University of Southern Queensland

Faculty of Health, Engineering and Sciences

Home Based Solar and Battery Optimisation

A dissertation submitted by

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in fulfilment of the requirements of

ENG4111 and 4112 Research Project

Towards the degree of

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Abstract

The aim of this project is to create a model households can use to optimize their battery and solar performance, for any load size and location within Australia. Initially a literature review will be undertaken of solar panels, batteries, household energy usage, system cost and economics. The background research informed the strategy for building a model and what effects the efficiency of the solar and battery systems. Data was gathered using Homer Pro software. Running test installation, consisting of a simple 1kW solar system, across different locations around Australia at different installation angles and directions data on solar performance was able to be gathered. This data was able to be analysis in Matlab and equations constructed for different variables. These equations were able to be entered into the excel model that was created and from this a model of solar panel performance was able to be created for any location in Australia and installation angle and direction. The battery model consisted of looking at the charge and discharge rate of the battery as well as its storage size. By using this and the solar and load profile already model, IF statements in excel were able to be used to construct a model of the battery. All this was then added to some economic analyses in the model that covered net present cost (NPC), payback period and savings.

Using the model the project then looked at optimizing solar and battery systems in three different locations with house sizes ranging from 200 to 75 kWh per Week loads. The model found when optimizing for NPC that a 10kW solar with no battery was the best. For the payback period, a 5 to 3 kWh solar system again with no battery was the best. When looking at savings a solar system of 10 kW with a range of battery size depending on the load was the best. And when optimizing for peak levelling a variety of sized solar and battery was needed depending on the load size. Overall the model was successful in determining the best performance for the needs of a household.

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Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

P. Becker

[redacted]

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I would like to take this opportunity to express my sincerest gratitude to the following people, who have helped me throughout my degree and without whom the completion of this research project would not have been possible.

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- Loris Becker, Mother, and proof-reader
- Hannah Becker, Sister, and proof-reader

List of Figures

List of Tables

Table of Contents

1. Introduction

1. Aims

The aim of this project is to find the most efficient and cost-effective solar and battery system for different types of domestic dwellings across Australia. These dwellings will include different sized houses, flats and units with different load sizes. This project will look at optimizing the following factors, net present cost, payback period, savings and peak levelling.

2. Objectives

The objectives of the project are to be able to create a tool or equations people can use to determine the optimum solar and battery setup for their individual situation. Most advertising for solar and battery system use lab or ideal figures. These figures are not accurate in the real world and some users can see up to 50% drop in energy generation then what was advertised. This project hopes to give consumers the information they need to get the best system for the house and location.

3. Australian Standards, Legislation and Regulation

The following Standards and Legislation apply to the installation of Solar and Battery systems in Australia

- Australian Wiring Rules AS3000
- Installation of Photovoltaic (PV) Arrays AS 5033
- Stand-alone Power System Part 1 &2 AS4509
- Wind loads AS1170

- Secondary Batteries for SPS AS4086
- Grid Connections of Energy Systems via Inverters AS4777

The Clean Energy Council (2014) provides accreditation for all Solar installers it is not mandatory to be accredited by the Clean Energy Council to install a solar system but if an installer is not accredited no rebates will be able to be received from the Australian Government for that system.

Each state in Australia has its own Electrical Act and Regulations. In Queensland there is the Electrical Safety Act 2002 and Electrical Safety Regulation 2013

As this project will just be using software to simulate solar and battery systems so these standards and regulations will not be considered when determining the optimum system. However, it must be noted due to the standards and legislation the optimum system may not be able to be installed.

4. Consequential Effects

This project will just be looking at the theoretical side and simulating different situations. It will not be installing or doing any testing on any battery and solar system. Because of this, I will not be considering if the determined optimum system will be able to be installed on a house. This should be left up to trained and accredited professionals.

If batteries are to be taken up in the home for energy storage it should be noted that recycling of batteries is still in its infancy, especially for Lithium-Ion batteries (Gaines 2018). If we are to have a sustainable energy future, recycling of batteries is going to be important or we could run out of the minerals to make them just like we will run out of fossil fuels one day.

5. Ethical Issue

All the data I am using to do my modelling is publicly available so I do not see there being any privacy or ethical issue with the project that I will need to monitor at this time.

2. Literature Review

1. Introduction

Rooftop solar generation in the domestic market has grown from 8000 in 2007 to 2.6 million in 2013. That means 11% of the Australian population are now getting their energy from the Sun (Flannery & Sahajwalla 2013). PV panels are only able to generate energy when the sun is shining and this means that PV panels are not generating or generating at a low level when the load on the system is at its peak. This problem has what has become known as the Duck Curve (Figure 1). The Duck Curve shows that an increase in PV generation has created a greater difference between the peaks and the troughs of demand.

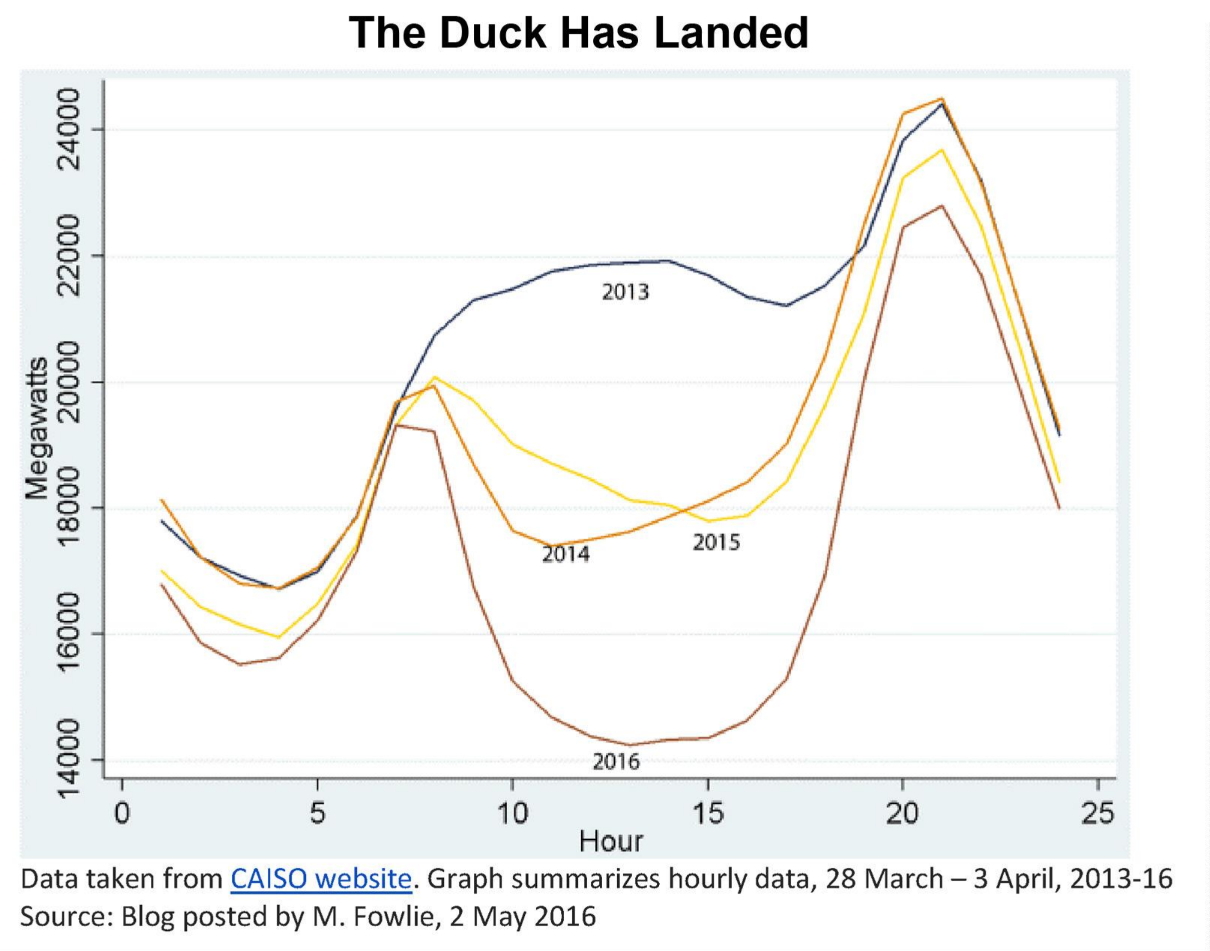


Figure 1- Duck Curve ('California's 'Duck Curve' Arrives Well Ahead of Schedule' 2016)

