks are revenue neutral.

³ The premium feed-in tariff cost includes those paid under transitional feed-in tariffs. It is assumed that some households on a premium feed-in tariff scheme will lose access before the closing date of the scheme.

This appendix outlines these assumptions and each of these calculations in detail. Table D.1 on page 26 outlines the results for each state and territory.

B.2 Key assumptions

B.2.1 Baseline scenarios

The baseline scenario used in the cost-benefit analysis (CBA) is a business-as-usual scenario in which no small-scale solar PV systems were installed between 2009 and March 2015. That is, the total power produced by all solar PV systems is replaced by centralised generation. For the purposes of the calculations it is assumed that households do not change their consumption habits after installing solar PV or in response to electricity price changes.

The baseline scenario used to calculate the cross-subsidies is different from that used in the CBA. It considers a scenario where the same number of solar PV systems are installed, but no cross-subsidies exist.⁴ This includes direct cross-subsidies arising from the SRES and premium feed-in tariffs, as well as indirect cross-subsidies arising as a result of network tariffs that are not cost-reflective.

B.2.2 Time frame and interest rate

The analysis calculates the present value of costs and benefits that have arisen due to the nearly 1.4 million small-scale solar PV systems installed since the beginning of 2009 until March 2015. It considers all costs and benefits arising between 2009 and 2030, reported in 2015 dollars, but it does not take into account the costs and benefits of

⁴In reality, the absence of cross-subsidies would greatly reduce the number of systems installed.

solar PV systems that are installed after March 2015. Costs, benefits and cross-subsidies are calculated on the basis of the policy settings presently in place.

The analysis uses a nominal interest rate of 5 per cent to discount future transactions and to adjust past transactions, reflecting the private cost of borrowing, or the opportunity cost of investing funds elsewhere.⁵ This is a low rate by which to discount future transactions, particularly given that the private cost of borrowing is typically higher than 5 per cent. The approach is consistent in the way that past and future transactions are adjusted to their present value. Given that nearly all of the costs of a solar PV system occur at the point of purchase, and the benefits accrue over time, a lower interest rate captures more of the benefits and less of the costs relative to a high interest rate.

It could be argued that the time frame considered for costs and benefits (2009 to 2030) is too short, given that solar PV systems may last longer. But given a relatively low interest rate used to discount future transactions, a shorter time frame is a reasonable compromise to account for uncertainty in the future. The choice of interest rate and the end date of 2030 are explored in a sensitivity analysis in Appendix B.5.

B.2.3 Solar PV output

The economy-wide analysis uses postcode installation data from the Clean Energy Regulator to approximate the number of each system size (1.5 kilowatts, 2 kW, 3 kW, 4 kW, 5 kW) installed in each capital

⁵The term 'interest rate' is used rather than 'discount rate', since it is applied to both past and future transactions. This is sometimes called the cost of capital. This method is equivalent to discounting all transactions from 2009, then adjusting the results to 2015 using the same rate.

city and in the balance of states and territories in 2009 and 2010, and in every month from January 2011 until March 2015.⁶

It is assumed that 75 per cent of solar PV systems are north-facing with a 30 degree tilt and 25 per cent are west-facing with a 30 degree tilt.⁷ The systems are predicted to run at an average efficiency of 75 per cent of their rated capacity, which accounts for inverter losses and shading. It is assumed that all systems produce the same output in 2030 as in 2015.

B.3 Calculation of each cost and benefit

B.3.1 Avoided generation

Avoided generation represents a benefit to the electricity sector in that energy produced by solar PV replaces the need for energy produced by conventional generators. This is true of both the solar energy consumed on site and the solar energy exported to the grid. This benefit is passed onto those with solar PV via reduced spend on electricity usage and income via feed-in tariffs.

Given that the wholesale generation market is currently oversupplied due to decreases in electricity consumption, existing solar PV is unlikely to have had much effect on preventing or delaying new generation infrastructure.⁸ This means the benefits of avoided generation are

⁶CER (2015b).

⁷A north-facing system with a 30 degree tilt is optimally aligned in terms of maximising output. But not all houses that have installed solar PV have a north-facing roof, and some that have installed larger systems have utilised east-facing and west-facing roofs.

⁸According to AER (2014), there is unlikely to be any need for new generation for at least ten years. Solar PV has contributed to declining consumption, but the decline began before the rapid uptake of solar PV, and much of this has been due to reduced energy demand from the manufacturing industry.

almost all avoided fuel and operating costs rather than avoided capital costs.

The average wholesale price of electricity across the eastern states is typically between three and five cents a kilowatt-hour.⁹ But solar PV typically displaces electricity generation in the middle of the day when demand is higher and the marginal cost of electricity is higher.

Independent regulatory bodies in most states have determined a 'fair and reasonable' feed-in tariff for solar energy exported to the grid. This is meant to reflect the average price a household would receive if they were to sell their solar energy on the wholesale market, but also set so that retail electricity prices do not increase for other consumers. In some cases this is set by the state government as a minimum mandated feed-in tariff, while in other states this tariff is used as a guide to retailers.¹⁰

These feed-in tariffs are used to estimate the value of each kilowatt hour of energy produced by solar PV. The total avoided generation benefit is calculated as the total energy produced by solar PV between 2009 and 2030 multiplied by the fair and reasonable feed-in tariff of the state the energy is produced in, appropriately adjusted using the interest rate. The fair and reasonable feed-in tariff used is assumed to increase by 3.5 per cent each year, slightly above inflation.

Over time, the wholesale market may adjust to the changes in electricity demand driven by solar PV by re-balancing baseload, intermediate and peaking power. This might eventually lead to solar PV displacing

⁹AEMO (2015b).

