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Solar PV & Storage in Residential Communities

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EXECUTIVE SUMMARY

The purpose of this report is to provide readers with a summary of solar photovoltaic systems and battery storage technologies currently available on the Australian market, and to identify and discuss issues which may impact adoption of storage technologies. As part of the project, an analytical tool has been developed by the author which (via a specifically created program) enables users to enter various relevant (user) data, and then be presented with various recommended systems to suit their needs. The reason this program was included was to assist the user in accurately determining a system that would suit their needs while also being provided with a general cost analysis and details of system specifications. The output data choices were determined, in part, through the use of a survey conducted to assess knowledge, perceptions and other relevant matters with a small but diverse demographic group, where the results were generally predictable, and will be discussed within the report. The results showed areas where the participants would like more information as well as factors contributing to the disinclination towards wide-scale solar adoption.

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1 INTRODUCTION

Renewable Energy power generation has generated much public debate in recent years due to the increasingly obvious need for power to be generated in a more sustainable manner and to enable the phasing out of the use of limited remaining fossil fuels. The occurrence of climate change has been well documented over recent years, with increasing carbon dioxide and other greenhouse gas emissions having a significant effect on the earth’s atmosphere. The widespread use of fossil fuels is now universally accepted as a major contributor to these increases in emissions which have led to significant increases of the Greenhouse Effect (NASA, 2016).

Fossil fuels first became popular with the invention of the steam engine in the industrial revolution in 1876. Its invention quickly rendered the physical labour of man and animal obsolete in many areas as they were much less efficient than their steam-powered replacements. The wide-spread adoption of steam-powered engines that then occurred required copious amounts of fuel, mainly in the form wood or charcoal, however soon there were insufficient resources to meet demand. Other fuels needed to be found as a replacement for wood and charcoal as surrounding woodlands were quickly becoming devoid of vegetation in an attempt to keep up with demand– one of these fuels was coal. As industry grew, so too the increasing need for power. Investigations followed into the potential use of fossil fuels including crude oil and natural gas, as both also have high energy densities (high energy content per unit volume) (Scheer, 2002). The evolution and expansion of industry on a global scale over the intervening decades has continued unabated, and the global climate, it is widely understood, is paying the price.

The effects of climate change include an increase in atmospheric temperatures leading to a rise in air and sea temperatures. This then leads to changes in rainfall and wind patterns causing more extreme weather events such as cyclones. The results of these changes can be very severe leading to droughts, famine and loss of habitat. Additionally, the rising temperatures are causing the polar ice caps to melt resulting in a rise in global sea levels (Scheer, 2002). Again, it is widely understood that we must find a solution to the dual dilemma of the need for fuel versus the destruction of the planet’s climate. This is exacerbated by the fact that fossil fuels are not available in unlimited supply. Renewable fuel sources are well placed to address these issues.

Renewable energy is generated through 'sustainable' means such as hydro-electric, utilising the power of moving water to generate electricity that is much cleaner than fossil fuel generated power and virtually free of emissions. Renewables are often used in locations where there is no reliable access to grid power or other fossil fuels, for example biomass (the burning of plant matter for heating and/or cooking i.e. crop residue or animal dung) is used significantly in developing countries (Scheer, 2002). The wide-scale adoption of renewable energy is crucial in reducing the pressure and reliance on fossil fuels; if fossil fuels were no longer the go-to for energy generation it would greatly decrease GHG (Greenhouse Gas) emissions and be beneficial for the environment.

Aside from hydro-electric and biomass, renewable energy sources include solar energy. Through the use of solar radiation and photoelectric cells, it is possible to generate electricity from sunlight. French physicist Antoine Becquerel discovered the photo effect in 1839, and semiconductors (used in today's solar cells) were developed about 100 years later. William Shockley developed a p-n model semiconductor, and Bell Laboratories created the first solar cell in 1954 with an efficiency of around 5%. Cost was not a consideration at this point as the initial cells were developed for space applications. Advances in technology have since led to an increase in efficiencies, and as many units are made mainly from silicone, another great advantage is modularity and flexibility.

Solar power has become more widely adopted in recent years however there are still gaps in efficiency, electricity being generated only during daylight hours affecting their reliability (Nelson, 2011). To address this significant drawback, the capability to store excess power produced during the day for use at night can been developed. This allows for more electricity generated by the system to be used within the system and minimizes contact with and reliance on the grid. At the moment, solar power and battery storage are still unaffordable for many Australians, as well as being mysterious to some extent due to the lack of available information, and the perceived difficulties in installation and utilization. These factors, as well as technologies currently available, will be discussed in more detail later in the report.

1.1 Aim and Objectives

The aim of this report was to investigate and analyse certain factors relevant to solar installation in Australia, in order to obtain an accurate "snapshot" of both the uptake and the potential for further deployment of battery storage in typical residential (and shared community) applications. This has involved investigating case studies of previous solar installations as well as delving into the system requirements and other relevant factors that affect uptake.

The aim was intended be achieved through the following objectives:

- To gather and analyse public opinion and perception through a survey
- To present Case Studies to assist in analysing relevant issues
- To provide an analytical tool to facilitate decision making as an example of ways to increase uptake of battery storage as an option/enhancement
- To provide results of an investigation of Relevant Factors related to solar installations in order to remove barriers which hinder increased uptake of solar panels and battery storage

A survey was designed and conducted in the initial stages of this project to provide information on the awareness and perceptions of potential purchasers on the feasibility of solar panel and battery storage installations in a residential context. The survey was taken by a small but very diverse demographic group covering age groups up to 80 years of age, across a wide income, cultural and professional range, in order to gauge public awareness and perceptions. While not in itself the focus of the project, it provided a useful starting point to prioritize issues for discussion. Using these responses, various issues related to the uptake of solar panels and battery storage have been determined and discussed within this report.

The report will commence with a literature review to provide specific information related to both the technology and the current issues. The Literature Review will provide a brief history of fossil fuels, the Greenhouse Effect and climate change, and renewable energy before focusing on solar power generation and battery storage. Past, present and upcoming technologies will be discussed as well as the feasibility of a more wide-scale adoption of solar power.

The methodology used in compiling this report will then be detailed, along with the outline of the analytical tool developed to increase awareness and acceptance of battery storage technology. This tool was developed as an example of ways to address the consumer knowledge gap, a tailored program (user friendly) has been written (by the author) to allow users to accurately determine their necessary needs in terms of a system. This program will be discussed in more detail later in this report. Case studies will then be discussed, and relevant issues raised as they relate to the subject of this report. The assumptions that have had to be made will also be outlined.

The results section will detail data obtained from the survey, economic analysis of potential systems and will summarise the relevant case study issues.

The discussion and conclusion will then discuss the findings and recommendations of this project, supporting the results with literature.

2 LITERATURE REVIEW

The focus of this report is to investigate the feasibility of wide-scale adoption and installation of solar systems in residential situations in Australia that also incorporate battery storage. Due to recent increases in interest in renewable energy systems, particularly in the last few years, there is a plethora of literature relating to the topics broached in this report. This is both due to the increased awareness, media and government focus and high cost of power generally and also because renewable energy generation (particularly solar) is the subject of constant advancements in technology and economy.

The topics that will be investigated in this literature review will be a brief history of fossil fuels and climate change (and the Greenhouse Effect), a basic overview of different types of renewable energy, solar photovoltaics and solar resources in Australia, existing technologies and solar storage. These are all relatively new and prevalent technologies at the moment and, as a result, there is a lot of information available in both journal and book form however due to the constantly advancing technologies a large amount of information is able to be found online. Additionally, there are many related news articles which have been referenced in the discussion.

2.1 Fossil Fuels

As mentioned earlier, fossil fuels became increasingly used following the invention of the steam engine. Firewood and hydro-electric/wind in the form of watermills and windmills had previously provided virtually all energy needs until 1876 when James Watt developed the steam engine (Nelson, 2011). Steam power was widely embraced and very quickly led to many traditional methods of work being abandoned in favour of the more efficient alternative. However, due to the nature of the fuel, and the inefficiency of conversion of fuel into steam power, steam engines required copious amounts of wood and charcoal. Due to the massive demand it soon became clear that another fuel source for the engine had to be found, as local woodlands and surrounding forests were very quickly becoming denuded (Scheer, 2002)

Coal was discovered to be a viable fuel alternative, and as demand increased further and steam engine applications continued to diversify, other fossil fuels were then adopted. Coal, and then crude oil, became the most critical fuel sources, and as motorised road traffics' popularity continued to increase, so too did the demand for petroleum products. After coal and crude oil became widely used, other fossil fuels were then investigated, resulting in natural gas becoming popular after WWII. As demand for power continued to increase globally, research into fuel sources continued at a similar pace. The game changer (nuclear fuel) reared its head in the 1960s (Nelson, 2011), and its checkered history and many issues are well known. Fossil fuels continued to be used with gay abandon, with apparently little concern for the environment or the potential impacts. Even if the climatic impacts resulting from their use were not foreseen, the environmental impacts associated with the retrieval of these fuels are not insignificant.

2.2 GHG (Green House Gas)

Particular gases act as a greenhouse and trap heat radiation within the earth's atmosphere. These gases are necessary to continue life on earth as we know it, as they promote the habitable conditions necessary; without the atmosphere's protection the earth's temperature would be as low as -18^{o}C, however these gases have both natural and anthropogenic sources (Nelson, 2011). The greenhouse gases are water vapour, carbon dioxide, methane as well as other trace gases. A demonstration of the greenhouse effect is a car interior on a hot day with the windows closed. Incident light passes through the glass and is absorbed by the interior materials and radiates heat. The glass is then opaque to infrared radiation and so the temperature continues to increase until the energy balance is restored (Scheer, 2002).

2.3 Climate Change

Since the industrial revolution, the level of emissions of greenhouse gases, mainly in the form of carbon dioxide (CO_2) and methane (CH^4), have increased at a phenomenal rate, having a significant and worrisome effect on the earth's atmosphere. These increases in carbon dioxide are mainly due to wide-spread fossil fuel use (according to V Nelson – author of *Introduction to Renewable Energy* Systems) and land use change, while methane is mainly due to agriculture (produced by grazing animals in their millions). There is a double whammy effect where massive quantities of vegetation (which could mitigate some of the effect by using CO_2) have been cleared (and continue to be cleared each year) to make way for livestock such as cattle which increase the problem (Nelson, 2011). The increased temperatures in the earth's atmosphere have a variety of effects on the weather, resulting in changes in average regional temperatures and also in wind, wave and rainfall systems. These rising temperatures in both air and sea have a large effect on the polar regions in particular, as they are melting at a phenomenal rate. Based on recent modelling and data, by 2100 sea levels are predicted to rise between 0.2 and 1m (Nelson, 2011). Large bodies of sea ice contribute to the cooling effect additionally by reflecting thermal radiation incident upon the earth's surface. Therefore, if there was a significantly smaller surface area taken up by sea ice, there would be positive feedback and continued rises in $CO_{2,}$ as less thermal radiation would be initially reflected. If the Greenland ice sheets were to melt entirely the extra water would add another 7m to the oceans and the West Antarctic ice sheet another 5m (Nelson, 2011).

2.4 Renewable Energy

Fossil fuels are finite, whereas renewable or sustainable energy will (by definition) be available as long as the sun shines – another 4 to 5 billion years based on current estimates. The energy from the sun is electromagnetic radiation called "insolation". When this radiation is incident upon the earth's surface it has many effects. Varying levels of heat radiation falling in different areas cause a difference in air density, thereby creating air movements and shifts - wind is caused by uneven heating of the earth's surface creating movement of air as well as the contribution from the movement of water and thermal energy through evaporation and precipitation (Nelson, 2011). The main forms of renewable energy are solar, wind, geothermal, bioenergy, hydro-electric, tidal and wave, so, in effect, all renewable sources of energy generation are created by the sun whether it be first or second hand or even third in the case of biomass (a form of bioenergy).

Insolation (as discussed earlier, namely the solar radiation incident upon the earth's surface), wind strength, hydropower potential, available land suitable for biomass crops and rainfall all affect the effectiveness of potential renewable energy sources. As such, different locations in different situations with different needs and with different natural resources at their disposal will therefore generate their energy in different ways (Scheer, 2002). In 2001, the renewable energy contribution to global usage was 13.5% with biomass providing 80% of total renewable energy sources. This small percentage of global renewable power is phenomenal when considering that only three centuries ago renewables provided entire energy sources. (Nelson, 2011)

Approximately 14% of the earth's energy comes from bioenergy – mainly the burning of wood and charcoal but also crop residue and animal dung for cooking and heating (Scheer, 2002). Bioenergy therefore does contribute to the deforestation and removal of topsoil occurring in some developing countries, so while it is a viable form of energy production it needs better management.

Renewable energy sources are sustainable, ubiquitous and have very little pollution when managed and used properly, however there are some associated disadvantages. These include variability in power supply, as natural resources aren't able to be controlled and weather events can be unforeseen. Prolonged periods of cloud cover can significantly reduce the amount of solar energy able to be harvested by solar panels (Catalyst, 2016). Additionally, for example, decreases in average rainfall and the presence of drought conditions affect the amount of water held in reservoirs and so the amount of hydro energy able to be generated for a given period (Clean Energy Council, 2014).

"… I love a sunburnt country…"

Weather patterns in Australian are notoriously harsh. Consider our iconic poetic history "… I love a sunburnt country… of drought and flooding rains…" ("My Country by Dorothea Mackellar, 1908). Changes in weather patterns have been the rule rather than the exception in

Australia's (relatively briefly documented) history to date. As an example, reduced rainfall in many regions in Australia in 2014 led to a fall in hydro power generation of 25%, contributing to a drop in renewable energy generation from 14.76% to 13.47% (Clean Energy Council, 2014). As hydro is the largest contributor of renewable energy in Australia this was quite a significant decrease. There are inherent risks in depending too heavily on one power source, as Figure 1 below illustrates.

	Theoretically inexhaustible?	*Risk-free source?*	*No geographical restrictions?*
PV electricity	Yes	Yes	Yes, with varying yield
Solar thermal electricity generation	Yes	Yes	No, depends on insolation
Wind power	Yes	Yes	No, depends on prevailing winds
Water power	Yes	Yes	No, depends on watercourse and the effects of deforestation and climate change
Wave power	Yes	Yes	No, depends on coastal situation
Geothermal power	No	Yes	No, depends on availability of underground heat
Ocean surface heat	Yes	Yes, albeit dependent on the effects of climate change	No, depends on geographical conditions
Solar heating	Yes	Yes	Yes, with variable efficiency
Air, ground and water heat	Yes	Yes	Yes
Biomass for energy generation and as raw material	Yes	Yes, if managed sustainably	No, depends on availability of suitable land

Figure 1: Characteristics of Solar Resources (Quasching, 2010)

Other forms of renewable energy such as biomass, wind turbines and geothermal however have detrimental components. As previously mentioned, biomass and bioenergy require the use of land for crops or livestock in order to produce fuel for combustion. As a result there is visual pollution and odour, as well as the previously mentioned deforestation. Wind power generation results in avian and bat mortality from wind turbines. Despite its critics, wind power is becoming increasingly popular, three wind farms (556.7 MW total capacity) were built including Trustpower's Snowtown 2 in South Australia -the second largest wind farm in Australia. Interestingly, solar farms are also becoming more common, the 20MW Royalla solar farm was the largest in Australia at the end of 2014. (Clean Energy Council, 2014).