Incorporating batteries into the system enables the ability to store energy and use it when it is more needed. This could help to flatten out peaks and even out the networks demand curve.

2. Energy Usage

The Australian Bureau of Statistics (2013) conducted a survey in 2012 looking at household energy consumption. The report found that on average Australian households are spending $39 per week on the energy inside the home. This includes all energy sources (electricity, gas and others). The average electricity consumption across Australia was 123.6kWh per week (Table 1).

Table 1-Average Electricity Usage By State (Australian Bureau of Statistics 2013)

	NSW	**VIC**	**QLD**	**SA**	**WA**	**TAS**	**NT**	**ACT**	**All Households**
kWh	133.7	107.4	127.7	109.9	112.1	171.1	187.5	154.8	123.6

The Northern Territory (NT) and Tasmania (TAS) had the highest usage with Victoria and South Australia the lowest. The high usage in the Northern Territory and Tasmania may be due to the climate in those areas. This is reflected in the data in Table 2, this however, does not explain why Victoria is so low with a lot of the state classed as climate Zone 7.

Table 2-Average Electricity Usage by Climate Zone (Australian Bureau of Statistics 2013)

	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 6**	**Zone 7**	**All households**
kWh	153.6	124.7	137.6	133.8	121.7	115.7	148.0	123.6
% of Average	24%	0%	11%	8%	-1.5%	-6%	20%	

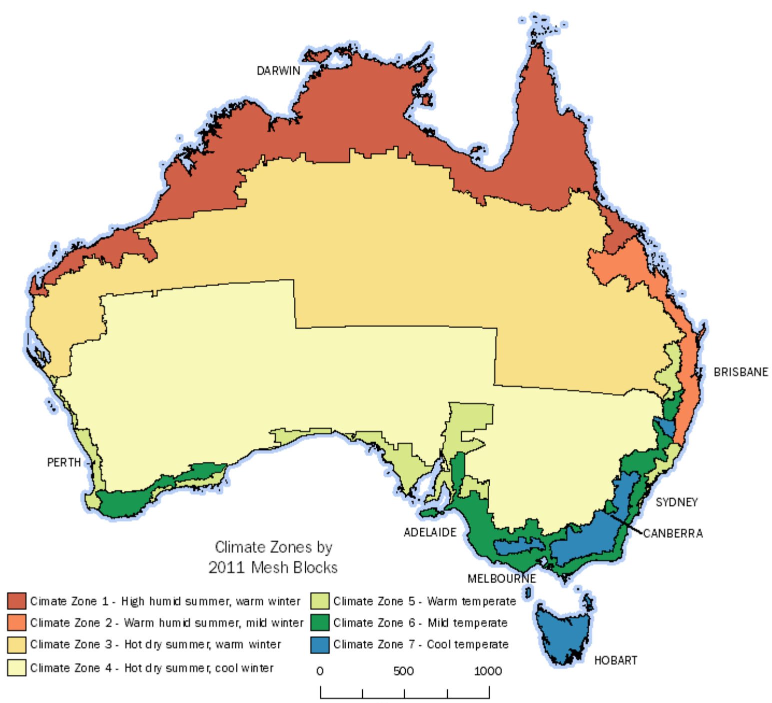


Figure 2 - Climate Zone Map (Australian Bureau of Statistics 2013)

The low usage in Victoria could be explained by the housing type. Victoria has one of Australia's biggest cities, Melbourne. Urban areas are more likely to have flats and units which on average used the lest energy per week (Table 3).

Table 3-Average Electricity Usage by Dwelling Type (Australian Bureau of Statistics 2013)

	Dwelling type			**Estimated age of the dwelling**				
	Separate house	**Semi-detached/ row or terrace house/ townhouse**	**Flat/ unit/ apartment**	**Less than 5 years old**	**5 years to less than 20 years old**	**20 to less than 30 years**	**30 or more years older**	**All households (a)**
kWh	131.5	103.9	82.9	108.4	126.6	136.0	120.8	123.6

The Data in table 3 could also be affected by the type of family living in the home (Table 4). A lone person on average uses the lest energy and would also be more likely to live in a smaller home like a flat or unit.

Table 4-Average Electricity Usage By Family Size (Australian Bureau of Statistics 2013)

	Family households				**Non-family households**			
	Couple family with dependent children	**One parent family with dependent children**	**Couple only**	**Other one family households**	**Multiple family households**	**Lone person**	**Group households**	**All households**
kWh	159.1	125.6	113.5	156.0	199.8	75.1	100.3	123.6

As can be seen, there is a lot of factors that contribute to a household's energy usage. The factors to energy usage are clearly linked with each other and care must be taken when making assumptions from the data. Of keynote is that the Australian Bureau of Statistics (2013) also discovered that household underreported there actual usage, only reporting 60-70% of their actual usage.

The standard pattern for electricity usage over a 24 hour period is one that has 2 peaks one around 7 am and the other around 7 pm. Roberts et al. (2019) found this to be true when comparing electricity demand in houses and units. It was also discovered that units tend to have lower peaks and flatter curves when compared to houses (Figure 3). These flatter usage curves would help in the optimisation of PV and battery on that property. A study done on Hong Kong usage patterns by Tso (2003) also found a very similar usage curve.