¹⁰The average fair and reasonable feed-in tariff across the capital cities is 6.9 cents per kilowatt-hour in 2015. Higher feed-in tariffs are used in regional Queensland, regional Western Australia, and Northern Territory.

baseload power instead of intermediate and peaking power. If a re-balancing occurs before 2030, this methodology would overstate the avoided generation benefits. This is explored further in Appendix B.5.

B.3.2 Emissions abatement

In the short term, solar PV output displaces more expensive forms of generation in the wholesale market, but this is usually less emissions intensive than the average wholesale generation. But if the wholesale market adjusts over the medium term, solar PV may displace baseload power, typically coal-fired generators.

Total emissions abatement for the period 2009 to 2014 is estimated as the total solar PV output in each year multiplied by the average emissions intensity of the electricity produced in the same state and the same year. Emissions abatement from 2015 to 2030 is based on the average emissions intensity of electricity produced in the second half of 2014 (post carbon tax).¹¹ This approach may overstate the total emissions abatement, at least in the short term.¹²

A carbon price of \$30 per tonne of CO₂ is used to value the total emissions reduction.¹³ Future emissions are not discounted, but it is assumed that the emissions intensity of the electricity sector declines

by 2 per cent per year. Thus, the value to society of emissions abatement is the total estimated emissions abatement between 2009 and 2030 multiplied by the carbon price of \$30.

The value of a tonne of emissions abated is somewhat subjective; many people will value this at a much higher or much lower price than \$30 a tonne. It is currently possible to purchase international permits at far lower prices, and Australia's current centrepiece climate change policy, the Emissions Reduction Fund, purchased its first round of emissions abatement at a price of \$13.95. These prices are likely to increase towards 2030 as emissions become more costly, so \$30 a tonne is a reasonable choice.

The emissions abatement calculation does not consider any CO₂ emissions arising in the production of the solar panels.

B.3.3 Capital costs

The total cost of installing a solar PV system is borne primarily by the household who has it installed, but some of this is covered by a subsidy under the SRES. Estimating the capital cost of each solar PV system installed involves an estimate of the household's out-of-pocket expenses as well as an estimate of the subsidy available at the time.

The out-of-pocket expenses for systems installed between January 2011 and December 2012 are based on data provided by the Clean Energy Regulator.¹⁴ Only an average price per kilowatt per quarter is reported. From January 2013 until March 2015, the average out-of-pocket expense per kilowatt for each system size (1.5 kW, 2 kW, 3 kW, 4 kW and 5 kW) is taken from the Solar Choice website.¹⁵ For

¹¹This is not significantly different to the emissions intensity of electricity before the carbon tax. The average emissions intensity of electricity produced in the eastern states is calculated using data from the Australian Energy Market Operator.

¹²This is because electricity displaced in the short term is more likely to come from peaking power, which typically is less emissions-intensive than baseload power.

¹³That is, Australia would be willing to pay \$30 for every tonne of CO₂ emissions abated. In part, this reflects the societal value of emissions abatement, but also the cost of reducing emissions elsewhere in the economy.

¹⁴CER (2015a).

¹⁵Solar Choice (2015).

systems installed before 2011, a price of \$3,500 per kilowatt is used for out-of-pocket expenses.¹⁶

There are two components to estimating the subsidy under the SRES for each solar PV system: the number of Small-scale Technology Certificates (STCs) the system is eligible for (which depends on location, system size, and the point in time at which the system is installed/registered), and the certificate price at the time of installation.

Systems installed at certain times were eligible for a multiplier on the number of certificates generated for the first 1.5 kilowatts. Secondly, the number of certificates generated depends on the climate zone of the postcode the system is installed in. The postcode installation data is used to determine the number of certificates generated at each location in each month.¹⁷

Direct data on the price of STCs could not be obtained, but the average monthly STC price is conservatively estimated using chart data from various sources.¹⁸ Technically, households that install solar PV can sell their STCs through the Clean Energy Regulator clearing house at a fixed price of \$40 per certificate. However, this requires a buyer, so transactions are unlikely to occur until the STC price hits \$40. For simplicity, the analysis assumes all certificates are traded at the market price at the time they were awarded. Prior to the SRES being established, rooftop solar PV was eligible for Renewable Energy Certificates (RECs). The average REC price in 2009 and 2010 is estimated at \$37.

¹⁶ APVI (2014).

¹⁷ Between January 2011 and December 2014, the Clean Energy Regulator estimates that 120,435,875 STCs were created due to solar PV. Over the same time, this analysis estimates that 119,741,845 STCs were created.

¹⁸ CCA (2012), CER (2014) and Green Energy Markets (2015).

The average monthly STC price is multiplied by the estimated number of certificates generated to calculate the aggregate subsidy paid under the SRES. This cost is added to the total out-of-pocket expenses to determine the total capital cost of households solar PV installed to date.

Figure D.1 on page 25 shows the average subsidised price and the average total cost (without subsidy) per kilowatt of solar PV installed over time, as used to calculate the total capital spend. As shown, a fixed cost is applied for systems installed in 2009 and 2010, since monthly installation data is not available for systems installed at this time.

Figure D.2 on page 25 shows how the cumulative capital spend has steadily increased over time, as the monthly installed capacity has been relatively consistent.¹⁹ It also demonstrates how the total capital spend is adjusted for the cost of borrowing.

Price and installation data from the Australian PV Institute were used as a robustness check for the capital cost calculation.²⁰ These data are not location-specific, but include the average cost per kilowatt (before the SRES subsidy is applied), the average system size, and the total number of systems installed each month from January 2010 to March 2014. Over the period January 2011 to March 2014 for which these data and the CER postcode installation data are available each month, the total interest-adjusted capital spend using APVI data is \$11.2 billion, compared to a figure of \$10.9 calculated over the same period using the CER postcode installation data and the alternative pricing data. The reported total capital cost of \$16.6 billion includes

¹⁹ While the number of systems installed each month has been decreasing, the average system size has been increasing.