Given the nature of the climate in Australia, and the very high availability of sunshine compared to the rest of the world, solar power is arguably the most obvious choice for further development and uptake (GeoScience Australia, 2016).

2.5 Solar Energy

2.5.1 Solar Power in Australia

Annually, the sun delivers approximately 15000 times the amount of energy consumed by the earth's population, approximately 3.9 x 10^{24} J or 1.08 x 10^{18}kWh (Quasching, 2010) and much more than is stored in any reserves – it is quite obvious that solar radiation is a widely underused resource (Scheer, 2002). Insolation, mentioned earlier, is the description of solar energy incident on the earth's surface and it can be direct or diffuse (if it travels through cloud cover). Based on the average insolation per square metre per year, aggregate demand and the output of solar panels in Germany, for example, there would only have to have solar panels installed on approximately 10% of its construction surfaces in order to meet their entire energy needs. However, this is best case scenario and would still be best teamed with other renewable energy sources in order to maximize reliability and stability (Scheer, 2002).

Australia has the highest insolation (solar radiation per square metre) of any continent in the world - approximately 58PJ - and therefore some of the best solar resources. However solar energy accounts for a small percentage of Australia's total energy usage, with the main applications being solar water heating (GeoScience Australia, 2016).

Further to this, according to Solar Choice, Australia has sufficient solar radiation, especially in the North-West desert regions, to provide sufficient energy to meet global electricity demands (let alone just Australia's). It is clear from this discussion that solar energy has massive potential in Australia. The figure shown below gives a visual representation of the solar resources in Australia as well as the areas that could provide sufficient energy for Australia's/global demands.

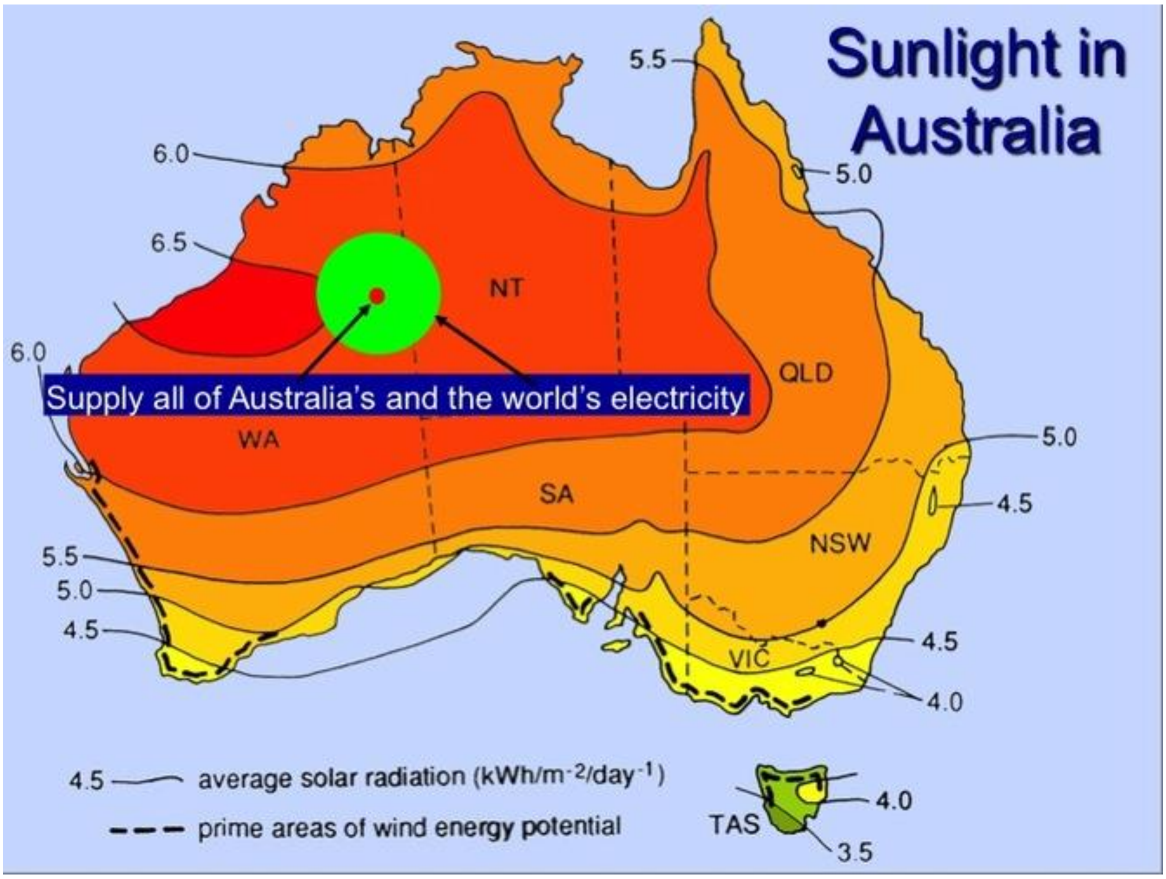


Figure 2: Sunlight in Australia (Solar Choice, 2016)

Local government on the Sunshine Coast is building – and funding – QLD's first large-scale solar farm due for completion by mid-2017. The 15GW farm, located behind Coolum, is costing $48.5M after federal funding was rejected – council members were unanimous in their vote to push forward and self-fund the project. The council plans to sell excess energy, as there will be energy created surplus to their demands; mainly for street lighting, libraries, parks, sporting facilities etc.; and the predicted savings to the council and ratepayers are in excess of $22M over the life of the farm (30 years) (Moore, 2016). Redland City Council is also considering investing in a similar solar farm; supporting the notion that solar installations are a viable and economically feasible replacement for fossil fuel generated power (Moore, 2016).

2.5.2 Solar PV

The photovoltaic panels used in solar energy generation are each made up of a large number of photovoltaic cells; these cells work by converting sunlight directly into electricity. The photo effect was discovered in 1839 by Becquerel, a French physicist, when he discovered during an experiment that some materials would produce small amount of electricity when exposed to sunlight (Quasching, 2010).
The photoelectric materials in the cell absorbs light causing an electron to then gain kinetic energy and transfer through the material. The main materials contained in PV cells are semiconductors, usually made from organic polymers (Nelson, 2011).

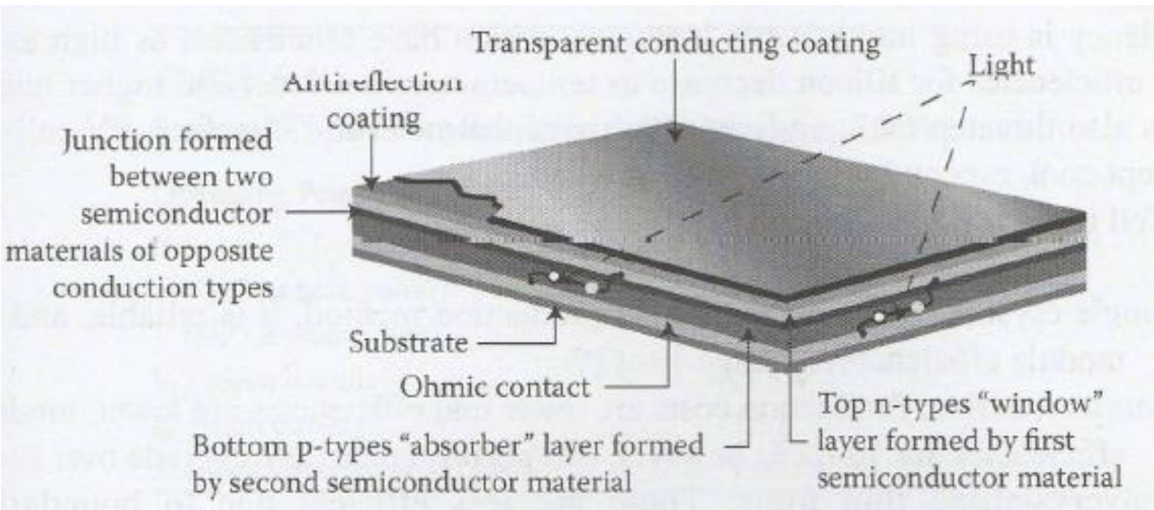


Figure 3: PV cell formed by n and p layers (Goswami, Kriefer & Kreith, 2000)

Semi-conductor materials have n and p type substrates (opposite types of conduction) separated by a layer of dielectric. When light is incident upon the solar cell it causes excess electrons to jump across to the p layer leaving the n side positively charged and the p type negatively charged. However, these electrons will only jump across if they have sufficient photon energy (i.e. greater than the band gap – difference in energy between the valence and conduction bands). Electrons that lack sufficient energy will remain in place but the electric energy is then converted to kinetic energy, resulting in heat. One of the reasons the conversion rate for solar PVs is so low is that a photon can free only one electron at a time (also has to be correct band gap). The key to solar energy generation is to channel the free electrons through an external load/resistance before they recombine with the holes thus, creating current (Goswami, Kreifer & Kreith, 2000).

A semi-conductor works by utilising current caused by the movement of electrons (negative) and holes (positive) between two layers material of opposite conduction types. Only light of a certain band is able to be absorbed by the PV cells so that, along with efficiency of the cell itself, means approximately 35-40% of light energy can be utilised by the PV cell. This is why efficiencies of solar panels are, although significantly better than they used to be, still quite low. Most current cells operate at around 10-15% efficiency. (Nelson, 2011)

There are several different types of photovoltaic cell. Single crystal is the most expensive and has a good efficiency; it is generally more expensive because it is a much more involved and delicate process creating the single crystal wafers used in the cells. Semi-crystalline is cheaper and easier to make than single-crystalline however the less pure crystal wafers lead to a decrease in efficiency. Poly-crystalline cells can be integrated into thin-film applications but are less efficient due to the numerous boundaries between the crystals. Amorphous cells are created through a process of vaporization of material and depositing onto glass or stainless steel. Amorphous cells also have thin film capabilities as well as being lower cost and efficiency but they do degrade over time. Silicon is second most abundant element in the earth's crust after oxygen (Quasching, 2010).

Cells are combined into modules. A typical module consists of (Nelson, 2010)

- Transparent top layer (usually glass)
- Encapsulant (usually thin sheets of ethyl vinyl acetate that hold together the top surface, solar cells and rear surface)
- Rear layer (thin polymer sheet, typically Tedlar, to seal module)
- Frame (typically aluminium)
- Electrical component

The efficiency of solar PV cells is affected by many factors. The actual efficiency is lower than theoretical efficiency because there will always be reflection of light from the surface of a cell. This can be minimized, however, by an anti-reflection coating under the top layer of glass (as can be seen in figure 3). This anti-reflection coating can reduce the reflection of a silicone cell to 3% from more than 30%. Shading of the cell also effects the actual efficiency this is due to the placement of current collecting electrical contacts. These impacts can be minimised by reducing the area of the contacts and/or making them transparent however this will then increase resistance of the cell to current flow. The recombination of the electrons and holes before they can contribute to the current can also decrease the efficiency and this can be reduced on polycrystalline and amorphous cells by using hydrogen alloys (Goswami, Kreifer & Kreith, 2000).

PV cell installations, like wind, do not require water which is advantageous, because it means once they're installed there is no need to be relying on water supplies. There are many advantages associated with the installation of solar panel systems for the generation of renewable energy. These advantages are:

- High reliability
- Low operating costs
- Modularity
- Low construction costs

Disadvantages are:

- High initial costs
- Variability
- Storage increases costs
- Lack of infrastructure in remote areas (Introduction to Renewable Energy page 99)

The size of an array needed is dependent upon the location and solar radiation etc., seasonal changes as well as the angle of the cell in relation to the sun position. Both fixed and tracking arrays are used, however a fixed array is most efficient facing the equator with the tilt angle equal to the latitude (or within 10˚). Tracking arrays are more complicated as they have more mechanical parts potentially leading to a greater risk of damage or malfunction. One-axis tracking arrays are reliant upon a change in the angle off rotation (North-South or East-West) whereas two-axis tracking arrays are a passive East-West system where the tilt angle changes by month. GPS is used in some tracking arrays in order to maximize the amount of solar radiation incident on the surface of the panel (Nelson, 2011).

A solid state solar PV installation is simple in design and requires very little maintenance. One of the major advantages is that they can be built in place as a stand-alone system and generate outputs from μW to MW (microwatt to megawatt). Solar cells have been used in a wide variety of applications for many years now such as for watches, calculators, water pumps, remote buildings, communications, satellites and MW power plants. They can be incorporated into external building fittings such as wall paneling and roof shingles. Due to the improvements in technologies the production of solar devices is now much more economical. This is definitely a positive as in the 60's and 70's it took more energy to produce a cell than that cell could ever hope to deliver during its lifetime. By 1996 the payback period for most solar PV cells was down to 2.5-5 years with a lifetime were over 25 years, although this payback period was still dependent upon the location of the installation (Goswami, Kreifer & Kreith, 2000).

In Australia, solar installations have been becoming much more prevalent, particularly in commercial applications. As of the end of 2014, more than 15000 businesses have installed solar energy generation systems, saving more than $64M each year. Eight of the top ten postcodes in Australia with the greatest number of solar installations were in QLD, and the other two in WA. The top three postcodes were Bundaberg, Mandurah and Hervey Bay. (Clean Energy Council, 2014). In 2014, South Australia was operating using approximately 40% renewably sourced energy however, the government decided to increase the target to 50% by 2025. As a show of force, on the 30/9/14 from 9:30am-6pm the entire state was completely powered by renewables (Clean Energy Council, 2014).

As a way to gauge the capacity of solar power, shown on the following page (Figure 4) is a table of the stand-by power consumption of various household electronics. It shows the approximate area (in m^2) of solar panel required to generate sufficient energy to power each device.