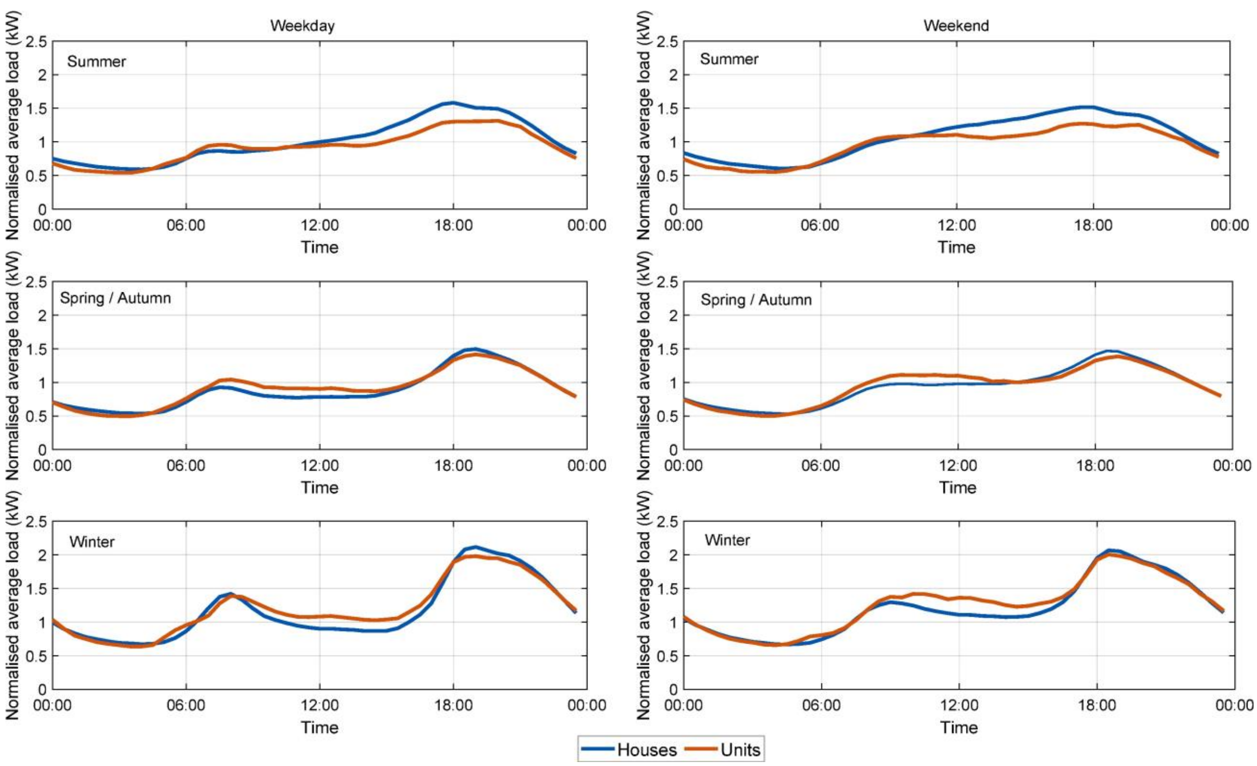


Figure 3-Average load over a 24 hour period (Roberts et al. 2019)

3. Energy Prices

Ergon (2018a) supplies electricity to most of Queensland and has several different tariffs for households. Tariff 11 is a general tariff and is the most popular tariff, it is charged per Kilowatt hour. Tariff 12A is a Time of Use tariff with a different price per kilowatt depending on the time of day. Tariff 14 is a Seasonal Demand tariff and has a price per kilowatt-hour and a price for peak kilowatt. All tariffs have a supply fee that is charged per day.

Table 5- Ergon Energy Tariffs

Tariff 11 (General Tariff)	$0.27828 / KWH $0.97843 / Day
Tariff 12A (Time of Use) Peak = 3-9:30pm Dec-Feb	Peak $0.68933 /KWH Off-peak usage $0.23621 /KWH $0.85391 /Day
Tariff 14 (Seasonal Demand) Demand Period = 3-9:30pm Peak = Dec-Feb	Peak $69.055 /KW Off-Peak $10.165 /KW $0.19352 /KWH $0.51062 /Day

For energy feedback into the network from solar, there are a few different prices depending on when you signed up. Before July 2012 the rate is 44 cents per kWh. If you have signed up after July 2012 you would be on a rate of 9.369 cents per kWh.

According to O'Neill (2018), Queensland is paying the lest per kWh in Australia and South Australia is paying the most (Table 6).

Table 6 - Average Energy Price By State (O'Neill 2018)

State	**Average Electricity Rates (per kWh)**
Queensland	27.6246c/kWh
Victoria	28.2461c/kWh
New South Wales	33.1118c/kWh
South Australia	42.8816c/kWh

4. Solar Panels

Australia receives the most solar radiation of any continent in the world, but currently, we only make use of 1/10000 of the energy (Imteaz & Ahsan 2018). Solar panels work by converting radiation from the sun into electricity. Solar radiation that hits a PV cell is made of 2 parts Direct and Diffused radiation (Nfaoui & El-Hami 2018).

- Direct Radiation – passes straight through the atmosphere to the PV ceil
- Diffused Radiation – comes of molecules in the atmosphere before hitting the PV ceil

The energy from these two forms can be calculated with the following equations

Direct Radiation (Nfaoui & El-Hami 2018)

$$I_{Dir}(Wm^{-2}) = Ae^{-Km} \tag{2.4.1}$$

$$A = 1160 + 75\sin\left(\frac{360}{365}(d - 275)\right) \tag{2.4.2}$$

$$K = 0.175 + 0.035\sin\left(\frac{360}{365}(d - 100)\right) \tag{2.4.3}$$

$$M = \frac{1}{\sin(h)} \tag{2.4.4}$$

A = Extraterrestrial Radiation

K = Optical Depth

d = Day number in the year 1-365

M = Length the sun's rays travels

Diffused Radiation (Nfaoui & El-Hami 2018)

$$I_{Dif}(Wm^{-2}) = A.I_{Dir}.R_{dif} \tag{2.4.5}$$

$$R_{dif} = \frac{1+\cos(a)}{2} \tag{2.4.6}$$

$$C = 0.095 + 0.04\sin\left(\frac{360}{365}(d-100)\right) \tag{2.4.7}$$

R_{dif} = Correction factor

C = Optical depth

a = Tlt angle

PV cells are only going to capture radiation that falls in their area. Solar radiation varies from location to location. Figure 4 shows the average radiation for a 12-month period across Australia. It can be seen that the northern areas of Australia have higher radiation than southern areas.