²⁰ APVI (2015).

an additional three years of data (2009, 2010 and April 2014 to March 2015).

B.3.4 Maintenance

This cost includes two components: a yearly cost to keep the solar PV system maintained, and an inverter replacement ten years after installation. Maintenance is assumed to cost \$20 per kilowatt per year (in 2015 dollars), while the cost of replacing the inverter is assumed to be 15 per cent of the out-of-pocket system cost.²¹ Both costs are appropriately adjusted using the interest rate.

The yearly maintenance cost goes towards the cost of cleaning panels and the potential for system repair. Not every household pays to maintain their panels, so this can be considered the average cost.

B.3.5 Other benefits and costs not considered

There are other benefits and costs that have not been included in the CBA. For instance, if solar PV has lowered network peaks, this could represent a benefit to society in terms of a reduced need for network infrastructure upgrades. Such benefits are difficult to quantify since network peaks occur at different times in different areas.

An analysis of consumption data suggests that a household installing a four kilowatt solar PV system: three kilowatts north-facing panels

and one kilowatt west-facing panels, can reduce their average monthly maximum demand in summer by about 10 per cent.²²

This assumes that the household does not change their consumption pattern after installing solar PV. But Victorian interval meter consumption data suggest that, on average, a household with solar PV has a higher maximum demand than a similar household without solar PV (though usually this occurs slightly later in the day), which suggests households may be changing their consumption patterns after installing solar PV. This could be driven by premium feed-in tariffs, which make it attractive for households to switch consumption away from times when the solar panels are producing and increase consumption when solar output is low or zero. It is likely that some solar PV households are helping to reduce network peaks and some are actually increasing them.²³ Solar PV may also have a negative impact on the network due to sudden surges and falls in electricity demand due to changes in cloud cover. This means that network businesses may have to invest more to maintain reliability.

A cost not considered in the analysis is the compliance and administration costs of the SRES. That is, there is a cost to the taxpayer in paying the Clean Energy Regulator to operate the scheme, and there are administrative costs to electricity retailers in having to purchase STCs.

Another component not considered is that some households may receive a non-pecuniary benefit from installing solar PV. For instance,

²¹Inverter costs are assumed to come down with the cost of solar PV systems, though this is likely to be less rapid over the next decade. Using 15 per cent of out-of-pocket expenses provides a realistic estimate of these costs.

²²This is the maximum demand during peak times, 2pm-9pm, which has a high correlation with a household's contribution to network peaks. The reduction in the average monthly maximum demand in winter due to solar PV is much smaller, only about 2 per cent.

²³This is a distortionary effect of feed-in tariffs set above the retail electricity tariff.

this could be a positive feeling of doing something for the environment, or of reducing dependence on the electricity grid. It is not standard practice to include such benefits in a CBA.

B.4 Calculation of cross-subsidies to households with solar PV

B.4.1 Upfront subsidy (SRES)

As described in the section on the calculation of capital costs, the total upfront subsidy paid to solar households is calculated as the total number of STCs generated multiplied by the average certificate price each month. This cost is paid by electricity retailers and passed onto consumers through their electricity bills. But some of the costs will be paid by other households with solar PV. The figure reported represents the proportion of this cross-subsidy paid by consumers without solar PV, assuming that the cost of the SRES is passed onto household consumers only.²⁴

B.4.2 Premium feed-in tariffs

Some of the premium feed-in tariff paid to households represents 'fair and reasonable' compensation for the electricity generated. Anything paid above this amount is considered a cross-subsidy.²⁵ As with the SRES cross-subsidy, premium feed-in tariffs are paid for by increasing electricity tariffs for all consumers, so part of the cross-subsidy will be

from solar households to other solar households. Again, the calculation is adjusted so that only the proportion paid by consumers without solar PV is reported.

Some states, such as NSW, had gross feed-in tariffs in which households are paid for all the energy produced by solar PV, and pay for all their electricity use at a much lower rate. The simulated consumption profiles of average households in each location are combined with the simulated solar output profiles to determine the average solar exports. For a three kilowatt system, just over half of all solar output is exported to the grid, on average.

The total amount paid to households with solar PV through premium feed-in tariff schemes is calculated using the total energy exported multiplied by the net present value of the feed-in tariff scheme available at the time of installation. It is assumed that, on average, households will lose eligibility for the schemes before the scheduled end date.²⁶ For schemes that run for a relatively short time period, such as that in NSW (about seven years), it is assumed that about 90 per cent of the premium feed-in tariffs are paid. In Queensland and South Australia, it is assumed that only 80 per cent of premium feed-in tariffs are paid.

Premium feed-in tariffs are paid at a fixed nominal rate, meaning that their real value declines with inflation. On the other hand, the fair and reasonable feed-in tariff is assumed to increase by 3.5 per cent per year (about one per cent in real terms). The value of energy exported under the feed-in tariff scheme is calculated by multiplying the energy exported by the net present value of the fair and reasonable feed-in tariff for each state, over the same time frame as each premium scheme is set to run. The total cross-subsidy is then calculated as

²⁴Retailers may pass the cost of the SRES onto commercial consumers as well as households, but this would mean a larger proportion of the SRES is paid by consumers without solar PV.

²⁵The analysis also includes transitional feed-in tariffs, but does not include standard feed-in tariffs, even those paid above the fair and reasonable rate.

²⁶For instance, in some states premium feed-in tariff schemes are not transferable to a new household in the same premises.

the total premium feed-in tariff paid less the total value of the energy exported. This amount is then adjusted to reflect the total cross-subsidy paid by consumers without solar PV.

B.4.3 Network tariff cross-subsidies

As explained in the report, network tariffs for households are not cost reflective. Instead of reflecting the strain that households place on the network during peak times, the amount that a household pays for the network is based on their overall electricity consumption. Households with solar PV consume much less electricity than those without solar, but still place a similar strain on the network at peak times, since residential peaks tend to occur in the evening when solar output is low. This means that solar households pay less for the network, and network businesses increase their tariffs on everybody to recover their costs.