	Stand-by power consumption			Annual stand-by power consumption			PV panel needed to supply the appliance, assuming that the power is transmitted over the grid (output and area)[2]					
	Average for existing appliances (Watts)	New, energy-efficient appliances (Watts)	Highest power consumption[1] (Watts)	Average for existing appliances (kWh/yr)	New, energy-efficient appliances (kWh/yr)	Highest power consumption[1] (kWh/yr)	Average for existing appliances W	m²	New, energy-efficient appliances W	m²	Highest power consumption[1] W	m²
Entertainment electronics												
Televisions	12	0.1	20	83	1	139	95	0.87	1.2	0.01	160	1.45
VCRs	15	1.0	28	126	8	235	145	1.32	9.2	0.08	270	2.45
Satellite receivers	20	3.0	35	139	21	242	160	1.45	24.1	0.22	278	2.53
Hi-fi systems	12	1.0	14.5	96	8	116	110	1.00	9.2	0.08	133	1.21
CD players	6	0.1	7	50	1	59	57	0.52	1.2	0.01	68	0.62
Household appliances												
Electric cooker with built-in clock	6	3.0	7	48	24	56	55	0.50	27.8	0.25	64	0.59
Microwave oven with built-in clock	3	3.0	4	26	26	35	30	0.27	30.0	0.27	40	0.37
Coffee machine with built-in clock	4	2.0	5	12	6	15	14	0.13	6.9	0.06	17	0.16
Communications equipment												
Telephones (2–10 units)	20	8.0	25	161	4	200	185	1.68	73.6	0.67	230	2.09
Answering machine	4	1.6	12	35	14	104	40	0.37	16.1	0.15	120	1.09
Fax machine	12	1.0	100	104	9	870	120	1.09	10.3	0.09	1000	9.09
Home computers												
PC and monitor	100	2.5	200	44	1	88	51	0.46	1.2	0.01	101	0.92
Ink-jet printer	10	2.0	70	4	1	31	5	0.04	1.2	0.01	36	0.32
Modem	8	3.3	10	2	1	2	2	0.02	1.2	0.01	2	0.02

1 Highest power consumption: primarily older units.
2 Output in watts per module (with optimum orientation) for equivalent annual power consumption in stand-by mode; panel area needed in m², assuming 11 per cent efficiency without generation and transmission losses.
Source: UBA/Hans-Joachim Bruch

Figure 4: Stand-by power consumption and equivalent PV panel area (Quasching, 2010)

There are many types and brands of solar cell available in today's market although the two most prevalent options for residential applications are multi-crystal and mono-crystal. There are many brands available offering different features, so in this literature review, in order to restrict the length of the report to the correct range, the three that will be used in later sections will be the ones discussed. Shown in the following table (Table 1) are the specifications found for various models of solar panel available in Australia. As mentioned previously, only three of these have been included in the final analysis (shaded).

Brand	CNPV CNPV-250P	JA Solar JAP6-60-260/3BB	Jinko JKM250P-60-A	LG LG300N1C-B3	QCells Q.PRO-G3255	Renesola JC260M-24/Bb	Simax SM660-250	Sunpower SPR-E20-327
Type	Multi	Multi	Multi	Mono	Multi	Multi	Mono	Mono
Wattage	250W	260W	250W	300W	255W	260W	250W	327W
Cost	$209	$217	$215	$373	$263	$224	$430	$499
Efficiency	15.3%	16.21%	15.27%	18.3%	15.3%	15.98%	15.3%	20.1%
Length	1650mm	1650mm	1650mm	1640mm	1670mm	1640mm	1640mm	1559mm
Width	990mm	991mm	992mm	1000mm	1000mm	992mm	992mm	1046mm
Depth	40mm	40mm	40mm	35mm	35mm	40mm	40mm	46mm

Table 1: Solar Panel brands (Sunpower, 2011; QCells, 2013; Simax, 2014; JA Solar 2015; Solar Design Tool, 2016)

The first battery that is being analysed is the CNPV-250P, a high performance 60 cell polycrystalline module produced by CNPV Solar Power SA. As the cheapest of the options, it still has a fairly good efficiency at 15.3% and has a 25year linear performance warranty and a 10 year workmanship warranty. It also has accredited ammonia/salt mist resistance which makes it ideally suited to marine and high pollution environments. According to solar choice this 250W panel is available for purchase in Australia for $209 (Solar Design Tool, 2016).

The LG300N1C-B3 (MonoX NeON) by LG is a monocrystalline cell with a higher power output and higher efficiency at 18.3%. The monocrystalline structure makes this cell more efficient but the double-sided cell structure incorporated into the design also helps increase power efficiency. The rear of the cell is also able to absorb reflected light that would have otherwise been lost to the system. This panel is a little more expensive, at $373 but it is also a 300W panel as opposed to the 250W of the CNPV panel. Additionally, this cell also has a 10 year workmanship warranty and a 25 year linear warranty. This warranty guarantees that after the first year the cell will still be operating at 98% initial capacity and, with 0.7% annual degradation, will still be operating at above 81.2% after 25 years (LG Corporation, 2016).

The final cell is the Sunpower SPR-E20-327 (Maxeon) which is the highest efficiency (20.1%) and also the highest price at $499 per panel. This monocrystalline cell is suited for areas with minimal roof space available or where a system upgrade with additional panels is likely and therefore space is at a premium. This high performance cell is touted to be very efficient in real-world applications with cloud cover resulting in a lower level of solar radiation reaching the cell. This cell also is the only cell to be built on a solid copper foundation resulting in an incredible reduction in the chances of standard cracking and panel degradation (SunPower, 2011).

Solar Batteries

Large scale batteries were initially built for submarines and they were lead-acid – like today's car batteries. Static supercapacitors, another type of battery storage, are crucial for solar-powered stand-alone and always-on devices such as calculators, radios etc. Electrochemical batteries, like lead-acid, work through the flow of power in through one electrode and out through another. This reversible process can be repeated tens of hundreds of times, making them economically feasible and with good efficiency (Scheer, 2002), however they do have a low energy density. Also, due to their components they pose some issues with disposal. Batteries with higher energy density but lower efficiency than lead-acid are nickel-hydride but they also have problems with safe disposal (Scheer, 2002).

While these batteries are still used for many smaller devices, there is now more of a push for lightweight, high capacity battery storage such as for electric cars. The EV (electric vehicle) concept has been around for more than a century, however there was limited incentive to pursue it as a viable fuel source as there were other, easily obtained alternatives (fossil fuels). Lithium ion or lithium polymer batteries are low weight, high efficiency, and high energy density, have a good life-span, are environmentally sound and require very little maintenance. Due to their adaptability and high capacity, lithium ion batteries power 50% of the small portable market (Scheer, 2002). They have become more common and have progressed further technologically due to the increased need for EV power (Quasching, 2010).

It makes sense for next step for lithium ion batteries to have become an option for home energy storage. Home energy storage systems can be broken into short-term (hours or days) and long-term (months). Long-term storage is still very expensive, so normally photovoltaic generators are oversized to compensate in wintertime when the solar radiation is decreased. This is often more cost effective than trying to store more power. It is generally accepted that three days of stored power should be sufficient in most situations, especially sunny locations like Australia (Catalyst, 2016).

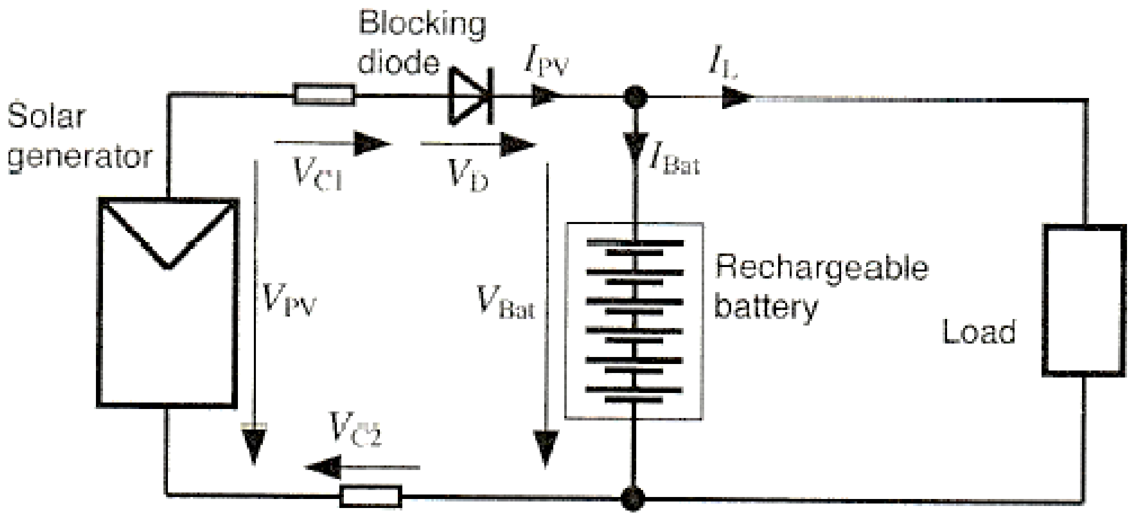


Figure 5: Simple PV system with battery storage (Quasching, 2010)

Figure 5 above shows a simple PV system with battery storage installed. The battery is installed parallel to the load (the structure using power), and any energy produced during the day but not drawn by the load is sent to the battery for storage. Battery storage, although still expensive, has become much more popular in recent years due to increased public demand for sustainability.

At the moment, there are many types of batteries on the market. One that has had a large degree of public interest lately has been the Tesla Powerwall (Origin Energy, 2016). Other batteries that have been gaining popularity of late are those supplied by Fronius as well as the PowerLegato distributed by AGL and AUO (Coast Wide Solar, 2016). A brief description of each of these batteries will be supplied here however the subsequent analysis will be discussed in depth in the Results and Discussion sections.

The newly released Tesla Powerwall is a home battery designed by US EV producer Tesla and its release has caused a massive stir in the industry. The Powerwall is only $3800 (wholesale, not including an inverter and not installed), and at 6.4kWh (usable) capacity that makes it much more affordable than other options on the market at present. It operates at approximately 92.5% efficiency and can operate between -20˚C and 50˚C making it a very versatile and high performance system (Tesla, 2016).

When compared to the PowerLegato (on offer by AGL to customers), which has an operating temperature of -20˚C to 40˚C, at 7.3kWh and $9990 (installed with inverter and basic connection to an existing PV system) there is quite a price disparity (AUO, 2013).

The Fronius Solar battery can be bought as part of a Fronius Energy Package, making it ready to connect to an existing PV system. This hybrid system includes a 3-phase inverter, smart metering system, battery as well as an emergency power function that allows power to be used when grid power is down. This function can be added from mid-2016 with a software update to the smart meter – a bidirectional meter that maximizes self-consumption and plots the load curve (Fronius, 2016).

The usable capacity of batteries is defined by the depth of discharge (commonly referred to as DOD) which is effectively a charge threshold below which the battery will no longer be able to continue discharging (PV Education, 2014). This is commonly referred to in specification documents as the ‘actual’ capacity or ‘usable’ capacity. For example, the 7.5kWh Fronius Battery has a 6kWh ‘usable capacity’ due to its 80% DOD (Fronius, 2016).

Since the power generated by solar PV panels is DC, it is necessary for there to be an inverter between the panels and the load to convert the DC to AC – which is able to be used by the load (AUO, 2013). Solar batteries also require an inverter as it is necessary to convert the current to AC. Some have an inverter built-in such as the PowerLegato, which also has system protection for the remote monitoring including password protection and battery emergency cut-off and dashboard information in the form of real-time PV generation and energy usage data (AUO, 2013).

The following figure shows how the PowerLegato is integrated into a system – DC electricity runs from the PV to the battery where it's converted into AC. The AC power can then be used throughout the home or sent back to the grid (if there is surplus). It also show the remote monitoring capabilities through the EnergyOptimizer Software (AUO, 2013).

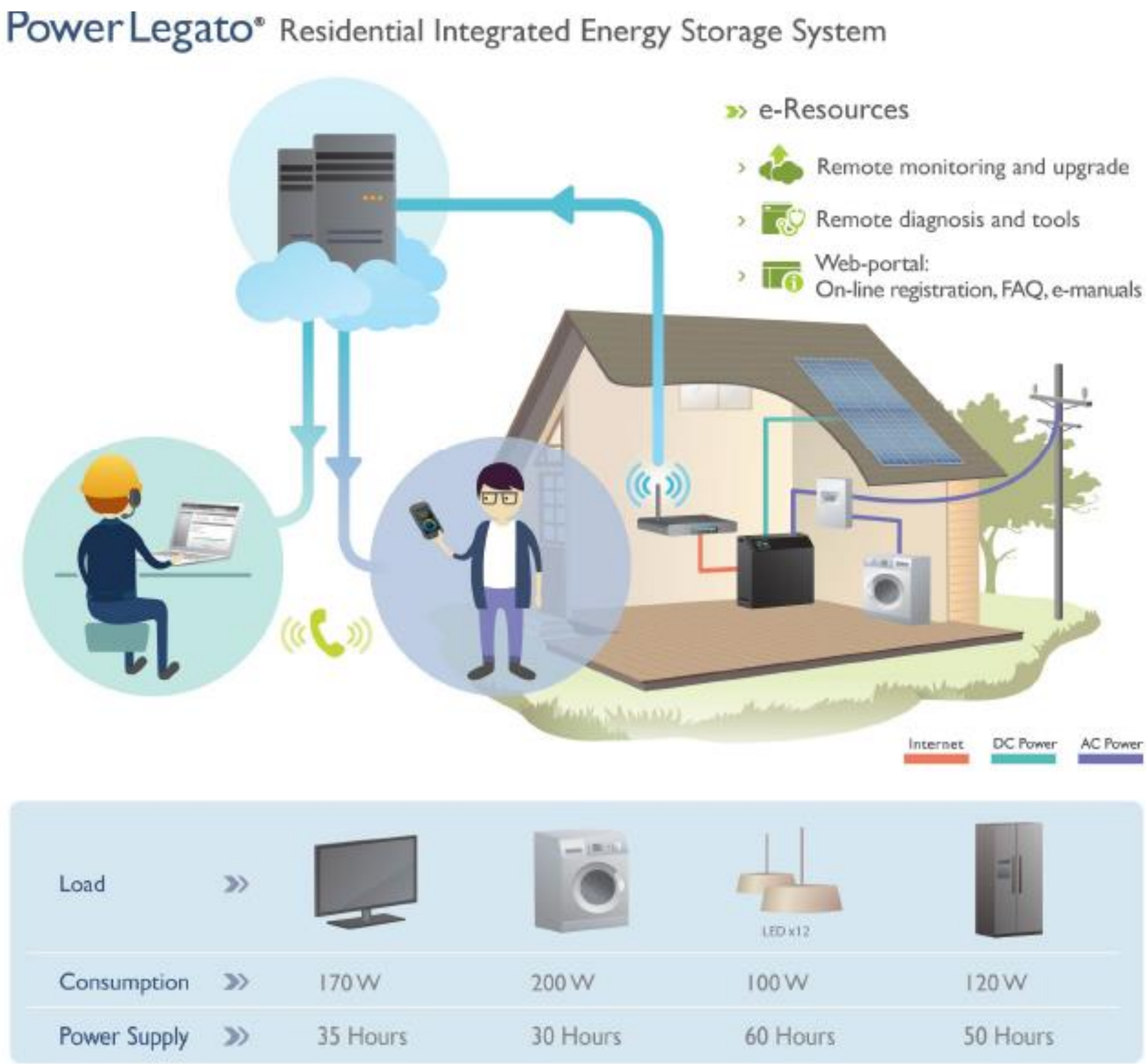


Figure 6: PowerLegato Integrated Energy Storage System (AUO, 2013)

There are a few options to consider when opting to include battery storage in a home. Since batteries are still quite expensive this makes long-term energy storage very uneconomical. The first is going off-grid entirely, for which battery storage has to be sufficient for at least a week of average power use – this is to mitigate the chances of being left without power if the weather is overcast for a prolonged period. The second option is to have sufficient panels and batteries to generate and store enough power but also keep the grid connection as a backup (*Catalyst*, 2016). This option also means that any surplus energy is sent back to the grid rather than be wasted. Another option is a smaller battery that charges during the day fed by the PV then is used at night when peak grid prices would otherwise be charged.