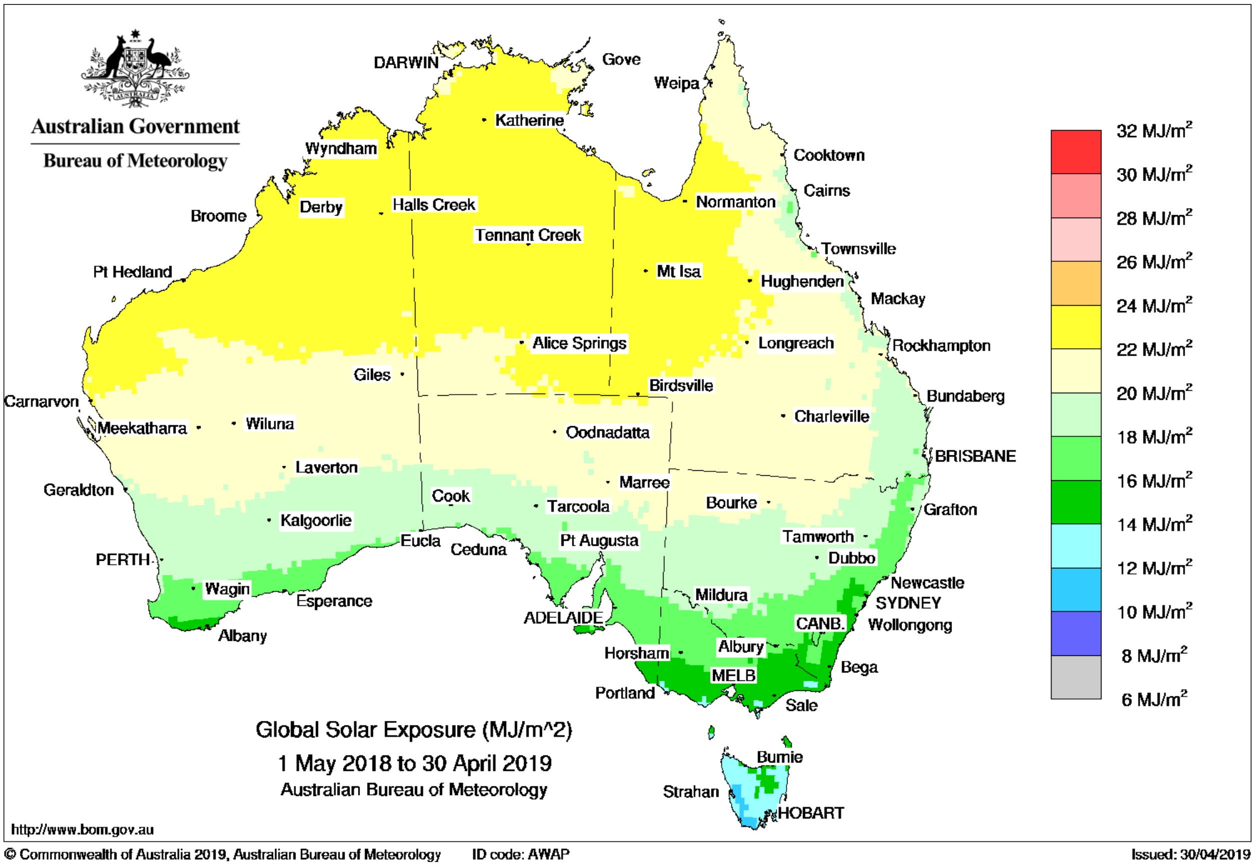
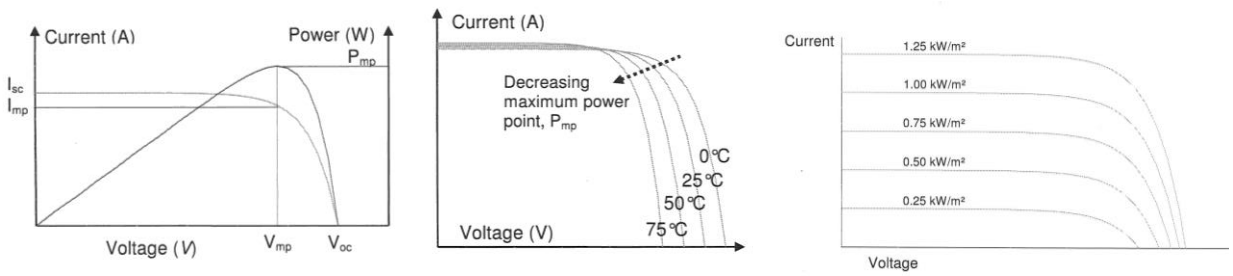


Figure 4- Average Solar Radiation per Day for 12 Month Period (Australian Bureau of Meteorology 2019)

5. Batteries

Batteries can provide great benefits to the electrical network. Batteries can be used for load levelling, peak shaving, power bridging and power quality improvement (Opiyo 2016). Power bridging and power quality improvement only require the batteries to operate for a few minutes or seconds, batteries are ideal for this kind of application. However, in the domestic market they are used more for load levelling and peak shaving. Batteries also help to keep solar panels at their maximum power point (MPP). The MPP of the solar cell changes throughout the day and is affected by the amount of radiation on the panels and the temperature (Figure 5). By using batteries the correct load can be applied to the solar panels keeping them operating at the MMP (Opiyo 2016).



A b c

Figure 5 – a) Power Curve and Maximum Power Point b) MPP Change with Temperature c) MPP Change with Radiation (Stapleton, Garrett & Thorne 2009)

There are a few different battery types available on the market, Lead-acid, Li-ion and Ni- Cadmium are the most common.

Lead-acid is most commonly found in cars. They are low cost, widely available and can handle abuse (overcharge or over-discharge). However, they only last for about 1 to 2 years and are sensitive to temperature (Opiyo 2016).

Li-ion batteries have become popular in recent years powering most mobile devices. They are smaller and lighter than other types of batteries. They have a long life span up to 5-7 years. They can be recharged fast and have a full depth of discharge capability. They are however, more expensive (Opiyo 2016).

Ni-Cadmium batteries are less sensitive to high temperatures and can handle abuse. They also have a lower cell voltage (1.2V) so more of them are needed to achieve a given voltage and they can be expensive (Opiyo 2016).

Table 7-Battery Properties (Das, Al-Abdeli & Woolridge 2019)

	Lead-acid	Li-ion	Ni-Cadmium
Lifetime	3-12	15-20	15-20
Life cycle	1500	500-2000	3000
Self-discharge rate	Very low	Medium	Very low
Energy Density	30 Wh/kg	100-200 Wh/kg	15-15 Wh/kg
Power density	180 W/kg	360 W/kg	50-100 W/kg
Efficiency	70-80	70-85	60-90

6. Efficiency

A solar and battery system can have inefficiencies in their design and installation it is important to recognize these so they can be minimized and the system can be optimized.

a. PV Cell and Panels

PV cells and panels work at their optimum when the sun's rays hit them at 90^{o} (Stapleton, Garrett & Thorne 2009). As the earth moves around the sun, the sun moves from being above the Tropic of Cancer to be above the Tropic of Capricorn. The optimum setup would be to have the PV panels follow the sun across the sky, but this is can be expensive and I also take energy to move the panel reducing the efficiency of the system. In most domestic applications that panels are fixed in one location and an optimum average angle is calculated for the year. Table 8 shows the ideal tilt angle for Australian capital cities

Table 8- Ideal Panel Angle (Solar Calulator 2018)

	Coordinates	The ideal angle of installation
Sydney	33.8688S, 151.2093E	33.9
Melbourne	37.8136S, 144.9631E	37.8
Perth	31.9505S, 115.8605E	31.9
Brisbane	27.4698S, 153.0251E	27.5
Hobart	42.8821S, 147.3272E	42.9
Adelaide	34.9285S, 138.6007E	34.9
Darwin	12.4634S, 130.8456E	12.5

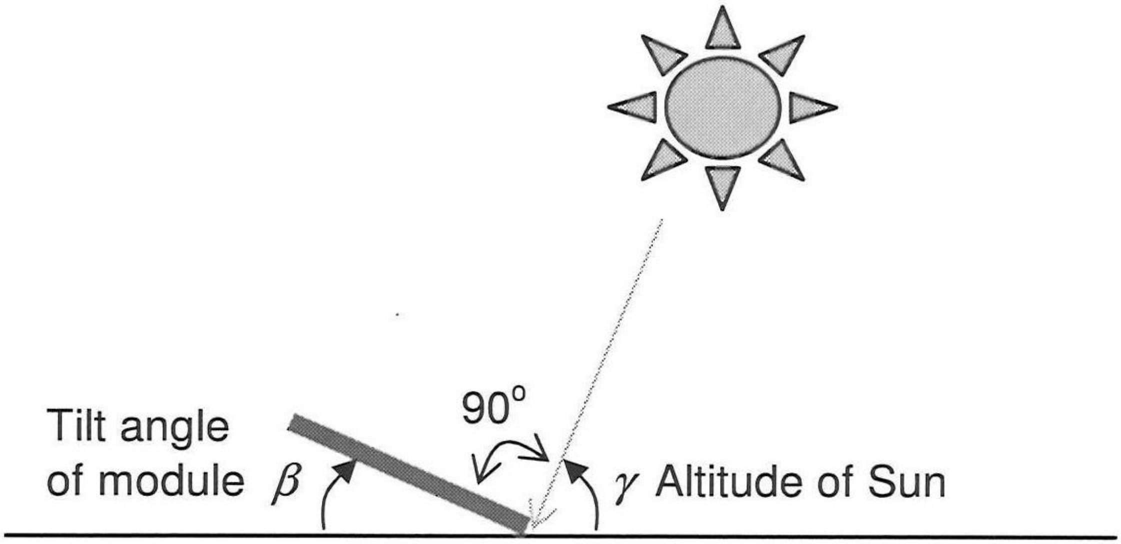


Figure 6 – Panel Tilt angle (Stapleton, Garrett & Thorne 2009)

Because the sun is changing its position throughout the day to get the most out of the panel you would want to have the panel track the sun across the sky. The National Oceanic & Atmospheric Administration (2011) has equations for calculating the sun position and the sunrise and sunset times.