To calculate the cross-subsidy from households without solar to households with solar due to network tariffs, a more cost-reflective tariff structure is designed. At the retail level, an average bill under this cost-reflective tariff can be divided into three components:

- a demand component equal to 40 per cent.²⁷ A household's maximum monthly demand during a 'peak window' (2pm to 9pm) each day is charged according to a demand tariff. The structure of this is based on a proposal by United Energy in Victoria.²⁸

²⁷This represents most of the network component. Even though the network component varies across states, this is kept fixed for simplicity.

²⁸Harrison (2014). The demand tariff is higher in summer months (December to March) and households are charged for a minimum monthly demand of 1.5 kilowatts.

- a time-of-use consumption component equal to 40 per cent (consumption charges are higher during the day, between 7am to 11pm, and lower overnight).
- a fixed component equal to 20 per cent.

The size of each tariff is calculated such that the total revenue across all households (both those with solar and those without solar) is equal to what it is under current tariffs, assuming consumption is the same. The average retail tariff in each location is assumed to be ten per cent higher than the best available market offer, except in areas where tariffs are regulated.

The cross-subsidy is calculated as the additional amount that households with solar would pay (until 2030) if cost-reflective demand tariffs existed from 2009, assuming the same take-up of solar PV.²⁹

B.5 Sensitivity analysis

This section explores how the results of the cost-benefit analysis and cross-subsidies change when alternative inputs and assumptions are used. These results are displayed in Tables D.2 to D.5 on pages 27–29.

If it is assumed that all solar PV systems are north-facing (instead of 75 per cent north-facing and 25 per cent west-facing, see Table D.2), this improves the total output of solar PV by about 13 per cent, increasing the benefits. The net economic cost is \$8.6 billion in this scenario. But north-facing systems also increase the cross-subsidies to solar

²⁹Since network businesses are revenue neutral, this is equal to the reduction in the amount that households without solar PV will pay towards their bills.

households since they export more to the grid and place a larger share of network charges on those without solar.³⁰

Alternative assumptions about the value of avoided generation are shown in Table D.3. If the average wholesale price of between three and five cents per kilowatt-hour is used to value avoided generation instead of the fair and reasonable feed-in tariff, the avoided generation benefit falls from \$7.1 billion to \$4.2 billion, and the net economic cost increases to \$12.6 billion. If it is assumed that solar PV prevents the need for new electricity generation (using a levelised cost of new generation of around ten cents per kilowatt-hour), the benefit rises to \$9.5 billion, which still represents a net economic cost of \$7.2 billion.

When an interest rate of 2.5 per cent is used instead of 5 per cent, essentially only accounting for inflation and not the cost of borrowing, the benefit of avoided generation is valued at about 20 per cent higher and the capital costs at about 7 per cent lower (see Table D.4). Maintenance is slightly more costly, while emissions abatement, which is not discounted, is valued at the same rate. This still results in a net economic cost of \$7.2 billion. A higher interest rate of 7.5 per cent (which is roughly equivalent to a 5 per cent real interest rate) increases the net cost to almost \$12 billion.

Interestingly, the total cross-subsidies do not change significantly with the interest rate, but the composition of the cross-subsidies changes significantly. Cross-subsidies due to the SRES have already occurred, whereas a significant proportion of the cross-subsidies due to premium feed-in tariffs and network tariffs are yet to occur. The cross-subsidies that are yet to occur are given more weight with a lower interest rate, while the SRES is given more weight with a higher interest rate.

³⁰West-facing panels produce more output later in the day, which better aligns with peak periods.

Extending the end date of the analysis period to 2040 increases the benefits of solar PV while adding little to the cost of maintenance (see Table D.5). If all costs and benefits are considered out to 2040, the net economic cost falls to \$6.5 billion. This, however, assumes that all systems operate optimally for a minimum of 25 years, and some for as long as 30 years.³¹

Under the extremely favourable assumptions of a 2.5 per cent interest rate, 100 per cent north-facing systems, and taking into account all costs and benefits to 2040, the cost-benefit analysis is approximately breaking even with a carbon price of \$30.³² Yet the total cross-subsidy to households with solar PV under these assumptions is \$18.7 billion.

³¹While some panels may last for this long, technological advancement means that many households are likely to replace their panels before the end of their useful life. If, for instance, a household can double their capacity of solar PV using the same amount of roof space in the future, they may be better off replacing their old panels with new ones.

³²There is a small net cost under this scenario, but it is trivial.

C Household economics of solar PV and battery storage

C.1 Summary

This piece of analysis aims to calculate the financial viability of a household installing solar PV today under the current tariff structure and with the current incentives in place, as well as under a more cost-reflective tariff structure. It explains the associated costs and benefits and calculates a net present value of each for each state capital city. It also investigates the necessary price reduction for home batteries to become economically viable, and the size of a solar PV and battery system required for a household to go off-grid. The analysis uses a real discount rate of 5 per cent and a time frame of 15 years.¹

The results are meant to be indicative of the circumstances that households face when deciding whether to install solar PV, but individual circumstances will vary greatly. For simplicity, the analysis is restricted to looking at a three kilowatt solar PV system and a seven kilowatt-hour battery.² Similarly, only households with average consumption profiles are considered. The results are determined using simulated consumption and solar output over 15 years.

The main benefits of installing a solar PV system include saving money on electricity bills by reducing consumption from the grid, and income

from exporting excess solar energy to the grid. Both of these are calculated using the current electricity tariffs and feed-in tariffs available, assuming each will increase by one per cent each year in real terms. Under a cost-reflective tariff, income from energy exports remains the same, but the benefit of reduced electricity consumption is less.