Until the start of 2015 batteries were much more expensive, the cheapest on the market was a 7kWh battery, installed, with an inverter for over $15000. Prices have dropped now, with the PowerLegato installed for $9990 mainly due to the release of the Tesla Powerwall, as mentioned earlier (Catalyst, 2016).

Although there are obvious benefits, battery storage isn't yet completely safe. There is still some risk of explosion (and fire), and at the moment new battery storage technologies aren't covered by the Australian safety standards. Standards Australia EL42 working group are coming up with new standards – AS/NZS 5039 which will ensure that batteries will only be able to be installed by those with sufficient demonstrated competency i.e. specific training. All products installed will also have to meet the new safety standards (once they have been released). At the moment there are no rules or regulations stipulating an installer must have training to install a storage device or that the device must meet certain standards (Clean Energy Council, 2016).

3 METHODOLOGY

The data that has been used in this project is both primary in the form of data gathered from the BOM (Bureau of Meteorology) and the questionnaire, and secondary in the form of internet research, books and journal articles. The objectives of this report are re-stated:

- To gather and analyse public opinion and perception through a survey
- To present Case Studies to assist in analysing relevant issues

- To provide an analytical tool to facilitate decision making as an example of ways to increase uptake of battery storage as an option/enhancement
- To provide results of an investigation of Relevant Factors related to solar installations in order to remove barriers which hinder increased uptake of solar panels and battery storage

In order to achieve the first objective, a limited survey was conducted (although the demographic consulted covered a wide spectrum). The information gleaned from the survey was then analysed numerically and used to determine what factors and information the public wished to know about solar systems. The second objective was achieved through research of existing solar systems in Australia, this was necessary to determine issues and hurdles relevant to an installation as well as setting a precedent for the type of system that might be installed for given requirements. The third objective, the analytical tool, was included as a way for users to be able to select and enter their specific needs and be presented with a potential system that would meet those needs. It was used to illustrate a way to engage and inform potential buyers, and therefore assist in overcoming resistance to uptake. The fourth objective was necessary as there are numerous issues involved in the regulation and installation of solar systems, including cost, safety, space, as well as rebates and Small Technology Credits (STCs). Although this report has identified these several factors in order to provide an accurate assessment of all factors that need to be considered before installing a solar system, given the dynamic nature of rebates and STCs (not just over time but from State to State) their inclusion in this report is limited to their identification and general impact rather than a detailed financial analysis, as such analysis would render this report specific only to the date of its issue.

3.1 Survey

In order to gather information about public opinions on solar power generation and the potential for battery storage from “every day” Australians, a survey was designed and completed by a small group. In this survey, (see Appendix III) participants were asked to detail what they knew about battery storage i.e. if they had heard about them. They were also asked whether they would consider investing in battery storage and what would make storage more feasible and/or desirable for them. The survey also asked participants to detail whether or not they had solar panels (and if not, why not) as well as their thoughts on renewable energy vs. fossil fuel power generation.

The participants surveyed were a very diverse demographic, in order to ascertain the critical factors that a range of residential customers consider would impact their purchasing decision. It was then determined what factors needed to be addressed in order to meaningfully evaluate the data. The sample size for this survey was 25 with an age range from 19-80, location generally South-East QLD, both genders and various income levels and professions, with generally a reasonable to high level of education.

The quantitative data has been analysed numerically to provide a graphical representation of the results. The qualitative data has been analysed a little more deeply, with like results and ideas pooled together as well as providing a wide array of thoughts and responses.

3.2 Case Studies

The case studies that have been investigated in this report have comprised the Alkimos Beach project north of Perth, Geraldton Fisherman's Co-operative in Geraldton (WA) and Joseph Banks Aged Care. Although all three of these case studies are larger than a standard residential installation, it is beneficial to analyse the factors that are involved in such an installation. This is especially the case for the Alkimos Beach Project as it is an entirely new community that has had solar energy generation and storage built into its core. In addition to the solar installation projects, solar payback information from an apartment building on the Gold Coast (QLD) has been used in the modelling in support of the accuracy of the analytical tool.

3.3 Data Required

In conjunction with the data gathered from the survey, which was used to help in the structure and formulation of the main program, data was also collected from the BOM (Bureau of Meteorology) and various Australian solar power and electricity retailers. The data necessary to present the desired outcome includes average irradiance across Australia, solar panel specifications, battery specifications and grid energy costs as well as an approximate value for the solar panel/battery storage system. These costs were necessary in order to provide an approximate payback period for the system recommended to the user based on their energy needs.

The logic behind the program that has been designed for this project, and why it is necessary, is to provide unbiased information that can be easily accessible to users, and to allow them to easily obtain a general system recommendation. From the survey results (which will be discussed later), it appears many people would be unaware of many facts about solar installations and energy storage and as such, the whole process can seem a little nebulous. This assumption is based on the fact that, overall, the demographic consulted shared a fairly high average level of education and awareness.

The program has the capability to take the energy usage (either directly inputted or selected from average, below average or above average for the state they live in), number of occupants, whether or not battery storage is wanted, and the location. After this data is entered, the user's subsequent responses dictate which (Australian) state data is to be applied, and the options for specific solar panel and battery specifications are used to calculate the payback period cost analysis for user comparison.

Since the cost of solar installations and storage systems are so inconsistent and prone to state-by-state variations (especially when one considers the unreliability of rebates), this analysis has not included the cost of the installation or any applicable rebates (or STCs) in the payback period. As such, the only costs included in the analysis are the costs of the system itself and the average cost of grid power in each state. This will provide a general, maximum payback period able to be fine-tuned (and hopefully reduced) by the relevant state distributors and installers (with the addition of rebates etc.). This analysis is useful because it allows users to get a ball-park figure for their installation and be armed with knowledge when they approach the retailers rather than going in blindly.

In order to analyse the recommended systems and data, there are some key calculations performed. A breakdown of all equations used for the modelling and analysis and a description of how data was gathered is included below.

Location data such as irradiance, average load and daylight hours were gathered using various methods. Irradiance data was gathered both from published data from the Bureau of

Meteorology (BOM, 2016). The average monthly values of irradiance were noted for each city and then the annual average taken in order to provide the most accurate and realistic system recommendation. The quarterly or annual load is able to be entered directly by the user if they know it, but if they don't they are permitted to select their approximate load value i.e. Location is Adelaide and load is below average.

An example of a household with a below average usage would be one where occupants were away at work all day with appliances on standby or turned off. A household with an above average energy consumption would be one with a pool and other large appliances running such as large, inefficient televisions or air conditioners, and/ or where occupants were home during the day. In order to obtain the average load for each city for various numbers of occupants, an online calculator provided by the Australian Government – "Energy Made Easy" was used (Australian Government: Energy Made Easy, 2015).

For each capital city the fields were adjusted accordingly in order to provide the average load for 1-5+ people with the data represented below (Table 2). These load value have been the basis of the modelling and calculations used in the analytical tool (program) as if the user load is not entered these become the assigned values (depending on City and number of occupants).

Location	Postcode	Occupants	No pool/gas	Pool no gas
Brisbane	4000	1	8.7	14.6
		2	13.5	19.4
		3	15.1	21.0
		4	19.1	25.0
		5+	20.4	26.3
Adelaide	5000	1	10.9	19.0
		2	16.4	24.6
		3	16.6	24.8
		4	17.7	25.8
		5+	23.4	31.5
Darwin	0800	1	9.6	15.8
		2	18.6	24.7
		3	18.5	24.6
		4	20.5	26.6
		5+	31.3	37.4

Canberra	2600	1	13.3	20.3
		2	17.5	24.5
		3	25.5	32.5
		4	36.0	43.0
		5+	36.3	43.3
Hobart	7000	1	16.9	42.5
		2	23.4	49.0
		3	27.2	52.8
		4	32.3	57.8
		5+	29.7	52.2
Melbourne	3000	1	11.6	19.8
		2	15.3	23.5
		3	19.2	27.4
		4	14.6	22.8
		5+	25.3	33.5
Sydney	2000	1	9.0	16.3
		2	15.4	22.7
		3	19.0	26.3
		4	20.1	27.4
		5+	25.7	33.1
Perth	6000	1	11.2	Your estimate will be based on WA consumption data from 2011, which is the most recent available to the AER. It assumes you have no pool and use an average amount of gas
		2	14.1	
		3	17.0	
		4	20.0	
		5+	22.9	

Table 2: Average load per number of occupants for each capital city (Energy Made Easy, 2015)

3.4 Calculations

The above average load used for each city and number of occupants was the predicted load with a pool. In order to provide a numerical representation of the below average usage figure it was assumed that 75% of the average daily load was an appropriate amount.

$$\text{Load}_{\text{below average}} = \text{Load}_{\text{average}} \times 0.75 \quad (\text{kWh}) \tag{1}$$

Aside from the make and model of the panel and battery, the specifications needed for the calculations are the irradiance at the location, size of the panel (i.e. area of the photoelectric surface) and efficiency of the module (shown as η). To calculate the maximum output of the solar panel at a given location the following equation must be used:

$$P_{solar\ panel} = \text{Irradiance} \times P_{area} \times \eta_{panel} \quad (kW) \qquad (2)$$

(Goswami, Kreifer & Kreith, 2000)

Although this equation returns a value much larger than the power able to be generated by a 250W panel, for example.

The AC power used in the house must first be converted from DC (the type of power generated by a solar panel) and there are some losses in this transition (reference). In order to determine the AC load needed to power the system the following equation is needed:

$$Load_{AC} = Load_{DC} / 0.8 \quad (kWh) \qquad (3)$$

(Understand Solar, 2015)

It is also necessary to take into account the hours of daylight at the location as this will affect the amount of solar radiation incident upon the panel surface as well as the AC load. Therefore, the amount of power needing to be generated each hour in order to meet the daily load is derived using the following equation:

$$Power_{Solar\ Panel} = Load_{AC} / \text{hours of sunlight} \quad (kW) \qquad (4)$$

(Understand Solar, 2015)

To accurately determine the number of solar panels needed to meet the daily energy needs (load) it was necessary to have technical data and specifications of the solar panels. This is in the form of the power output from the solar panel (power rating). Three models of solar panels currently available across Australia have been used in this analysis to provide a more varied series of results.

$$\text{Number of Solar Panels} = \text{Power}_{\text{Solar Panel}} / \text{panel output} \qquad (5)$$

To determine the number of batteries needed to power the system it is crucial to know the battery specifications as well. The capacity of the battery, the efficiency (η) and the cost is necessary to contribute to the total cost of the system in order to be able to work out the payback period. Storing large amounts of solar energy is very expensive at the moment so the average system in a sunny location such as Australia usually stores enough power for around 3 days (Catalyst, 2016).

$$\text{Amount of Storage Needed} = (\text{Load x days of storage}) / \eta_{\text{battery}} \quad (\text{kWh}) \qquad (6)$$

$$\text{Number of Batteries} = \text{Amount of Storage Needed} / \text{Capacity}_{\text{battery}} \qquad (7)$$

As mentioned in the literature review, the three solar panel brands being analysed are the CNPV-250P by CNPV, the LG LG300N1C-B3 (MonoX NeON) and the SunPower SPR-E20-327 (Maxeon) and their specifications that have been used for the analysis have been obtained from the datasheets available on the respective company websites.

For the payback period analysis, the cost of the recommended system is required along with the grid electricity costs that will be offset through the use of the solar system. The grids costs have been obtained from the relevant state authorities (see Table 6 in Results) and the relevant costs are the electricity costs solely (c/kWh) (not the daily access charge as this won't affect the payback period).

Since the user will have the option to select whether or not they want battery storage the payback period for both needs to be included. The total cost of the system is required and the equations for the total cost and payback period (with and without battery storage) are shown below:

$$\text{Total Cost}_{\text{No Storage}} = \text{Number of Solar Panels x Cost of panel} \quad (\$) \qquad (8)$$

$$\text{Payback}_{\text{No Storage}} = (\text{Total Cost}_{\text{No Storage}} / (\text{ Grid cost x Load}_{\text{DC}})) / 365 \quad (\text{years}) \qquad (9)$$

$$\text{Total Cost}_{Storage} = (\text{No. Panels x Cost of Panels}) + (\text{No.Battery x Cost of Batteries}) \ (\$) \tag{10}$$

$$\text{Payback}_{Storage} = (\text{Total Cost}_{Storage} / (\text{Grid cost x Load}_{DC})) / 365 \quad \text{(years)} \tag{11}$$

3.5 Assumptions

Since solar installations are so variable and dependent upon the exact location and situation, there have been a number of assumptions required to be made in order to generate this program. Firstly, since irradiation and insolation values vary with geographical location and season, it has been assumed (in order to allow for the most general approximation of a recommended system) that the values used will be an annual average. For example, in Brisbane the irradiance in winter in significantly less in winter than it is in summer and so, the annual average is the value selected for use.

Secondly, there are many available solar panel brands and installations. It would be almost impossible to be able to accurately analyse the performance of all panels currently available in Australia within this time frame allowed for this project. As a result, the report has been limited to three popular panels currently available in Australia which have been used for the analysis.

Each state has different energy providers and, as a result, different costs for grid power. In order to provide consistent results generally, an average cost of grid power in each state has been used. As such, and as discussed earlier, when evaluating the installation costs, government rebates and STCs will not be included in the cost analysis of the systems.

The energy distributors in Australia are:
Queensland – Ergon Energy and Energex
New South Wales – Ausgrid, Endeavour Energy and Essential Energy
Australian Capital Territory – ActewAGL (Essential Energy also service some areas)
Victoria – Citipower, Jemena, Powercor Australia, AusNet Services and Energy United Distribution (Essential Energy service a small area)
South Australia – SA Power Networks

Tasmania – TasNetworks

Western Australia – Horizon Power, Western Power

Northern Territory – Jacana (formerly Power and Water Corporation)

Since the state electricity provider control most solar installations, it will be necessary for users to contact their relevant electricity distributors and gain relevant approvals before proceeding with a solar installation (Origin Energy, 2016).