First, the fractional year γ is given by

$$\gamma = \frac{2\pi}{365}\left(day\ of\ year - 1 + \frac{hour - 12}{24}\right) \quad (2.6.1)$$

Then the equation of time can be found

$$eqtime = 229.18(0.000075 + 0.001868\cos(\gamma) - 0.032077\sin(\gamma) - 0.014615\cos(2\gamma) - 0.040849\sin(2\gamma)) \quad (2.6.2)$$

and next the declination angle

$$\text{decl} = 0.006918 - 0.399912\cos(\gamma) + 0.070257\sin(\gamma) - 0.006758\cos(2\gamma) + 0.000907\sin(2\gamma) - 0.002697\cos(3\gamma) + 0.00148\sin(3\gamma) \quad (2.6.3)$$

now sunrise and sunset time can be found

$$sunrise = 720 - 4 * (longitude + ha) - eqtime \qquad (2.6.4)$$

where the hour angle (ha) is

$$ha = \pm \arccos\left\{\frac{\cos(90.833)}{\cos(lat)\cos(decl)} - \tan(lat)\tan(decl)\right\} \qquad (2.4.5)$$

where the positive is sunrise and negative is sunset

lat is latitude

(National Oceanic & Atmospheric Administration 2011)

The sunrise and sunset time are in UTC time and then would need to be converted to the local time zone.

The temperature has a big impact on PV cell efficiency. Panel efficiency is normally claimed to be about 13-18% by manufacturers but is this ideal lab conditions, not in the real world! (Imteaz & Ahsan 2018). PV panel efficiency will actually drop to around 6% during the hottest time of the day less than half their optimum (Charfi et al. 2018). This drop-in efficiency is usually masked by the fact that the hottest time of the day is also the time of the highest solar radiation hitting the panels. This decrease in efficiency is due to the fact the electrical components have an increase in resistance the hotter they get. The manufacturer will normally supply a de-rating factor per degree-C. Below are the typical ones (Stapleton, Garrett & Thorne 2009).

Monocrystalline Modules -0.45%/^{o}C

Polycrystalline Modules -0.5%/^{o}C

Thin Film Modules -0.1%/ ^{o}C

It must be noted that the temperature referred to here is the temperature of the cell itself not the ambient air temperature above the panel. Rule of thumb is cell temperature is usually 25 degrees above ambient (Stapleton, Garrett & Thorne 2009).

The age of the panels also affect efficiency. A study done by Imteaz and Ahsan (2018) found that the panels they tested installed in the year 2000 had an efficiency of 4.88% compared to those installed in the year 2009 with an efficiency of 7.07%.

Other inefficiencies that may affect PV panels are dirt, shadows, voltage drop and mismatch modules (Stapleton, Garrett & Thorne 2009).

b. Invertors

Invertors normal have an efficiency rating of around 94%. PV panels are normally connected in strings or in series with each other and then connected to the invertor. Most investors have Maximum Power Point Trackers (Stapleton, Garrett & Thorne 2009). This enables the transformer to keep the panel operating at their maximum throughout the day. The Maximum Power Point (MPP) of a PV cell changes with temperature, as it increases the voltage decreases and the maximum power point is shifted as can be seen in Figure 5.

Because of shading on the panels or being installed on different parts of a roof one part of the string can have a different MPP then the rest which will lower the efficiency of the system. Multi-String inverters have more the one input. This way 2 strings could be wired, for example, one for each side of the roof and both could be kept at their MPP increasing efficiency.

c. Batteries

Most of the energy lost by batteries is done through heat. Noyanbayev, Forsyth and Feehally (2018) found in their study that during the charging process the battery they tested rose 6 degrees and when discharging it rose 5 degrees. Figure 7 shows that as the State of Charge (SOC) increases more energy is required to lift the voltage.

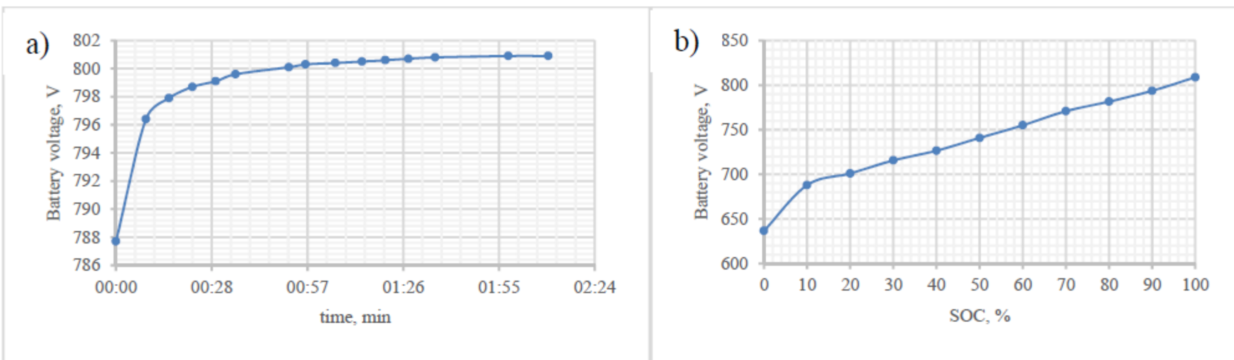


Figure 7-a) Voltage over time while charging b) Voltage v State of Charge (Noyanbayev, Forsyth & Feehally 2018)

7. System Cost

d. Solar System

Solar systems are normally sold as a package that includes the panels, inverter and installation. Table 9 shows the cost of solar systems by state. The best value per watt is a 5kW system in most states.

Table 9-Average Cost of Solar System by State (Solar Choice 2019)