The costs include the price of installing the system (taking into account the SRES subsidy, assuming a certificate price of \$35), and ongoing maintenance costs of \$20 per kilowatt per year, plus replacing the inverter after ten years at a cost of \$400 per kilowatt.³

Under the current tariff, it is assumed that a household with solar PV will charge a home battery using any excess solar energy, then begin discharging the battery as soon as demand for electricity exceeds solar output. But under a more cost-reflective demand tariff, the cheapest time to charge the battery is overnight when prices are lower, and the most cost-effective time to discharge it is when demand for electricity is high during the peak window. Under such an approach, the battery is used less than half as much as one used daily, which means it lasts for longer. The break-even price of a seven kilowatt-hour home battery under a demand tariff is calculated assuming a 15-year life relative to a 10-year life under the current tariff.

It is assumed that a household who leaves the grid completely will be prepared to trade off some reliability for a lower upfront cost. Using 15 years of simulated consumption and solar output, the analysis

¹A negative net present value indicates that a household does not receive a payback within 15 years.

²Three kilowatts is the most commonly installed solar PV system, and seven kilowatt-hours is likely to be a common size of a home battery. For instance, the Tesla Powerwall will be available as a seven kilowatt-hour battery, see [Tesla Motors \(2015\)](#).

³An inverter replacement cost of \$400 per kilowatt is about 16 to 19 per cent of the total system cost.

determines the required size of a solar PV and battery storage system in order to meet a given level of reliability. This reliability level is determined as the proportion of a household's consumption that can be met by the off-grid system.

C.2 Key assumptions

C.2.1 Time frame and interest rate

Net present values are calculated over 15 years using a real discount rate of 5 per cent. This discount rate is higher than that used in the economy-wide analysis (which used a nominal rate of 5 per cent), reflecting that households tend to discount future transactions by more than the cost of borrowing. The time frame of 15 years reflects that most households would expect a payback within this time period.

C.2.2 Electricity tariffs

Electricity tariffs, including feed-in tariffs, are assumed to increase by one per cent each year in real terms. It is assumed that households are able to source a competitive electricity tariff from a major retailer.⁴ The same demand tariff is used as described in Section B.4.3, and this is also assumed to increase by one per cent each year in real terms.

⁴A household who pays a high tariff for electricity will technically benefit more from installing solar PV than they would if they were on a more competitive tariff, but they are better off overall on the competitive tariff.

C.2.3 Efficiency of solar and battery systems

Solar PV systems are assumed to run at an average efficiency of 80 per cent, which is higher than that assumed for the economy-wide analysis.⁵

Batteries are assumed to run at 85 per cent efficiency, and are discharged to a maximum depth of 80 per cent of rated capacity.⁶

C.3 Calculation of private costs and benefits due to solar PV

C.3.1 Reduced electricity usage

This is calculated as the amount that a household would save on their electricity bill by installing solar PV (not counting income from exporting energy to the grid), assuming no change in their consumption pattern. It is calculated using the simulated consumption of an average household over 15 years combined with simulated solar PV output to determine the average yearly electricity consumption offset by solar production. The yearly value of this under a volumetric tariff is calculated in a straightforward manner by multiplying this figure by the electricity tariff.⁷

The calculation is more complicated under a demand tariff. This requires comparing the average household's maximum demand each month with no solar installed to their maximum demand with solar

⁵Essentially this assumes households have access to unshaded north-facing roof space.

⁶These parameters are typical of lithium-ion batteries. A higher depth of discharge can significantly shorten battery life. Having a battery efficiency less than 100 per cent means that the energy used to charge the battery is greater than the energy output.

⁷Adjustments are then made to calculate the net present value over 15 years and to account for electricity price rises.

installed. On average, the demand component of the bill for a solar household is about seven per cent less than that of a household without solar, which is a saving of about \$50 a year, depending on location. But under this structure, the standard tariff during daytime hours is only about half of what it is under current tariffs. Households with solar therefore make a small saving on the demand component of their bill, and an additional saving by reducing their consumption. But the total saving is less than it is under the current tariff structure.

C.3.2 Export income

Any solar output that does not offset a household's consumption of electricity from the grid is assumed to be exported to the grid. This is paid at a fixed rate according to the feed-in tariff available. It is assumed that households are able to source a feed-in tariff that is ten per cent higher than the 'fair and reasonable' feed-in tariff set in each state (which is often set as a minimum regulated feed-in tariff).

C.3.3 SRES subsidy

The subsidy is calculated using the number of certificates (STCs) generated from installing a solar PV system, which depends on the location. Melbourne and Hobart are in Zone 4, which receives the smallest number of certificates, while all other state capital cities are in Zone 3. The subsidy received assumes a certificate price of \$35. While the average certificate price over the last twelve months has been closer to \$40, the price chosen is more reflective of the long-term certificate price.⁸

⁸This assumes the SRES subsidy is paid before 2017, at which point the subsidy begins to wind down over 15 years.

C.3.4 Cost of solar PV systems

The price of installing a solar PV system varies across each city. In part, this is because the subsidy under the SRES is location-dependent, but there may also be differences in the cost of installation.

The total installation cost (before subsidy) in each city is determined by an analysis of monthly installation data from Solar Choice from February 2014 to January 2015 from each capital city and each panel size (1.5 kW, 2 kW, 3 kW, 4 kW, and 5 kW).⁹ For each month and system size, the analysis takes the midpoint between the average sized system and the lowest price recorded, then adds the appropriate subsidy. Under the assumption that the average cost of equipment is the same in each city, and accounting for price decreases over time, the analysis determines a fixed equipment cost of \$1800 per kilowatt (before subsidy), plus installation costs of between \$1000 (Perth) and \$1400 (Hobart).