Average daily energy usage differs per state and also depends on the number of people in the household. Users are able to input their annual or quarterly energy usage into the program (if they know it) and their resulting system will be more accurately selected to fit their specific needs. However, if the user doesn't know their energy usage or doesn't have the bill available, they are still able to use the program. The program prompts the user and asks for the number of people in their household, as well as whether they use an average amount of power, (or below average or above average). Depending on their answers, an average value for a daily energy load will be assigned.

Users are also asked to select which capital city they are closest to. For example, a user living in the Sunshine Coast would select Brisbane. Capital cities are used for consistency, as there would be little variance in irradiance within limited distances, and such grouping also allows for simpler definition of the state in which the user lives. This also allows for the various costs to be more accurately assigned.

The number of panels/batteries needed for the system was rounded to the nearest whole number, and it was assumed that all panels included for analysis are able to be installed in a system with odd numbers (and that they don't each require a matched pair in order to operate).

There are other costs associated with grid connected electricity that will not be incorporated into these analyses in order to keep the report within the range required. These costs include a daily service charge and, assuming the system will remain connected to the grid for backup power, this cost will remain static and therefore not influence the payback period of the system.

It is also assumed that the building in question would have sufficient roof space to house an installation recommended to meet the energy requirements.

3.6 Other Factors Affecting Cost/Feasibility

The costs of a solar installation are extremely variable for a number of reasons, and although the installation costs themselves are not included in the analysis, it is still necessary to flag other cost factors which are associated with a solar installation. Rebates, for example, have in the past provided a buffer of sorts and made the initial investment more attractive.

Some rebates reduce the purchase price of the system, such an example are STCs (Small Technology Credits). When a solar system is installed, the system is entitled to one STC for every megawatt (MW) it's expected to produce over the next 15 years. (Infinite Energy, 2016). It is common for the STCs to be transferred to the retailer in exchange for a reduction in the purchase price of the system. For example, if an installed system would be allocated 40 STCs with a value of $2000, transfer of the STCs to the retailer will result in a $2000 discount.

There are other rebates available to PV owners in the form of tariffs, these tariffs allow excess power generated by the system (and not stored in a battery) to be bought back by the electricity distributor. These rebates are quite low now, for example in QLD, 7.13c/kWh is paid for surplus energy sent to the grid (Infinite Energy, 2016). However, energy used from the grid costs an average of 22.238c/kWh in QLD (Queensland Competition Authority, 2016) so there is little financial incentive to sell electricity to the grid. The most economical option is to store the excess energy and use it during peak times instead of grid power.

4 RESULTS

4.1 Survey Results

By using the data gathered in the survey conducted for this report, it was possible to make assumptions about what "every day" Australians know about solar power and storage, as well as gathering their thoughts on various aspects related to solar installations and battery storage.

For example, price is clearly still a factor when considering solar installations as 56% said that price and value for money was the most crucial aspect, 24% said reliability, 12% said that capability for storage would make the more interested and 8% said they'd like more information to be publicly available (see Figure 7). It was also assumed that the general public are of the opinion that government incentives were beneficial as they provided a buffer of sorts, decreasing the upfront costs for installing a solar system.

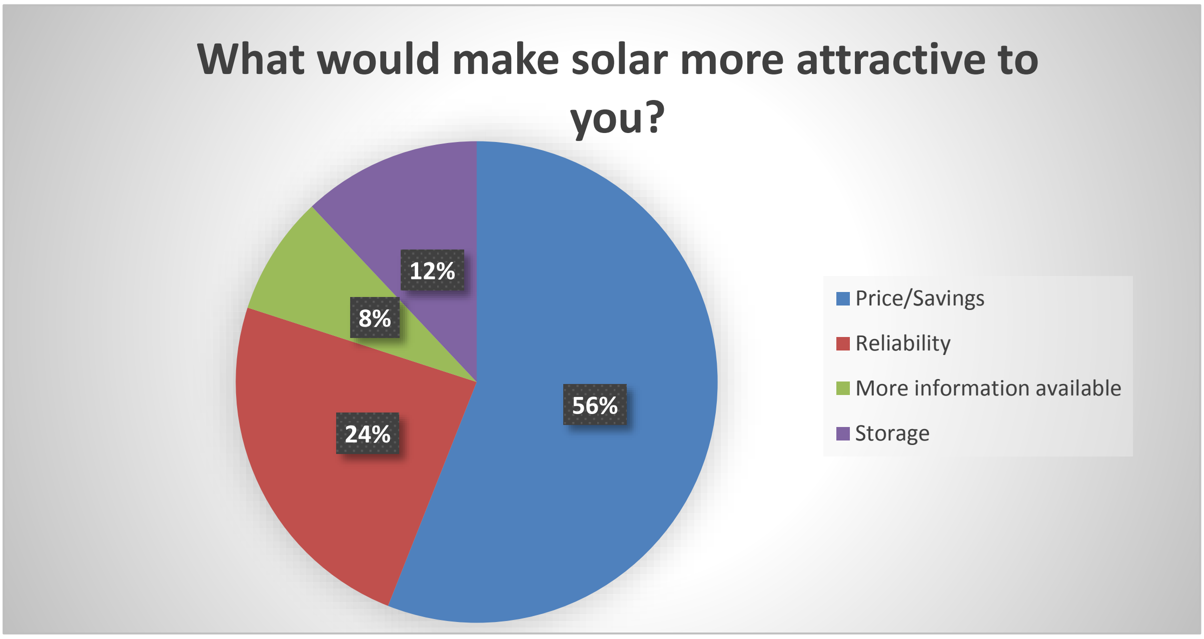


Figure 7: Survey responses to question 10

All surveyed individuals said they would like an energy neutral home if cost weren't a factor. The below graph (Figure 9) shows the reasoning for why they'd want their home to have off-grid capabilities. Figure 8 shows the amount of money those surveyed would find acceptable for off-grid power.

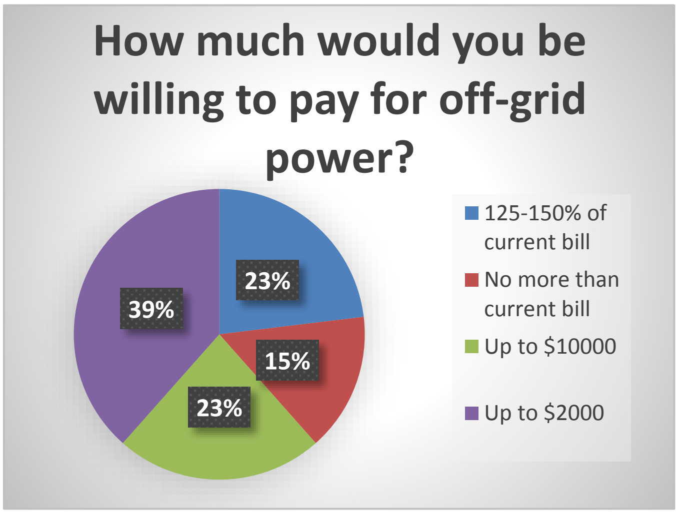


Figure 8: Survey responses to Q5

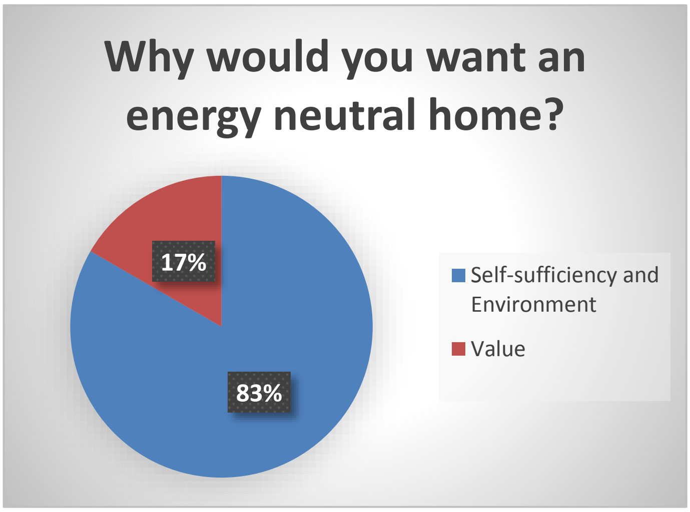


Figure 9: Survey responses to Q14

The responses from the survey have helped shape the direction of the program. For example, it was also gathered from the survey responses that people want to know more about batteries and their specifications. These technical details can be quite hard to find for various brands and models so therefore a concise and accurate list of these details being used and represented to the user would fill this gap. As a result, the pricing for the systems and general payback period will be included along with the specifications and details of the solar panels and battery brands used in the analysis. This will arm the user with a factual base and general assessment as the initial step in the installation process.

The survey results are located in Appendix II.

4.2 Case Study Results

Solar Energy Systems in multi-building communities are quite a new concept, and as a result, case studies on multi-building communities with shared power are still limited. As these applications are so important however, given the increase in the number of such facilities (e.g. Joseph Banks Aged Care (Infinite Energy, 2015)) a discussion of the studies that are available, even if limited, is crucial in considering the issues raised and the aims and objectives of this report. The case studies available have been analysed, and the relevant detail available has been considered in the designing of this program.

Although privacy laws prevent energy providers from releasing certain specific installation data on customers' installations they have completed, it is clear that such installations are economically viable (and assumptions may be made that factors such as the cost/benefit analysis/feasibility study/Corporate green credentials etc. warranted expenditure). For example, an interesting project in Western Australia installed by Infinite Energy, comprised a large installation across multiple rooves powering a retirement home. Speaking to staff at Infinite Energy confirmed that information pertaining to the actual installation at Joseph Banks Aged Care Facility could not be released without their clients' consent, (and subsequent contact made with staff at Joseph Banks was also unsuccessful). However, information was sourced from the Infinite Energy homepage and it is clear from this data that this installation, while fairly standard, was not small. 153 REC panels were installed across three rooves of the main building. This installation required the use of 2 inverters and a remote monitoring system (SMA). The analysis used to decide this was the best system for the needs was not shared by Infinite Energy however their installation resulted in a decrease in CO_2 emissions of around 52 tonnes per year.

Company	Joseph Banks Aged Care
Location	Canningvale
Installation Date	02 / 2015
Industry	Education & Medical
Solution	Solar Power & Grid Electricity - System capacity 39.78 kW 153 x REC Solar Panels 2 x SMA Sunny Tripower Inverters Integrated SMA Remote Monitoring Solution
CO_{2-} e. Abatement Per Year	52 tonnes
CO_2 Equivalent Reduction	188 trees saved per year
Energy Output Per Year	68,600 kWh
Solar % of Consumption	45%

Figure 10: Joseph Banks Aged Care Project (Infinite Energy, 2015)

The Joseph Banks Aged Care project was initiated after management started investigating ways the relive some of the costs associated with rising electricity prices. Due to the nature of the facility (aged care - and the therefore constant requirement for electricity) there was really only one feasible option to mitigate the spiraling electricity prices.

After Infinite Energy was contacted by management, they were able to do a very detailed analysis and assessment of the system requirements and, in addition to installing the solar system, Infinite Energy were able to also generate a customized tariff for the facility in order to save yet more costs.

Additionally, a larger, multi-building installation (also by Infinite Energy) was at the Geraldton Fisherman's Co-operative in Geraldton, WA. This installation was mentioned by staff of Infinite Energy in response to an enquiry about larger systems involving multiple buildings. This installation, completed in 2014, comprises 384 REC panels and is almost a 100kW capacity system. The environmental impacts due to this installation include approximately 122 tonnes of carbon dioxide abatement as well as more than 450 tree saved (Infinite Energy, 2015). The price of this system was not publicly available, and after contacting Geraldton Fisherman's Co-operative no further information about their installation was able to be obtained. The following data was available relating to the installation summary from Infinite Energy.

Company	Geraldton Fisherman's Co-operative Ltd (Brolos)
Location	Geraldton
Installation Date	12 / 2014
Industry	Agriculture, Produce & Wineries
Solution	Solar Power System - System capacity 99.84 kW 384 x REC Solar Panels 12 x SMA HV Inverters Integrated SMA Remote Monitoring Solution
CO_{2}- e. Abatement Per Year	122 tonnes
CO_2 Equivalent Reduction	457 trees saved per year
Energy Output Per Year	161,700 kWh

Figure 11: Geraldton Fisherman's Co-operative Ltd Project (Infinite Energy, 2015)

The Geraldton Fisherman's Co-operative Ltd - the world's largest rock lobster exporter and processor - were looking to reduce their energy bill as well as a reduced carbon footprint. Like the Joseph Banks Aged Care facility, the system recommendation from Infinite Energy was the result of extensive analysis of the system requirements. The system recommended by Infinite Energy was boasted as a market leading system with a payback period of 12 months (this is in part due to the very large size of the system installed).

The Alkimos Beach project started in 2012 and is due for completion by 2020 by which time it will boast over 6000 homes, schools, shops and all structures will have solar. This project, will have 1.2MW of stored power – enough to power 100 households for a full day. This will make this community the first community-level lithium ion application in a residential application in Australia. This project differs greatly to the two Infinite Energy projects (purely due to its size and conception) however have all required similar analysis of needs and therefore have provided a viable platform from which to base an analysis of factors relevant to solar installations in Australia.

After approaching solar teams from many energy providers and retailers seeking information, it was determined that in order to obtain information about the prices and specifications of solar panels and batteries that it was the best options to communicate directly with either the manufacturers or the retailers. For example, in QLD, Energex only deal with existing solar installations and pricing and recommended Origin as having more appropriate information. Origin Energy have three separate solar teams:

- Solar cells team who control price and procedures hpcasemanagement@originenergy.com.au
- Solar enquiries solarbilling@originenergy.com.au
- Solar new connection team after installation meter solarmeters@originenergy.com.au

In addition to the Infinite Energy projects, data contained in the report of a prospective Gold Coast client of Wattblock (an Energy savings company operating out of Brisbane) has been used to compare modelling results to determine accuracy (Wattblock, 2016).

4.3 Data Analysis Tool

As discussed in this report, it appears that increasing consumer demand (and uptake) of solar systems with battery storage has obstacles to overcome, including cost, government and safety policy, and availability. A major obstacle however seems to be a general lack of information available to consumers, and a corresponding lack of awareness of how to address this problem. Accordingly, as one example of a solution to this problem, this analytical tool has been developed to provide a mechanism for consumers to be able to plug in their specific information, and receive in return not only information but recommendations.

As detailed in the Methodology, the purpose of the analytical tool is to be able to recommend a system to a user based on their location, energy needs and tailored preferences. The program takes the user input and utilizes it to assist in determining the number of panels required to provide sufficient energy, as well as giving the option of battery storage. If battery storage is also required, the load and output of the solar panels can also be used to determine how many batteries would be required to store sufficient energy for that residence.