	1.5kW	2kW	3kW	4kW
SA	$ 2,690.00	$ 2,880.00	$ 3,370.00	$ 3,940.00
$/watt	$ 1.79	$ 1.44	$ 1.12	$ 0.99
QLD	$ 3,230.00	$ 3,540.00	$ 3,940.00	$ 4,670.00
$/watt	$ 2.15	$ 1.77	$ 1.31	$ 1.17
ACT	$ 2,610.00	$ 2,830.00	$ 3,470.00	$ 4,110.00
$/watt	$ 1.74	$ 1.42	$ 1.16	$ 1.03
NT	$ 4,860.00	$ 5,600.00	$ 6,950.00	$ 7,930.00
$/watt	$ 3.24	$ 2.80	$ 2.32	$ 1.98
TAS	$ 2,940.00	$ 3,300.00	$ 4,040.00	$ 5,070.00
$/watt	$ 1.96	$ 1.65	$ 1.35	$ 1.27
VIC	$ 3,070.00	$ 3,380.00	$ 3,800.00	$ 4,290.00
$/watt	$ 2.05	$ 1.69	$ 1.27	$ 1.07
NSW	$ 3,020.00	$ 3,180.00	$ 3,640.00	$ 4,080.00
$/watt	$ 2.01	$ 1.59	$ 1.21	$ 1.02
WA	$ 2,400.00	$ 2,650.00	$ 2,870.00	$ 3,360.00
$/watt	$ 1.60	$ 1.33	$ 0.96	$ 0.84
	5kW	7kW	10kw	
SA	$ 4,470.00	$ 6,470.00	$ 9,250.00	
$/watt	$ 0.89	$ 0.92	$ 0.93	
QLD	$ 5,090.00	$ 6,830.00	$ 9,420.00	
$/watt	$ 1.02	$ 0.98	$ 0.94	
ACT	$ 4,700.00	$ 6,630.00	$ 9,140.00	
$/watt	$ 0.94	$ 0.95	$ 0.91	
NT	$ 9,510.00	$10,990.00	$14,100.00	
$/watt	$ 1.90	$ 1.57	$ 1.41	
TAS	$ 5,500.00	$ 8,060.00	$13,570.00	
$/watt	$ 1.10	$ 1.15	$ 1.36	
VIC	$ 4,820.00	$ 7,520.00	$11,070.00	
$/watt	$ 0.96	$ 1.07	$ 1.11	
NSW	$ 4,440.00	$ 6,950.00	$ 9,490.00	
$/watt	$ 0.89	$ 0.99	$ 0.95	
WA	$ 3,420.00	$ 5,400.00	$10,100.00	
$/watt	$ 0.68	$ 0.77	$ 1.01	

e. Batteries

What battery will be used will depend on the application, on-grid or off grid-connected. I contacted ACDC Energy (A Solar and Battery installer in my local area) on the 2nd of May 2019 and the following was suggested to me:

For On-Grid Sonnen and Redback inverters are used and both use Pylontech batteries (Figure 8) in their system the Poyontech US2000B retails for $1999 (Solar Quotes 2019).

Specification

Specification	Basic Parameters	US2000B Plus	Phantom-S
Nominal	Nominal Voltage（V）	48	48
	Nominal Capacity（Ah）	50	50
Physical	Dimension（mm）	440*410*89	445*428*97.5
	Weight（Kg）	24	24
Electrical	Discharge Voltage（V）	45 ~ 54	45 ~ 54
	Charge Voltage（V）	52.5 ~ 54	52.5 ~ 54
	Charge / Discharge Current（A）	25（Recommended）	25（Recommended）
		50（Max）	50（Max）
		100（Peak@2s）	100（Peak@2s）
Others	Communication Port	RS232，RS485，CAN	RS232，RS485，CAN
	Working Temperature/℃	0~50	0~50
	Shelf Temperature/℃	-20~60	-20~60
	Authentication Level	TÜV / CE / UN38.3	TÜV / CE / UN38.3
	Design life	10+ Years（25℃/77℉）	10+ Years（25℃/77℉）
	Cycle Life	>4500 (90% DoD)	>4500 (90% DoD)

Figure 8- Pylontech Battery Specification

LG-Chem batteries are also used, the RESU10 model is priced at $7655 (Solar Quotes 2019). Figure 9 shows their specifications

48V

Models		RESU3.3	RESU6.5	RESU10	RESU13
Total Energy [kWh] [1]		3.3	6.5	9.8	13.1
Usable Energy [kWh] [2]		2.9	5.9	8.8	12.4
Capacity [Ah]		63	126	189	252
Nominal Voltage [V]		51.8			
Voltage Range [V]		42.0~58.8			
Max Power [kW]		3.0	4.2	5.0	5.0
Peak Power [kW] (for 3 sec.)		3.3	4.6	7.0	7.0 11.0 (Backup Mode)
Dimension [W x H x D, mm]		452 x 403 x 120	452 x 656 x 120	452 x 484 x 227	452 x 626 x 227
Weight [kg]		31	52	75	99
Enclosure Protection Rating		IP55			
Communication		CAN2.0B			
Certificates	Cell	UL1642			
	Product	UL1973 / TUV (IEC 62619) / CE / FCC / RCM			TUV(IEC 62619)/CE/FCC/RCM

Compatible Inverter Brands : SMA, SolaX, Ingeteam, GoodWe, Sungrow, Victron Energy, Selectronic - More brands to be added
1) Total Energy is measured at the initial stage of battery life under the condition as follows : Temperature 25℃
2) Usable Energy is based on battery cell only

Figure 9- LG-chem Specification

For off-grid systems, Lead-acid batteries are predominantly used as they are a tried and tested technology, as opposed to lithium-ion batteries. In an off-grid application you do not have the grid to provide back up if your batteries were to fail so it is important to go with something trusted. ACDC Energy uses the Sonncnschien brand of batteries for their off-grid systems and the specification can be seen in Figure 10.

Specifications:

> Nominal capacity 294 – 3919 Ah C_{120} (20°C)
> Cycling performance at 20 °C (with IU charging): 2400 cycles at 60 % Depth of Discharge (C_{10}) at 20 °C
For enhanced performance and for systems ≥ 48 V we recommend IUI charging, to reach 3000+ cycles at 20 °C
> Designed in accordance with IEC 61427 and IEC 60896-21/22
> Long shelf life up to 2 years at 20 °C without recharge due to the very low self discharge rate
> Also available as flame-retardant version on request (V0)
> Manufactured in Europe in our ISO 9001 certified production plants
> Trouble-free transport of operational cells, no restrictions for rail, road, sea and air transportation (IATA, DGR, clause A67)
> Approval: UL (Underwriter Laboratories)

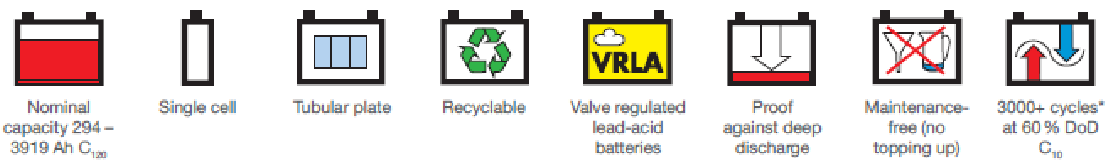


Figure 10 - Sonncnschien Specifications

Table 10 shows the average cost of different types of batteries. Lead-acid batteries are the cheapest but also has the smallest maximum cycles or shortest life.

Table 10 - Average Cost of Battery Types (Opiyo 2016)

	Lead Acid	**Ni-Cd**	**Ni-MH**	**Li-Ion**
Cell Voltage (V)	2	1.2	1.2	3.6
Specific Energy (Wh/kg)	1-60	20-55	1-80	3-100
Specific Power (W/kg)	<300	150-300	<200	3-100
Energy Density (kWh/m^3)	25-60	25	70-100	80-200
Power Density (MW/m^3)	<0.6	0.125	1.5-4	0.4-2
Maximum Cycles	200-700	500-1000	600-1000	3000
Discharge Time Range	>1 min	1 min-8h	>1 min	10s-1h
Cost ($/kWh)	125	600	540	600
Cost ($/kW)	200	600	1000	1100
Efficiency (%)	75-90	75	81	99

8. Economics

Value for money is one of the main concerns when purchasing a solar system. Homer Pro (2019) calculates the net present cost of a system. The net present cost (NPC) is the total cost of installation and operation minus all the revenue the system earns over the lifetime of the system (Equation 8).

$$NPC = \sum_{t=1}^{T} \frac{Operating\ Cost}{(1 + discount\ rate)^t} - Initial\ Investment \tag{2.8.1}$$

T = number of years

Ideally you will want to have a minus NPC as this means over the life of the system you have paid it back and are making money.