C.3.5 System maintenance

These costs assume general maintenance as well as replacement parts. Not all households will clean and maintain their panels, but this is likely to lead to poorer performance and output over time. The yearly cost of maintenance is set at \$20 per kilowatt, while it is assumed that the household will replace the inverter after ten years at a cost of \$400 per kilowatt.¹⁰

⁹Solar Choice (2015).

¹⁰The inverter replacement cost discounted over ten years is \$246 per kilowatt.

C.4 Economics of home batteries

C.4.1 Home battery use for a grid-connected household

Under current tariffs, a household with solar PV on a standard feed-in tariff has an incentive to store excess energy produced in a battery, then consume this once electricity demand exceeds solar output. This is because the standard feed-in tariff is lower than the standard electricity tariff.¹¹

Under a demand tariff with time-of-use pricing, the incentive to use a home battery is very different. The price of electricity during the day (between 7am and 11pm) is higher than the feed-in tariff, but it is about half of what it is under the current volumetric tariff. Thus, the benefit of using a battery during the day is less than what it is under the current tariff. In addition, the overnight tariff is lower than the current feed-in tariff, so a household will be better off charging their battery using electricity from the grid overnight instead of using their excess solar energy.

The main benefit of a home battery under a demand tariff is to reduce a household's maximum monthly demand. The analysis assumes that the battery switches on whenever a household's demand for electricity from the grid exceeds 1.5 kilowatts during the peak window (2pm to 9pm), ensuring that a household does not consume more than 1.5 kilowatts from the grid until the battery discharges to its maximum.¹²

Demand for electricity for an average household only exceeds 1.5 kilowatts roughly once every two days, and usually only for a relatively

¹¹Households currently earning a premium feed-in tariff for electricity exported to the grid do not have this incentive.

¹²This is a relatively simple battery algorithm. In reality, more advanced algorithms could be used to improve the way that a battery is used.

short time. This means that a battery is used far less under a demand tariff, and battery life will be much longer as a result.

Calculating the installed price of a battery at which which a household will break-even requires calculating a net present value and finding the price at which this is equal to zero. Because the battery is used much less often under a demand tariff, it is assumed this will last for at least 15 years. Consistent with the analysis about the economics of solar PV, the net present value is calculated over a 15-year time frame. But a battery charged and discharged daily is assumed to only last for ten years.¹³

C.4.2 Home battery use for an off-grid household

For a household that is not connected to the grid, home batteries are assumed to be charged using excess solar output, and discharged to their maximum depth (80 per cent) to meet consumption that is not met by solar output. The reliability level is calculated as the proportion of an average household's consumption that can be met by the off-grid system.

It is important to acknowledge that households who do go off-grid are likely to change their consumption habits. For instance, this would mean consuming less energy when battery levels are low (and more when the battery is fully charged and solar output is high), and investing in more efficient appliances. But in order to compare the reliability of an off-grid system with that of the electricity grid, it is fair to assume that households have the same consumption patterns. In any case, while households that consume less require a smaller off-grid system, the size of the system required is primarily driven by variation in solar

¹³The seven kilowatt Tesla Powerwall has a ten-year warranty.

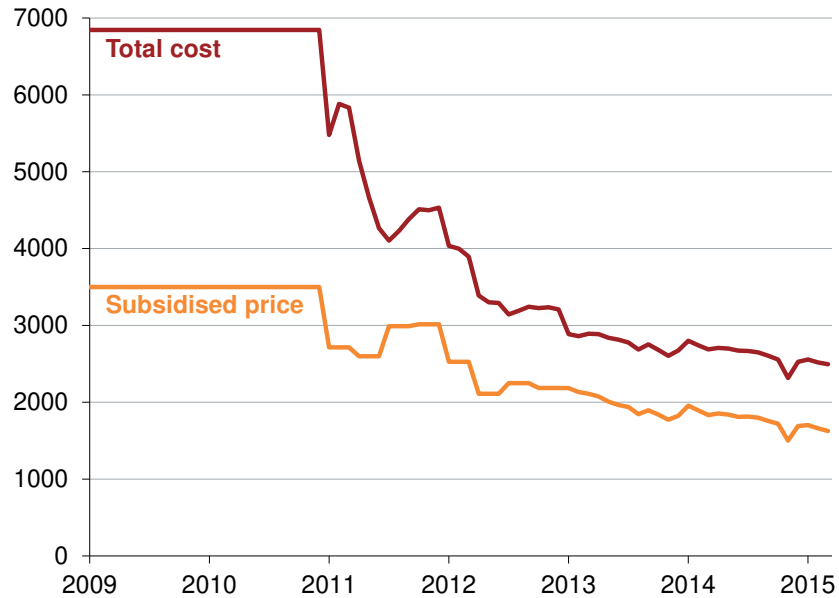
radiation rather than variation in consumption. On consecutive days where there is little sunshine, a large battery can be discharged quickly given that solar output is low.¹⁴

The analysis determines a cost-effective combination of solar PV and battery storage to meet a given level of reliability: 95 per cent, 99 per cent, and 99.9 per cent. This is determined using various combinations of solar PV and battery storage, based on the simulated consumption and solar output.

¹⁴It is also worth noting that days with little sunshine tend to be colder, meaning that households use more heating.