The data required for the analysis in this project was discussed in Section 3 and included the following parameters:

- Solar Panel Specifications
    - Brand/Model
    - Type (Monocrystalline or Multicrystalline)
    - Efficiency
    - Cost
    - Power Rating
    - Size (area of top face of panel)
- Battery specifications
    - Brand/Model
    - Type
    - Efficiency
    - Cost
- Grid Costs
    - Price of electricity in each state (c/kWh)
- Load data
    - Average load per state/number of occupants
- Irradiance/hours of sunlight per day data
    - To determine the maximum possible amount of solar radiation incident upon the surface of the panel each day

In order to retrieve this data is was necessary to first select the 3 solar panels and solar batteries that would be used. The following pages shows the specifications of the solar panels and batteries selected.

Brand	**CNPV CNPV-250P**	**LG LG300N1C-B3**	**Sunpower SPR-E20-327**
Type	Multicrystalline	Monocrystalline	Monocrystalline
Wattage	250W	300W	327W
Cost	$209	$373	$499
Efficiency	15.3%	18.3%	20.1%
Length	1650mm	1640mm	1559mm
Width	990mm	1000mm	1046mm
Depth	40mm	35mm	46mm

Table 3: Specification of the 3 chosen panels (Sunpower, 2011; LG Corporation, 2016; Solar Design Tool, 2016)

Brand	**Tesla Powerwall**	**PowerLegato**	**Fronius Solar Battery**
Type	Lithium-ion	Lithium-ion	Lithium-ion
Efficiency (%)	92.5	90	88
Cost ($)	3800	8188	8000
Capacity (kWh)	6.4	7	3.6

Table 4: Specifications of the 3 chosen batteries (Tesla, 2016; AUO, 2013; Fronius; 2015)

The grid electricity costs also needed to be obtained in order to perform the necessary calculations to determine the system payback periods. The following table gives an approximate representation of the average electricity prices in each state.

State	Electricity Price (c/kWh)	Distributor/Regulator
ACT	17.270	Origin Energy
NSW	23.991	Origin Energy
NT	25.54	Power Water
QLD	22.238	Queensland Competition Authority
SA	31.680	Origin Energy
TAS	25.200	Aurora Energy
VIC	27.742	Origin Energy
WA	25.7029	Government of Western Australia

Table 6: State-by-state electricity prices (Government of Western Australia, 2015; Aurora Energy, 2016); Origin Energy, 2016; Power Water, 2016)

4.4 Calculations

In order to do the analysis and perform the necessary calculations it has been necessary to determine the irradiance of various locations around Australia as well as the average load for varying levels of occupancy in each city. Determining the number of panels required for a system requires considerations of many involved aspects. For example, as mentioned previously, the number of people in the household (and subsequent daily load), system voltage, the location (affects radiance and number of daylight hours), panel specifications (i.e. dimensions, output, efficiency, cost etc.) and battery specifications (cost, capacity and efficiency).

The program has been coded using C (the programming language selected) involving various functions and including all relevant data to account for all possible eventualities. The user is asked to input the number of occupants in the residence, select the geographical location closest to them (nearest capital city), select whether or not they want battery storage and enter their energy usage (either a quarterly or annual amount). If the energy usage amount is not easily to hand or unknown then there is also the option to select below average, average or above average energy usage. In that case an average value will be assigned.

After the user has entered their data into the system then the analysis is performed by the system with the equations that were discussed in the methodology. For each capital city there is a separate series of values assigned for the daylight hours and irradiance. These irradiance and daylight hours calculations are used only to ensure that sufficient solar radiation falls on the panel surface in that location although, in Australia, due to our high insolation, that is almost a given. Additionally for each number of occupants a different average load value is used, depending on whether it's below average, average or above average energy use.

Also, as each state has different rules and regulations regarding solar installations (as well as different energy costs and installation costs) there will also be different installation outcomes depending on the state in which the residence is located.

After the relevant values have been assigned and conditional loops set, then the calculations take place and a series of information is returned to screen. The system uses user data to assist in determining the most suitable installation then present this information back to the user in a clear format. At present, due to the nature of the coding, the input/output is just through a terminal screen on a computer, however with the application of an appropriate user interface it could easily become an online calculator or a downloadable program.

The inputs, outputs and processes involved in the program have been clearly listed below:

Inputs:

- Location
- Energy usage
    - Enter known value (quarterly or annual figure)
    - If value is unknown then select below average, average or above average (the equations used to determine an appropriate value will be discussed later in this section)
- Desire for battery storage (yes or no) – will in turn affect total cost of system
- Number of occupants (only necessary if the actual energy usage is not known)

Data:

- Average irradiance in capital cities of Australia
- Average load of households in Australian capital cities (1-5+ people)

- Solar panel specifications
    - Dimensions
    - Efficiency
    - Cost
    - Lifespan
- Battery specifications
    - Cost
    - Efficiency
    - Depth of discharge (DOD)
    - Capacity
- Grid energy costs (c/kWh different values per state and energy provider. An average value for each state is used)

Outputs:

- Number of panels
- Number of batteries
- Cost of potential installation
- Payback period for the system
- Feedback of user entered data i.e. for a family of 5 living in South-East Queensland who don't have an energy bill accessible and use an average amount of power (no pool) the response from the program for this data would be:

"You have selected Brisbane as your closest capital city, you use an average amount of power and you have 5 occupants in your household"

The tables on the following pages show the results for the system recommendations using the previously defined calculations and data. Due to the extensive quantity of results that have the potential to be generated through this system (the program) these results are only for a one person home in Adelaide for each below average, average and above average energy use. It also shows the payback period for each solar panel/battery combination.

For example, the shaded cells show the system requirements and associated costs for a single person household with average energy usage using the LG MonoX NeON panel system and a Tesla Powerwall as the battery option.

City	Number of Occupants	Load Type	Load DC (kWh)	Irradiance (kW/m^2)	Solar Panel Brands	Efficiency (%)	Area (m^2)	Wattage (kW)	Cost ($)	AC load (kW)	Irradiance incident on panel surface (kW)
Adelaide	1	Below Average	8.175	19.6	CNPV-250P	15.3	1.6335	0.25	209	1.703125	32.0166
					LG LH300N1C-B3	18.3	1.64	0.3	373	1.703125	32.144
					Sunpower SPR-E20-327	20.1	1.630714	0.327	499	1.703125	31.9619944
		Average	10.9	19.6	CNPV-250P	15.3	1.6335	0.25	209	2.27083333	32.0166
					LG LH300N1C-B3	18.3	1.64	0.3	373	2.27083333	32.144
					Sunpower SPR-E20-327	20.1	1.630714	0.327	499	2.27083333	31.9619944
		Above Average	13.625	19.6	CNPV-250P	15.3	1.6335	0.25	209	2.83854167	32.0166
					LG LH300N1C-B3	18.3	1.64	0.3	373	2.83854167	32.144
					Sunpower SPR-E20-327	20.1	1.630714	0.327	499	2.83854167	31.9619944

City	Number of Occupants	Load Type	Load DC (kWh)	Irradiance (kW/m^2)	Solar Panel Brands	Maximum ideal power ouptut from panel (kW) with no limits other than efficiency	Number of Panels Needed	Cost of panels	Battery Brands	Efficiency of batteries (%)	Capacity (kW)
Adelaide	1	Below Average	8.175	19.6	CNPV-250P	4.8985398	6.8125	1463	Tesla Powerwall	92.5	6.4
									Fronius Battery 4.5	90	3.6
									Power Legato	88	7
				19.6	LG LH300N1C-B3	4.918032	5.677083333	2238	Tesla Powerwall	92.5	6.4
									Fronius Battery 4.5	90	3.6
									Power Legato	88	7
				19.6	Sunpower SPR-E20-327	4.890185143	5.208333333	2495	Tesla Powerwall	92.5	6.4
									Fronius Battery 4.5	90	3.6
									Power Legato	88	7
		Average Above Average	10.9	19.6	CNPV-250P	4.8985398	9.083333333	1881	Tesla Powerwall	92.5	6.4
									Fronius Battery 4.5	90	3.6
									Power Legato	88	7
				19.6	LG LH300N1C-B3	4.918032	7.569444444	2984	Tesla Powerwall	92.5	6.4
									Fronius Battery 4.5	90	3.6
									Power Legato	88	7
				19.6		4.890185143	6.944444444	3493	Tesla Powerwall	92.5	6.4

					Sunpower SPR-E20-327				Fronius Battery 4.5	90	3.6
									Power Legato	88	7
		Above Average	13.625	19.6	CNPV-250P	4.8985398	11.35416667	2299	Tesla Powerwall	92.5	6.4
									Fronius Battery 4.5	90	3.6
									Power Legato	88	7
				19.6	LG LH300N1C-B3	4.918032	9.461805556	3357	Tesla Powerwall	92.5	6.4
									Fronius Battery 4.5	90	3.6
									Power Legato	88	7
				19.6	Sunpower SPR-E20-327	4.890185143	8.680555556	4491	Tesla Powerwall	92.5	6.4
									Fronius Battery 4.5	90	3.6
									Power Legato	88	7

Table 7 (part one): Modelling and calculated results of recommended systems for a one person household in Adelaide. Shows results for each below average, average and above average power consumption (assuming actual load was not entered)

Part two is shown on the following page.

City	Number of Occupants	Load Type	Load DC (kWh)	Solar Panel Brand	Battery Brand	Storage Amount	Number of Batteries	Cost of single battery	Cost of system batteries	Total Cost With Storage	Total Cost Without Storage	Payback period without storage (years)	Payback period with storage (years)
Adelaide	1	Below Average	8.175	CNPV-250P	Tesla Powerwall	5.523648649	0.8630701	3800	3800	5263	1463	1.547670581	5.567594169
					Fronius Battery 4.5	5.677083333	1.57696759	8118	16236	17699	1463	1.547670581	18.72332305
					Power Legato	5.806107955	0.90720437	8000	8000	9463	1463	1.547670581	10.01066761
				LG LH300N1C-B3	Tesla Powerwall	5.523648649	0.8630701	3800	3800	6038	2238	2.367523418	6.387447006
					Fronius Battery 4.5	5.677083333	0.88704427	8188	8188	10426	2238	2.367523418	11.02940087
					Power Legato	5.806107955	0.82944399	8000	8000	10238	2238	2.367523418	10.83052044
				Sunpower SPR-E20-327	Tesla Powerwall	5.523648649	0.8630701	3800	3800	6295	2495	2.639397198	6.659320785
					Fronius Battery 4.5	5.677083333	1.57696759	8188	16376	18871	2495	2.639397198	19.96315211
					Power Legato	5.806107955	0.90720437	8000	8000	10495	2495	2.639397198	11.10239422
		Average	10.9	CNPV-250P	Tesla Powerwall	7.364864865	1.15076014	3800	3800	5681	1881	1.492396632	4.507339323
					Fronius Battery 4.5	7.569444444	2.10262346	8118	16236	18117	1881	1.492396632	14.37413598
					Power Legato	7.741477273	1.20960582	8000	8000	9881	1881	1.492396632	7.839644402

				LG LH300N1C-B3	Tesla Powerwall	7.364864865	1.15076014	3800	3801	6785	2984	2.367523418	5.383259515
					Fronius Battery 4.5	7.569444444	1.18272569	8188	8188	11172	2984	2.367523418	8.863931511
					Power Legato	7.741477273	1.10592532	8000	8000	10984	2984	2.367523418	8.714771188
				Sunpower SPR-E20-327	Tesla Powerwall	7.364864865	1.15076014	3800	3801	7294	3493	2.771367058	5.787103154
					Fronius Battery 4.5	7.569444444	2.10262346	8188	16376	19869	3493	2.771367058	15.76418324
					Power Legato	7.741477273	1.20960582	8000	8000	11493	3493	2.771367058	9.118614827
		Above erage	13.625	CNPV-250P	Tesla Powerwall	9.206081081	1.43845017	3800	3800	6099	2299	1.459232262	3.871186415
					Fronius Battery 4.5	9.461805556	2.62827932	8118	16236	18535	2299	1.459232262	11.76462374
					Power Legato	9.676846591	1.51200728	8000	8000	10299	2299	1.459232262	6.537030478
				LG LH300N1C-B3	Tesla Powerwall	9.206081081	1.43845017	3800	3802	7159	3357	2.130771076	4.543994678
					Fronius Battery 4.5	9.461805556	1.47840712	8188	8188	11545	3357	2.130771076	7.32789755
					Power Legato	9.676846591	1.38240666	8000	8000	11357	3357	2.130771076	7.208569292
				Sunpower SPR-E20-327	Tesla Powerwall	9.206081081	1.43845017	3800	3802	8293	4491	2.850548973	5.263772576
					Fronius Battery 4.5	9.461805556	2.62827932	8188	16376	20867	4491	2.850548973	13.24480192
					Power Legato	9.676846591	1.51200728	8000	8000	12491	4491	2.850548973	7.928347189

5 DISCUSSION

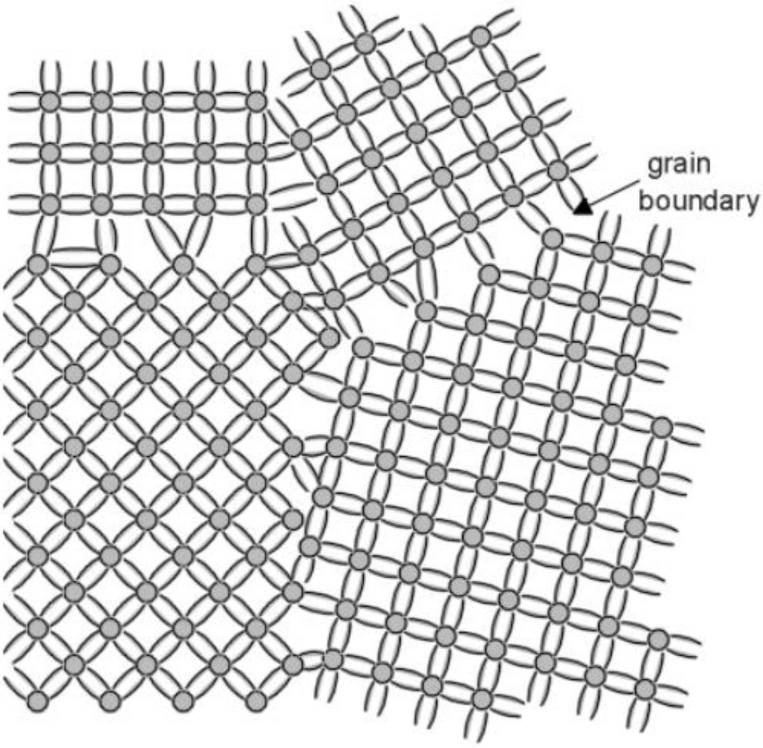
The discussion of the report results will address the panel models chosen, battery options, pay back periods, and use of the results of the analytical tool by consumers.