The Operating Cost (OC) is the annual sum of all costs and revenue of the system excluding the initial cost (Homer Pro 2019). Homer Pro uses the following equation to calculate the operating cost.

$$OC = Total\ Annualized\ Cost - Total\ Annualized\ Capital\ Cost \tag{2.8.2}$$

$$Total\ Annualized\ Cost = CRF.NPC \tag{2.8.3}$$

$$CRF = \frac{i(1 + i)^N}{(1 + i)^N - 1} \tag{2.8.4}$$

i = discount rate

N = Number of years

A negative OC means the system is making money.

The payback period is the amount of time needed to recoup the cost of the initial investment. To find the payback period for the system the following equation can be used

$$Payback = \frac{Initial\ Investment}{OC} \tag{2.8.5}$$

This project will be looking to have a low NPC, OC and Payback period. Homer Pro is able to calculate and compare these values.

3. Methodology

The objective of my project is to create a tool for people to use to determine their optimum solar and battery system for their house and location. I will be confining my study to the continent of Australia. I want to make the results of the project accessible and relevant to as many people as possible. I do not have the time to test every combination of battery and solar system on the market and with prices changing all the time I want to make sure my results stay relevant for a long as posable so want to look at key factor for each component in the system and determine how they affect optimisation. These factors are:

- PV Panels
  - Size
  - Cost
  - Climate/Location
- Battery
  - Type
  - Size
  - Cost
- Energy Usage
  - Demand
  - Tariff price

I will set the search perimeter for these factors so that time is not wasted simulating unrealistic situations. They are as follows in Table 11:

Table 11 – Test Perimeters

PV Panels	
Size	1.5,2,3,4,5,7,10 kW
Cost	$0.5/kW to $2/kW
Location	Australia
Battery	
Type	Li-ion and Lead-acid
Size	To 20 kWh
Energy Usage	
Demand	75kWh – 200kWh per week
Tariff Price	25-50c/kWh

It is not posable in this project in the time frame and with the resources available to test real-world solar installation around Australia and gather the data needed to do the model. Because of this Homer Pro will be used to run tests for different solar installations across Australia.

Homer Pro is a microgrid analysis tool. With Homer Pro I am able to test different locations right across Australia with different solar and battery setups early and quickly making it ideal for this project. Homer Pro could be used on its own to model optimum solutions across Australia but it is a subscription service starting at $42 per month (Homer Pro 2019). As the goal of this project is to have a tool that is easily accessible to everyone this price puts it out of the reach of some people and is why in this project a new model will be created. Homer Pro is available on the University of Southern Queensland computers so it can be used to create this new model. Homer Pro has access to NASA surface meteorology and solar energy database and using this Homer Pro is able to import temperature and radiation data for any location on earth. An example of this can be seen in Figure 11 and Figure 12.

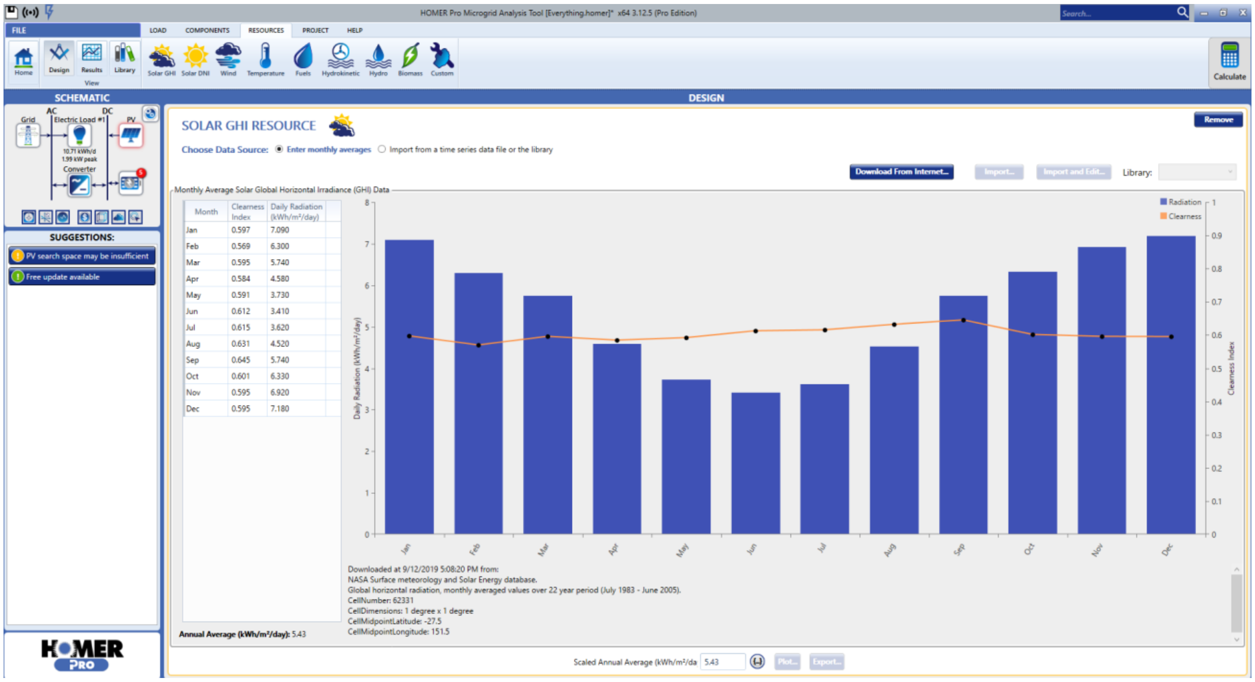


Figure 11 - Homer Pro Solar Radiation

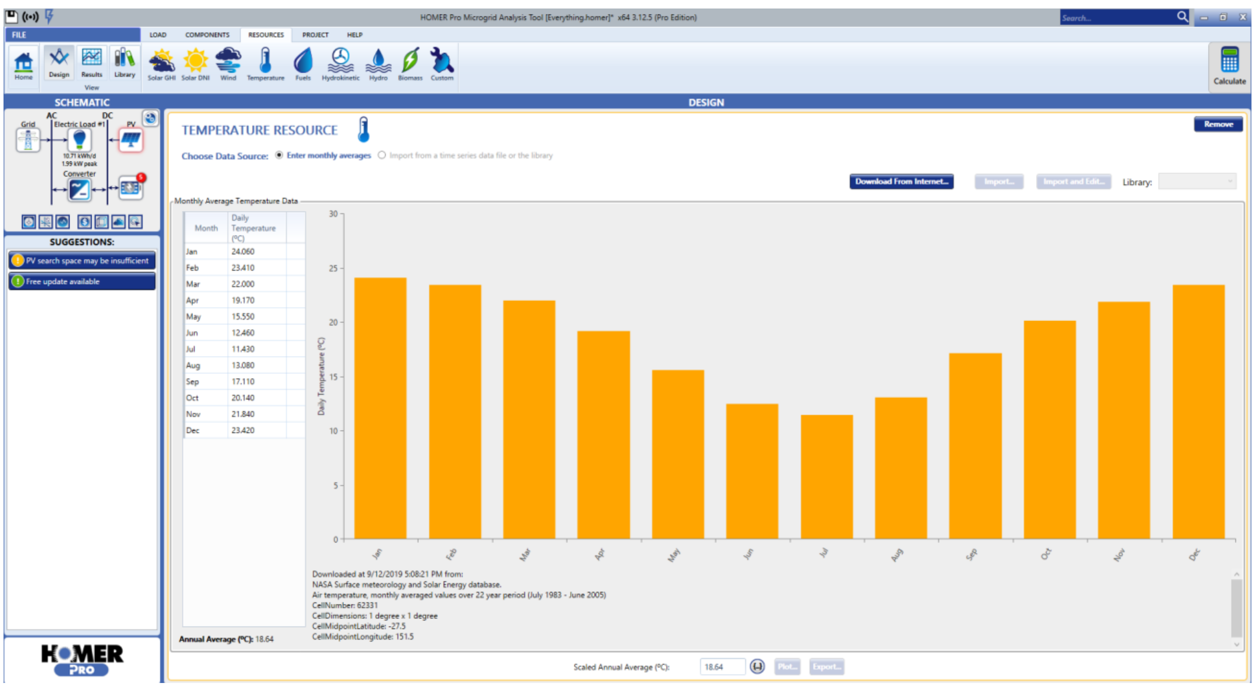


Figure 12 - Homer Pro Temperature Data

Using this data a grid that covers Australia will be created so that an even spread of points across Australia can be tested.