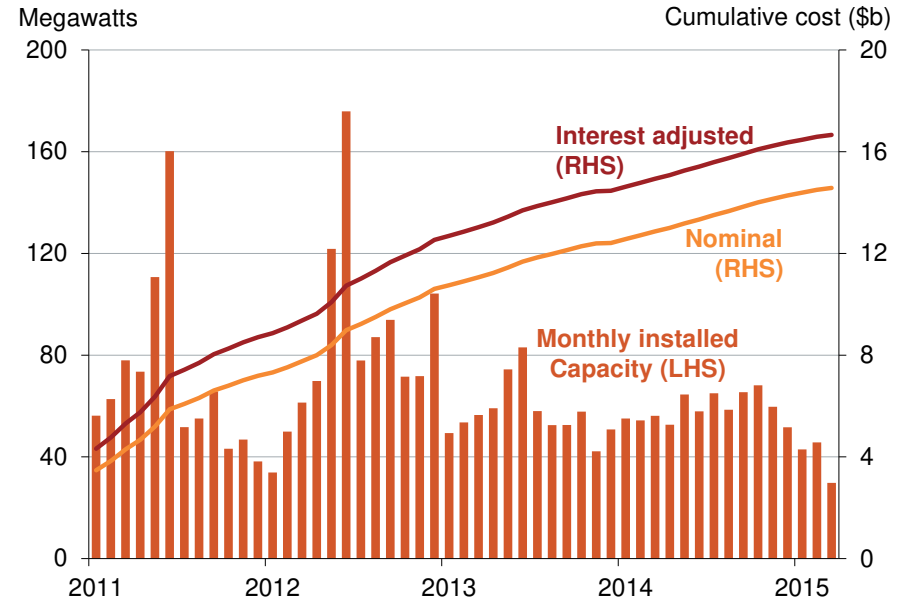
D Tables and Figures

Figure D.1: Average price of solar PV over time
\$ per kilowatt (nominal)



Notes: Average price is based on data sources used in analysis. A fixed price is applied to installations before January 2011
 Source: CER (2015b), APVI (2014), CER (2015a), Solar Choice (2015), CCA (2012), CER (2014) and Green Energy Markets (2015)

Figure D.2: Cumulative total capital cost and monthly installed capacity of solar PV



Source: CER (2015b), APVI (2014), CER (2015a), Solar Choice (2015), CCA (2012), CER (2014) and Green Energy Markets (2015)

Table D.1: Economy-wide analysis by state

Net present value (\$m)

State	Avoided generation	Emissions abatement	Capital cost	Maintenance	Net benefit	Cost/tonne of CO ₂ (\$)
NSW/ACT	1,484	462	-3,986	-471	-2,511	193
Vic.	919	450	-2,758	-369	-1,757	147
Qld	2,856	685	-5,314	-675	-2,447	137
SA	682	169	-2,305	-294	-1,747	339
WA/NT	1,040	204	-2,027	-244	-1,028	180
Tas.	81	2	-254	-36	-208	3,121
<i>Total</i>	<i>7,063</i>	<i>1,974</i>	<i>-16,645</i>	<i>-2,090</i>	<i>-9,698</i>	<i>177</i>

State	SRES	Premium feed-in tariffs	Network tariffs	Total cross-subsidies
NSW/ACT	1,486	1,239	498	3,223
Vic.	866	669	339	1,874
Qld	1,642	2,117	1,537	5,297
SA	680	670	722	2,072
WA/NT	696	219	552	1,467
Tas.	73	64	20	157
<i>Total</i>	<i>5,443</i>	<i>4,977</i>	<i>3,669</i>	<i>14,089</i>

Table D.2: Sensitivity analysis: different system orientation

Net present value (\$bn)

System orientation	Avoided generation	Emissions abatement	Capital cost	Maintenance	Net benefit	Cost/tonne of CO ₂ (\$)
75% north, 25% west	7.1	2.0	-16.6	-2.1	-9.7	177
100% north	8.0	2.2	-16.6	-2.1	-8.6	145

System orientation	SRES	Premium feed-in tariffs	Network tariffs	Total cross-subsidies
75% north, 25% west	5.4	5.0	3.7	14.1
100% north	5.4	6.0	4.0	15.4

*Notes: All systems assumed to have a 30 degree tilt***Table D.3: Sensitivity analysis: different avoided generation prices**

Net present value (\$bn)

Avoided generation price	Avoided generation	Emissions abatement	Capital cost	Maintenance	Net benefit	Cost/tonne of CO ₂ (\$)
Average wholesale price	4.2	2.0	-16.6	-2.1	-12.6	221
Fair and reasonable FiT	7.1	2.0	-16.6	-2.1	-9.7	177
Levelised cost of energy	9.5	2.0	-16.6	-2.1	-7.2	140

Avoided generation price	SRES	Premium feed-in tariffs	Network tariffs	Total cross-subsidies
Average wholesale price	5.4	5.6	3.7	14.7
Fair and reasonable FiT	5.4	5.0	3.7	14.1
Levelised cost of energy	5.4	4.5	3.7	13.6

Table D.4: Sensitivity analysis: different interest rate

Net present value (\$bn)

Interest rate (%)	Avoided generation	Emissions abatement	Capital cost	Maintenance	Net benefit	Cost/tonne of CO ₂ (\$)
2.5	8.6	2.0	-15.4	-2.4	-7.2	139
5	7.1	2.0	-16.6	-2.1	-9.7	177
7.5	6.0	2.0	-18.0	-1.9	-11.9	212
10	5.2	2.0	-19.5	-1.7	-14.1	244

Interest rate (%)	SRES	Premium feed-in tariffs	Network tariffs	Total cross-subsidies
2.5	5.0	5.2	4.1	14.3
5	5.4	5.0	3.7	14.1
7.5	5.9	4.8	3.4	14.1
10	6.5	4.7	3.1	14.2

Notes: All interest rates are nominal

Table D.5: Sensitivity analysis: different length of study

Net present value (\$bn)

End date	Avoided generation	Emissions abatement	Capital cost	Maintenance	Net benefit	Cost/tonne of CO ₂ (\$)
2025	5.5	1.5	-16.6	-1.8	-11.5	262
2030	7.1	2.0	-16.6	-2.1	-9.7	177
2035	8.5	2.4	-16.6	-2.3	-8.0	130
2040	9.9	2.8	-16.6	-2.5	-6.5	99

End date	SRES	Premium feed-in tariffs	Network tariffs	Total cross-subsidies
2025	5.4	4.9	2.7	13.0
2030	5.4	5.0	3.7	14.1
2035	5.4	5.0	4.6	15.0
2040	5.4	5.0	5.4	15.8