When gathering information about solar panel systems and batteries available in Australia there was a wealth of information, at times it was excessive and a little contradictory. Conversely, certain relevant financial data is not available due to privacy legislation, however even after taking these points into consideration, the overarching trend seems to be positively in favour of increasing the number of installations in direct proportion to reducing the need for reliance on power generated from fossil fuels. The solar panels brands/models that were selected to be analysed and included in the coding each had something different to offer, and although a limitation on the scope of the report to three popular models exists, the results clearly have general application to a wider number of options.

The following discussion examines the specific models chosen and further details the relevant features and specifications.

The LG LH300N1C-B3 is a monocrystalline cell with a higher cost and efficiency than the multi-crystalline or poly-crystalline cells such as the Jinko JKM250P-60-A. This increase in cost and efficiency is explained by the more complicated process involved in creating the silicone wafers for the cells. The silicone used in this process has to be very pure in order to produce the highest efficiency and the wafers used in the cells are developed by using the Czochralski method. This method involves using a seed crystal silicone rod is then placed so that is in in contact with the surface of the liquid silicone before it is slowly lifted while it rotates. This process leads to the silicone atoms all being oriented the same way, leading to a very pure and homogenous crystal, called an ingot (Sumco, 2015). These ingots can be very large and are then sliced into very thin sections called wafers.

Multi-crystalline wafers are simpler to make and are therefore cheaper as can be seen for the CNPV solar panel – cheapest price and lowest efficiency. Multi-crystalline cells are produced through a casting method done using a crucible. However these methods have many resulting disadvantages when compared to the monocrystalline process. The main shortcoming is the decreased efficiency. Since the atoms are not oriented in a uniform manner there are 'grain boundaries' (Sumco, 2015), these surface boundaries between the crystal grains cause an increase in electrical losses and therefore a decrease in efficiency when compared to mono-crystalline wafers. Figure 12 shows the differences between monocrystalline, multi-crystalline and amorphous.



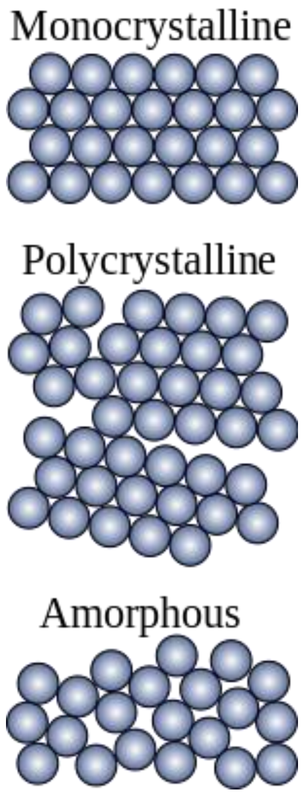


Figure 12: Difference between monocrystalline and polycrystalline structures (Wikipedia, 2016; PV Education (unknown))

As a result of these differences in price and efficiency, both multi-crystalline and mono-crystalline panels have been used in the program analysis to provide a more thorough and realistic representation.

The batteries that were selected for analysis were the Tesla Powerwall, the Fronius Solar Battery and the Power Legato and all of these battery systems are currently available in Australia. It was necessary to find the specifications of each individual model for use in the equations as the efficiency greatly affect the amount of energy the unit is able to effectively store (capacity). It was also made clear, from the survey, that the public are interested in learning more about solar batteries as they want to be able to make an informed and calculated decision best suited to their needs. It was decided, therefore, that along with the number of batteries and cost that the efficiency of each model would also be delivered back to the user. By presenting a variety of options it allows the user to visualize the different installation recommendations and determine which they think would best suit them based on their needs.

In order to determine the payback period for each system it was necessary to approximate and average price of grid electricity per kWh in each state. This allows the program to, once a city has been selected, assign the relevant values for the irradiance, load (if not entered) and grid energy cost. The payback period is only the system costs and doesn't take into consideration the installation costs or any rebates as these costs are variable and would quickly render the program dated and inaccurate. These costs differ by state and installer and the rebates are dependent upon the government agenda.

If the program is run and the location is selected to be Brisbane, with 3 people (and an above average energy consumption) and battery storage is not wanted, the approximate daily DC load is approximately 17kWh (average of 3 occupants and 4 occupants from Table 2 in Methodology). The system that is recommended by the program for this application would be a 3.5kW system using that could be made up in the following combinations:

Load DC	**Panel Brand**	**Power Rating (W)**	**Number of panels recommended**	**Size of System (kW)**	**Total cost of panels ($)**	**Payback period (years)**
17kWh	CNPC-250P	250	14	3.5	2926	2.42
	LG-300N1C-B3	300	12	3.6	4476	3.70
	SPR-E20-327	327	11	3.597	5489	4.54

Table 8: Results for a 3-4 person household using the analytical tool.

A 'quick quote' obtained from Energy Matters (Energy Matters, 2015) recommended an identical family (3-4 people) in a 2 story house in Brisbane, with a pitched roof install a 3.12kW system. As can be seen on the following page, the system they recommend includes 12 JA solar panels with a 10 year warranty. When comparing this to the program recommended system they are very similar. The JA panels on offer from Energy Matters are 260W whereas the CNPV panels are 250W. This implies that the modelling and analysis used in the program are very similar to those used by existing solar companies. The additional benefit of the program is, that by providing an unbiased cost analysis as well, it allows the user to make an informed assessment of their own system needs.

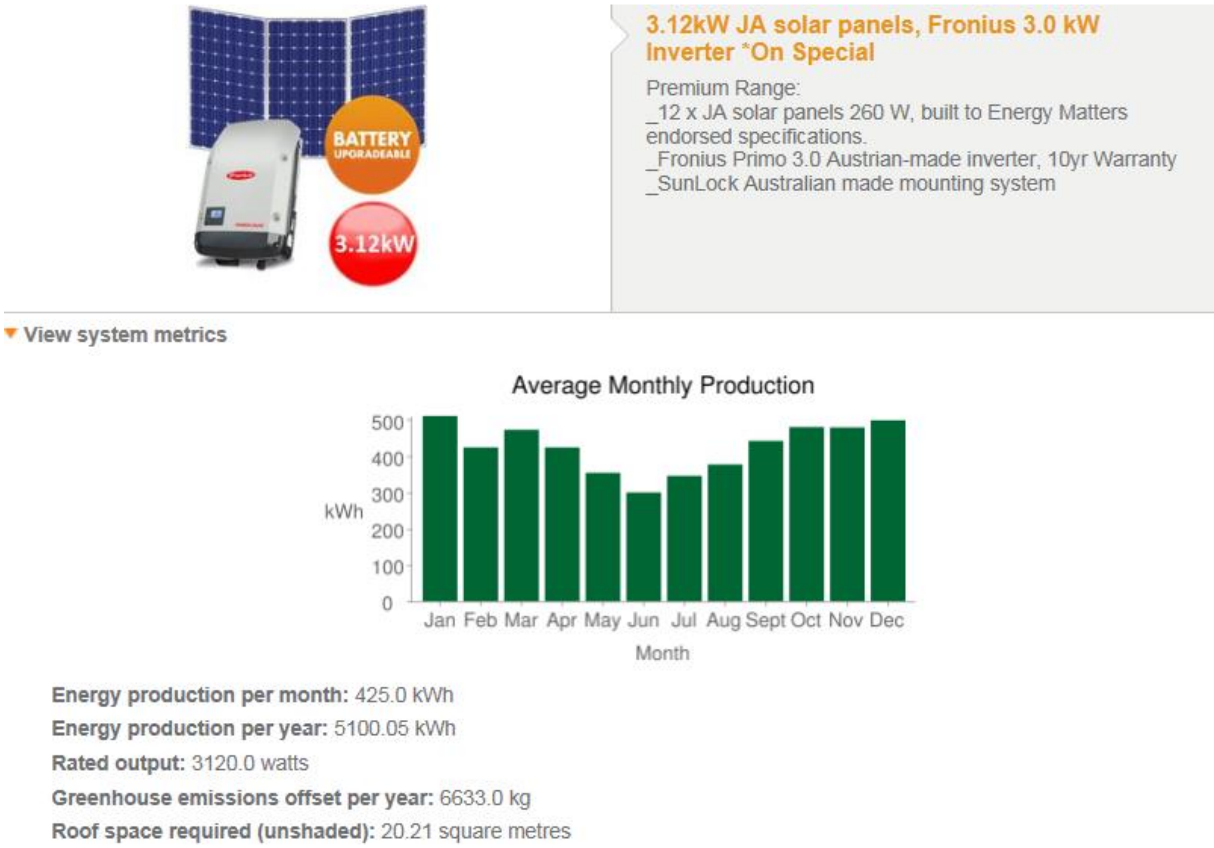


Figure 13: Energy Matters 'Quick Quote' for 3-4 person household in Brisbane (Energy Matters, 2015)

The case studies discussed in this report have included Joseph Banks Aged Care, Geraldton Fisherman's Co-operative and an apartment building on the Gold Coast in QLD.

An energy savings report generated by Wattblock for the Gold Coast apartment building involved a large amount of analysis and many assumptions. The report takes into account upgrades done in the building, including a cost estimate, energy savings and payback period (for lighting, heating etc.). A 7kW solar PV system was recommended as part of the upgrade; this obviously wouldn't meet all the energy needs but would make a fair contribution.

Using the equations listed in the Methodology, a 7kW system could provide sufficient electricity to meet a 33kWh DC load. Since it's an apartment building, the roof space would be limited therefore a higher efficiency panel would be more suitable. For the purpose of system analysis the 270W LG MonoX NeON will be used.

A7kWh system would require 26 MonoX NeON panels and, costing $373 each, the total system costs (not including installation or an inverter) would become $9698. Assuming a standard QLD electricity price of 22.238 c/kWh the payback period for this system would be approximately 3.61 years.

When this is compared to the system costs and payback generated by the Wattblock generator it is clear that the two systems are fairly similar in the cost and payback. This therefore supports the notion that the program developed for the purposes of this project are fairly accurate for generic system recommendations.

The battery discussed in the below figure is a Tesla Powerwall, 14kWh of capacity would be approximately equal to 2 units. As it was stated earlier in the Results section the 7kW Powerwall unit has approximately 6.4kWh of usable capacity. Since each Powerwall costs approximately $3800 this would bring the total cost of the program recommended system to $24012 with a

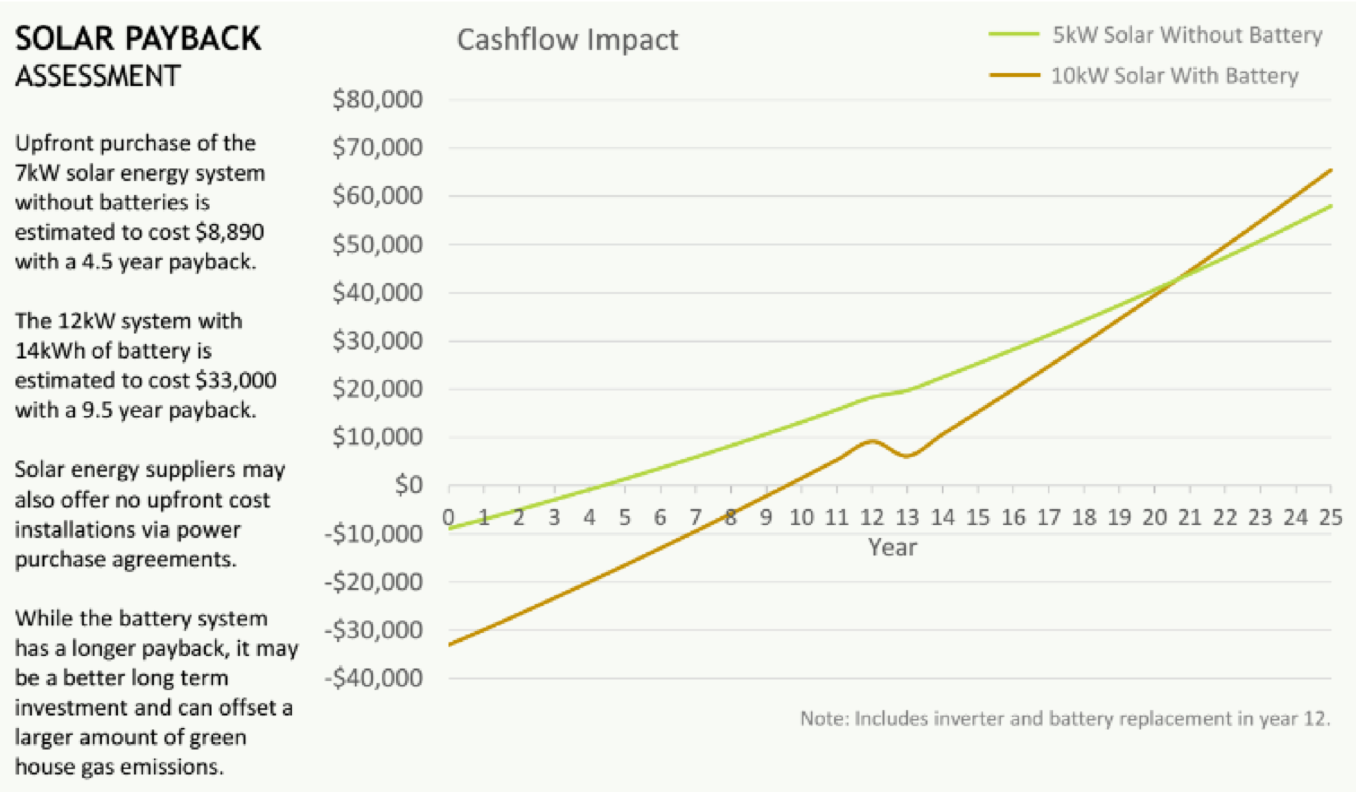


Figure 13: Cashflow Impact (Wattblock, 2016)

payback period of approximately 8.96 years. Again, this is very similar to the cost and payback period determine by the Wattblock modelling.

6 CONCLUSION

The aim of this report was to investigate and analyse certain factors relevant to solar installation in Australia, in order to obtain an accurate “snapshot” of both the uptake and the potential for further deployment of battery storage in typical residential (and shared community) applications. The methodology employed, which included the survey along with a literature review and the case study review highlighted the fact that while interest and motivation is high, information and access lag behind when it comes to the “next generation” of solar power installations which can make better use of power generated at all times of the day and night via the use of storage (batteries).

As stated, this report was created to provide a timely and relevant review of the uptake and potential for further deployment of battery storage in solar installations. The survey identified gaps in consumer awareness and access to information. The case studies showed that large shared installations appear to be economically viable. The analytical tool is a step in the right direction in providing information and assistance, and the discussions relating to relevant factors which may hinder increased uptake not only identify barriers, but serve as a basis for further research and review.

Overall, the recommendations which can be made as a result of this report to increase both uptake and potential for further deployment of battery storage and solar installations generally would include a need to:

- Increase awareness of systems available (more publicity by suppliers and/or government to meet “green energy” targets)
- Increase information and independent comparisons available (Independent review eg “iSelect” type site)
- Decrease cost (increased demand through measures above should naturally lead to economies of scale in time)
- Influence government policy in relation to installation of solar systems (in effort to increase uptake).

7 REFERENCES

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APPENDIX I

	Hours of Daylight												
City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average (hours and decimal)
Adelaide	14:15	13:22	12:19	11:12	10:19	9:49	10:00	10:47	11:50	12:55	13:56	14:29	12:06
	14.25	13.36	12.31	11.2	10.31	9.81	10	10.78	11.83	12.91	13.93	14.48	12.0975
Brisbane	13:41	13:02	12:17	11:27	10:46	10:25	10:33	11:07	11:53	12:42	13:27	13:51	12:05
	13.68	13.03	12.28	11.45	10.76	10.41	10.55	11.11	11.88	12.7	13.45	13.85	12.0958333
Canberra	14:17	13:23	12:19	11:11	10:16	9:47	9:59	10:47	11:51	12:55	13:57	14:31	12:06
	14.28	13.38	12.31	11.18	10.26	9.78	9.98	10.78	11.85	12.91	13.95	14.51	12.0975
Darwin	12:46	12:30	12:10	11:49	11:32	11:23	11:27	11:41	12:01	12:21	12:40	12:51	12:05
	12.76	12.5	12.16	11.81	11.53	11.38	11.45	11.68	12	12.35	12.66	12.85	12.0941667
Hobart	14:59	13:47	12:26	10:56	9:42	9:02	9:18	10:20	11:45	13:11	14:33	15:19	12:06
	14.98	13.78	12.43	10.93	9.7	9.03	9.3	10.33	11.75	13.18	14.55	15.31	12.1058333
Melbourne	14:29	13:30	12:22	11:08	10:06	9:33	9:46	10:38	11:48	13:00	14:08	14:45	12:06
	14.48	13.5	12.36	11.13	10.1	9.55	9.76	10.63	11.8	13	14.13	14.75	12.0991667
Perth	14:00	13:13	12:19	11:19	10:30	10:04	10:14	10:55	11:51	12:49	13:44	14:13	12:05
	14	13.21	12.31	11.31	10.5	10.06	10.23	10.91	11.85	12.81	13.73	14.21	12.0941667
Sydney	14:09	13:18	12:20	11:15	10:23	9:54	10:05	10:50	11:50	12:53	13:51	14:23	12:05
	14.15	13.3	12.33	11.25	10.38	9.9	10.08	10.83	11.83	12.88	13.85	14.38	12.0966667

The hours of daylight in each capital city of Australia were gathered to be able to calculate the total light incident of a solar panel on an average day. These numbers however are optimum and maximum and usually the 'hours of daylight' used in analysis is only about 6-8 hours. This is due to the position of the sun in the morning and afternoon being inopportune and leading to a lighter fall of solar radiation.

APPENDIX II

	Total	Yes	No	Maybe	News/current affairs	Colleagues/family	Other	Not a home owner	Too expensive	Would if I had panels	150% of current bill	125% of current bill	$10,000	$2,000	Depends on the amount	Govt. promises
Q1	7	15	8													
i)	6				8	3	1									
Q2	7	5	17													
Q3	2	4	7													
i)	5							5	7	1						
Q4	7	22														
Q5	7	13	1													
i)	4										1	1	3	5		
Q6	7	13	1	2												
Q7	7	9	1	3												
i)	2														2	1

	Total	Yes	No	Maybe	Legal risks	Price/ Saving	Reliability	More info	Storage	Environment	Sustainability	Other	Rebates	Economics	Self-sufficiency/ environment	Value
Q8	7	14	6	3												
i)					5	1										
Q9	7	22														
Q10	7					13	6	2	1							
Q11	7	22														
i)	7									7	4	1				
Q12	7	11	5	5												
i)													3	2		
Q13	7	22														
Q14	7	22														
i)	7														3	1

APPENDIX III

The following code is the program written to perform the necessary functions and analysis.

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <math.h>

#define CITYMAXLENGTH       10
#define CITYCOUNT           8

int main(int argc, char **argv) {
  char *cities[CITYCOUNT];
  cities[0] = "Brisbane";
  cities[1] = "Sydney";
  cities[2] = "Melbourne";
  cities[3] = "Hobart";
  cities[4] = "Adelaide";
  cities[5] = "Perth";
  cities[6] = "Darwin";
  cities[7] = "Canberra";
  float *acloads[CITYCOUNT];
  float acload0[] = { 0.0,  8.7, 13.5, 15.1, 19.1, 20.4 };
acloads[0] = acload0;
  float acload1[] = { 0.0,  9.0, 15.4, 19.0, 20.1, 25.7 };
acloads[1] = acload1;
  float acload2[] = { 0.0, 11.6, 15.3, 19.2, 14.6, 25.3 };
acloads[2] = acload2;
  float acload3[] = { 0.0, 16.9, 23.4, 27.2, 32.3, 29.7 };
acloads[3] = acload3;
  float acload4[] = { 0.0, 10.9, 16.4, 11.9, 17.4, 23.4 };
acloads[4] = acload4;
  float acload5[] = { 0.0, 11.2, 14.1, 17.0, 20.0, 22.9 };
acloads[5] = acload5;
  float acload6[] = { 0.0,  9.6, 18.6, 18.5, 20.5, 31.3 };
acloads[6] = acload6;
  float acload7[] = { 0.0, 13.3, 17.5, 25.5, 36.0, 36.3 };
acloads[7] = acload7;
  float gridcosts[] = { 22.238, 23,991, 27.742, 25.200, 31.680,
25.703, 25.540, 17.270 };
  float averagegridcost = 0.0;
  int g = -1;
  while (++g < CITYCOUNT)
    { averagegridcost += gridcosts[g]; }
  averagegridcost /= CITYCOUNT;
  float averageloads[] = { 0.0, 0.0, 0.0, 0.0, 0.0, 0.0 };
  int i = -1, maxoccupants = 5;
  while (++i <= maxoccupants) {
    int j = -1;
    while (++j < CITYCOUNT)
      { averageloads[i] += acloads[j][i]; }
    averageloads[i] /= CITYCOUNT;
    fprintf(stdout, "averageloads[%d]: %f\n", i, averageloads[i]);
  } // (^ calculate average load per occupancy)
```

```
  float sunlighthours = 6.0;
  char *spanels[] = { "", "CNPV-250P", "LG LH300N1C-B3", "Sunpower
SPR-E20-327" };
  float spowers[] = { 0.0,    0.25,     0.3,      0.327 }; // kW
  float speffic[] = { 0.0,    0.153,    0.183,    0.201 }; // 0.%
  float spareas[] = { 0.0, 1600*920, 1600*920, 1600*920 }; // L*W
  float sprices[] = { 0.0,  209.0,    373.0,    499.0 };   // $
  char *batters[] = { "", "Tesla Powerwall", "Fronius Solar
Battery", "PowerLegato" };
  float bcapacs[] = { 0.0,    6.4,      3.6,    7.0 };     // kWh
  float beffics[] = { 0.0,    0.925,    0.9,    0.88 };    // 0.%
  float bprices[] = { 0.0, 3800.0,   8880.0, 8000.0 };     // $
  // calculate results based on city, occupancy, usage
  fprintf(stdout, "Welcome to the calculator!\n");
  fprintf(stdout, "Please enter your Daily Energy Usage as a number
in kWh (e.g. 19.1).\n");
// to add: allow /3m for per 3 months
  fprintf(stdout, "If you do not know your energy usage, type your
nearest Capital City\n");
  fprintf(stdout, "  (e.g. Brisbane) to use the average usage value
for that city.\n");
  fprintf(stdout, "Enter 0 to use the average usage across all
capital cities.\n");
  float useracload = 0.0;
  float usergridcost = averagegridcost;
  char needoccupants = 'e';
  int useroccupants = 0;
  int cityindex = -1;
  char citystr[CITYMAXLENGTH];
  char cityfmt[CITYMAXLENGTH];
  sprintf(cityfmt, "%%%d[^\n]", CITYMAXLENGTH - 1);
  while (cityindex == -1) {
    fprintf(stdout, "Usage or City: \n");
    fscanf(stdin, cityfmt, citystr);
    while (fgetc(stdin) != '\n');
    float inputusage = atof(citystr);
    if (inputusage > 0.0) {
      // usage amount provided directly
      useracload = inputusage;
      usergridcost = averagegridcost;
      needoccupants = 'n';
      break;
    } else if (citystr[0] == '0') {
      // use all-city average
      needoccupants = 'y';
      break;
    } else {
      // use typed city name
      int tci = -1;
      while (++tci < CITYCOUNT) {
        if (tci == 0 && citystr[tci] >= 'a' && citystr[tci] <= 'z')
          { citystr[tci] = citystr[tci] - 'a' + 'A'; }
        else if (tci > 0 && citystr[tci] >= 'A' && citystr[tci] <=
'Z')
          { citystr[tci] = citystr[tci] - 'A' + 'a'; }
        if (strncmp(citystr, cities[tci], 1) == 0)
```

```
          { cityindex = tci; needoccupants = 'y'; break; }
      }
      if (cityindex == -1) {
        fprintf(stdout, "Please enter a capital city of an
Australian state.\n");
      }
    }
  }
  while (needoccupants == 'y') {
    fprintf(stdout, "Please enter the number of occupants in your
household (maximum 5).\n");
    fprintf(stdout, "Occupants: ");
    fscanf(stdin, "%d", &useroccupants);
    if (useroccupants < 1 || useroccupants > 5) {
      fprintf(stdout, "Please enter a number between 1 and 5.\n");
    } else {
      needoccupants = 'n';
      if (citystr[0] == '0' || cityindex < 0) {
        useracload = averageloads[useroccupants];
        usergridcost = averagegridcost;
      } else {
        useracload = acloads[cityindex][useroccupants];
        usergridcost = gridcosts[cityindex];
      }
      break;
    }
  }
  fprintf(stdout, "AC Load (kWh): %.2f\n", useracload);
  float userdcload = useracload / sunlighthours / 0.8;
  fprintf(stdout, "DC Load (kW): %.2f\n", userdcload);
  // calculate best combination of panel 1,2,3 : battery 1,2,3
  int panel = 0;
  while (++panel <= 3) {
    char *spn = spanels[panel];
    float spp = spowers[panel] * 1000;
    float spe = speffic[panel] * 100;
    fprintf(stdout, "%s: %.0fW/panel (%.0f%% efficiency)\n", spn,
spp, spe);
    float numberofpanels = ceil(userdcload / spowers[panel]);
    fprintf(stdout, "  Number of Panels Required: %.0f\n",
numberofpanels);
    float totalpanelcost = sprices[panel] * numberofpanels;
    fprintf(stdout, "  Total Panel Cost: $%.2f\n", totalpanelcost);
    float totalpanelpayback = (totalpanelcost / (useracload *
usergridcost)) / 365;
    float panelpaybackyears = floor(totalpanelpayback);
    float panelpaybackmonths = ceil((totalpanelpayback -
panelpaybackyears) * 12);
    fprintf(stdout, "  Panel Payback Period:");
    fprintf(stdout, "%.0f years, %.0f months\n", panelpaybackyears,
panelpaybackmonths);
    int battery = 0;
    while (++battery <= 3) {
      char *btn = batters[battery];
      float btp = bcapacs[battery];
      float bte = beffics[battery] * 100;
```

```
      fprintf(stdout, "%30s: %.1fkWh (%.0f%% efficiency)\n", btn,
btp, bte);
      float storageneeded = (useracload * 3.0) / beffics[battery];
      float numberofbatteries = ceil(storageneeded /
bcapacs[battery]);
      fprintf(stdout, "  %30s: %.0f\n", "Number of Batteries
Required", numberofbatteries);
      float totalbatterycost = bprices[battery] * numberofbatteries;
      fprintf(stdout, "  %30s: $%.2f\n", "Total Battery Cost",
totalbatterycost);
      float totalbatterypayback = (totalbatterycost / (useracload *
usergridcost)) / 365;
      float batterypaybackyears = floor(totalbatterypayback);
      float batterypaybackmonths = ceil((totalbatterypayback -
batterypaybackyears) * 12);
      fprintf(stdout, "  %30s: ", "Battery Payback Period");
      fprintf(stdout, "%.0f years, %.0f months\n",
batterypaybackyears, batterypaybackmonths);
      float totalpayback = totalpanelpayback + totalbatterypayback;
      float paybackyears = floor(totalpayback);
      float paybackmonths = ceil((totalpayback - paybackyears) *
12);
      fprintf(stdout, "  %30s: ", "Total Payback Period");
      fprintf(stdout, "%.0f years, %.0f months\n", paybackyears,
paybackmonths);
    }
  }
  return 0;
}
// - daily or quarterly input (/3m)
// - above or below average usage
// - battery y/n
// - ask for city anyway (for grid cost)
```

APPENDIX IV

1. Have you heard about battery storage to store excess power produced by solar panels?

a) Yes

Where did you hear about them?

b) No

2. Do you have solar panels installed on your roof? (if "No" proceed to part b)

a) Yes

b) No

Why not?

3. Would you consider a battery for storage?

a) Yes

b) No

Why not? For example price/personal choice/impracticality?

4. Would you like your home to have potential for self-sufficiency and not rely on grid power? This would allow your home to remain powered for some time during grid failures (duration depends on the capacity of your solar batteries)

a) Yes

b) No

5. Would cost be a factor?

How much would be acceptable for off-grid power?

6. Would investing in a new technology be something you would be likely to do?

7. Would government incentives sway you?

a) Yes

b) No

Why not?

8. If you had space on your roof for extra panels (i.e. surplus to your energy needs) but your neighbour had no viable space would you share the cost and benefits of solar panels on your entire roof space with your neighbour? Assuming there was no added cost/detriment to you.

a) Yes

b) No

Why not?

9. Would you like to be able to accurately monitor your home's energy usage in real-time? i.e. an app on your phone showing where power was being used most

a) Yes

b) No

Why not?

10. What would make solar power and battery storage more attractive to you? What would make you want to install it in your home if you don't already have it? For example price/output/efficiency/reliability/longevity/rebates

11. Do you think that solar generated power is preferable to fossil-fuel generated power?

a) Yes

Why?

b) No

Why not?

12. Do you think that solar power is becoming more affordable for everyday Australians?

a) Yes

b) No

Why not?

13. Do you think that renewable energy is the way of the future?

a) Yes

b) No

Why not?

14. If cost wasn't a factor would you consider having an entirely energy neutral home? I.e. no power drawn from the grid, only excess power produced by solar panels fed back to the grid.

a) Yes

Why?

b) No

Why not?

15. Are there any other comments/thoughts you have about solar power or battery storage?