Notes: Costs, benefits and cross-subsidies taken from 2009 until end date

Bibliography

- AEMO (2015a). *Aggregated Price and Demand Data Files*. Australian Energy Market Operator. URL: www.aemo.com.au/Electricity/Data/Price-and-Demand/Aggregated-Price-and-Demand-Data-Files.
- _____ (2015b). *Carbon Dioxide Equivalent Intensity Index*. Australian Energy Market Operator. URL: www.aemo.com.au/Electricity/Settlements/Carbon-Dioxide-Equivalent-Intensity-Index.
- AER (2014). *State of the Energy Market 2014*. Australian Energy Regulator. URL: www.aer.gov.au/node/29358.
- AGL (2015). *Price and Contract Information*. URL: www.agl.com.au/residential/energy-plans/electricity-and-gas-plans.
- APVI (2014). *Australian PV in Australia Report 2013*. Australian PV Institute. URL: www.apvi.org.au/pv-in-australia-2013/.
- _____ (2015). *Australian PV market since April 2001*. URL: <http://pv-map.apvi.org.au/analyses>.
- Aurora Energy (2015). *Aurora PAY AS YOU GO rates and charges*. URL: www.auroraenergy.com.au/your-home/aurora-pay-as-you-go/aurora-pay-as-you-go-rates-and-charges.
- CCA (2012). *Renewable Energy Target Review*. Chapter 2: Performance of the Renewable Energy Target. URL: <http://climatechangeauthority.gov.au/chapter-2-performance-renewable-energy-target>.
- CER (2014). *Renewable Energy Target, 2014 Administrative Report*. Summary of certificate activity in 2014. URL: www.cleanenergyregulator.gov.au/About/Accountability-and-reporting/administrative-reports/the-renewable-energy-target-2014-administrative-report/Summary-of-certificate-activity-in-2014.
- _____ (2015a). *Calculation of out-of-pocket expenses for small generation units*. URL: <https://web.archive.org/web/20150403173209/https://ret.cleanenergyregulator.gov.au/Forms-and-Publications/Publications/publication-of-oope>.
- _____ (2015b). *RET postcode data*. Clean Energy Regulator, Commonwealth of Australia. URL: www.cleanenergyregulator.gov.au/RET/Forms-and-resources/Postcode-data-for-small-scale-installations.
- Energy Australia (2015). *Plans*. URL: www.energyaustralia.com.au/residential/electricity-and-gas/plans.
- ESC (2014). *Minimum electricity feed-in tariff to apply from 1 January 2015: Final Decision*. Essential Services Commission, August. URL: www.esc.vic.gov.au/getattachment/0364a70d-f8c7-4fb2-a341-3c3d6694adf6/Final-Decision-Minimum-Feed-in-Tariff-for-2015.pdf.
- ESCOSA (2014). *2015-16 Minimum Retailer Solar Feed-in Tariff*. URL: www.escosa.sa.gov.au/projects/213/2015-16-minimum-retailer-solar-feed-in-tariff.aspx.
- Green Energy Markets (2015). *Spot LGC price exceeds STC price for first time in nearly 2 years*. 23 Feb 2015. URL: <http://greenenergytrading.com.au/news-events/spot-lgc-price-exceeds-stc-price-for-first-time-in-nearly-2-years>.
- Harrison, Stephen (2014). *United Energy 2015 Pricing Proposal*. URL: <http://www.aer.gov.au/sites/default/files/United%20Energy%20-%20Approved%20annual%20pricing%20proposal%202015.pdf>.
- Hyndman, R. J. and S. Fan (2010). 'Density forecasting for long-term peak electricity demand'. In: *IEEE Transactions on Power Systems* 25.2.

- IPART (2012). *Solar feed-in tariffs: setting a fair and reasonable value for electricity generated by small-scale solar PV units in NSW*. Independent Pricing and Regulator Tribunal. URL: www.ipart.nsw.gov.au/files/81824c4b-8b4b-475f-8e28-a01400f5d55e/Final_Report_-_Solar_feed-in_tariffs_-_March_2012.pdf.
- Origin Energy (2015). *Pricing*. URL: www.originenergy.com.au/for-home/electricity-and-gas/plans/energy-plans/vic.html.
- OTTER (2015). *Feed-in Tariffs*. Office of the Tasmanian Economic Regulator. URL: www.energyregulator.tas.gov.au/domino/otter.nsf/elect-v/30.
- Power and Water Corporation (2014). *2014-15 Electricity Network Tariffs and Charges and Future Price Trends*. URL: www.powerwater.com.au/__data/assets/pdf_file/0011/85277/2014-15_electricity_network_tariffs_chargesfuture_price_trends.pdf.
- QCA (2013). *Factsheet: Fair and reasonable solar feed-in tariffs for Queensland*. Queensland Competition Authority. URL: www.qca.org.au/getattachment/3d4776bc-f08f-49c5-beb5-f14c4eb6682c/Solar-feed-in-tariff-review-fact-sheet.aspx.
- Solar Choice (2015). *Solar PV Power System Prices*. URL: www.solarchoice.net.au/blog/category/installation-advice/solar-system-prices-2/residential-solar-system-prices/.
- Synergy (2014). *Renewable Energy Buyback Scheme and Net Feed-in Tariff Price Schedule*. September. URL: www.synergy.net.au/docs/REBS_Pricing_Schedule.pdf.
- _____ (2015). *Synergy - Tariff Finder*. URL: www.synergy.net.au/at_home/tariff_finder_res.xhtml.
- Tesla Motors (2015). *Powerwall; Tesla Home Battery*. URL: www.teslamotors.com/en_AU/powerwall.
- Victorian Government (2014). *Advanced Metering dataset*. Department of Economic Development, Jobs, Transport and Resources.