Using the data gathered from Homer Pro, Matlab will be used to plot and create an equation that can predict solar generation across Australia. These equations then can be put into the excel model to predicted solar generation for a given location.

The next step will be to model the battery. The model of the batteries will depend on its capacity and charge and discharge rate. The model will have to look at the current state of charge, energy demand and solar generation and determine, if for that time period, if the battery needs to charge or discharge, while also checking the battery is capable of discharging or charging at the rate required.

After developing the tool I then hope to test it to determine its accuracy. I will do this by comparing it back to the Homer Pro software simulations. If time allows I would make changes and improvements to the tool.

I will not be able to, as part of this project, compare my tool with the real world. There would not be enough time for me to gather the data needed for this as I would have to collect data from solar and battery systems for at least a 12 month period.

After determining the model is working correctly it will then be used to optimize different households across Australia. Because different households would be looking for different things form their solar systems this project will look to optimize the system on the following factors:

- Net Present Value
- Payback Period
- Savings
- Peak Levelling

The first three look at financial factors and the last at an energy usage factor. The financial factors are what most people discuss when looking at getting solar and the energy usage factor looks at what would be best for the network to reduce the Duck Curve talked about earlier.

4. Modelling

Simulations were undertaken in Homer Pro to gather data on solar generation performance across Australia. Load data from the Australian Bureau of Statistics (2013) household energy consumption survey will be used alongside Homer Pro built-in load covers to create a loading model. Battery data sheets were used to create the modelling for the battery's behaviour.

Appendix D has an example of some of the finial excel formula used in the model. It also has directions to accessing a copy of full the excel document.

1. Solar Modelling

A model in Homer Pro of a 1kW solar system connects to a consent 1kW load tested at different locations across the grid. These tests gave the following data points for different longitude and latitude values.

Mean output (kW)

Mean output (kWh/d)

Production (kWh/yr)

Maximum Output (kW)

Hours of Operation (hrs/yr)

An example of the results are shown in Figure 13.

Figure 13- Homer Pro 1kW System test results location -25,145

The simulations in Homer Pro used solar radiation and temperature data from NASA. This meant that the data gathered had included in its allowances for changes in the solar cell's efficiencies due to the weather. The data gathered from these tests were used to create equations for the different data points listed above. The equations generated came in the form of a 4th degree polynomial in the following form:

$$z = p + xp_{10} + yp_{01} + x^2p_{20} + xyp_{11} + y^2p_{02} + x^3p_{30} + x^2yp_{21} + xy^2p_{12} + y^3p_{03} + x^4p_{40} + x^3yp_{31} + x^2y^2p_{22} + xy^3p_{13} + y^4p_{04} \quad (4.1.1)$$

where x is latitude

y is longitude

z is the data point

p is the coefficients

The coefficients for these equations can be found in Appendix B Table 28. Figure 14 shows one of these models and the raw data collected for Homer Pro can be found in and be seen in Appendix C, Table 27.

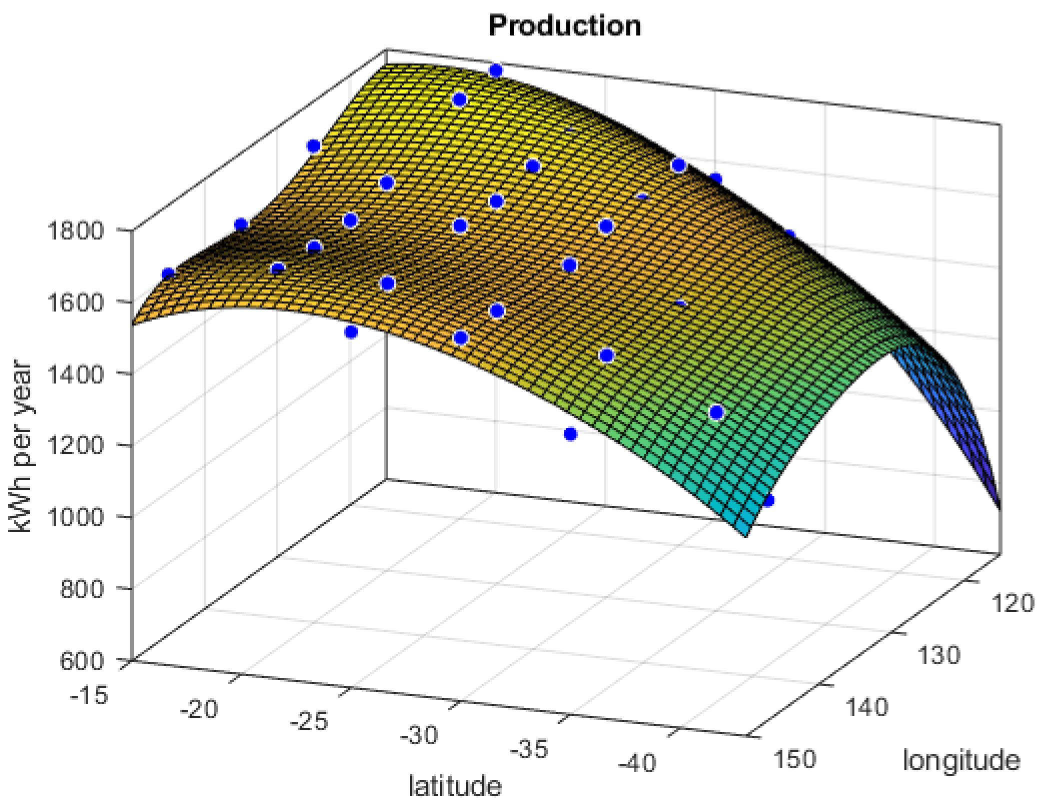


Figure 14 - Production Model

The highest error between the data points and the model was at its highest 6%. New data points were also gathered and tested for error and this also had an error of 6% at its highest. The error between the model and the data points is shown in Table 12.

Table 12 - Model Error

	mean	max
mean output kW	1.80%	6.04%
mean output kWh/d	1.78%	5.74%
Production	1.79%	5.71%
max output	0.71%	2.76%
hours of op	0.25%	0.76%

By adding more data points this could be reduced but with time limitation this is not possible at this time. The 6% error is small enough for the purpose of this project to move forward.

The effect from the installation angle of the solar cells was also taken into account. Again simulations were done with the installation angle changing from 0 to 90 degrees. This was done at different latitudes. The production (kWh per year) from the different locations was normalised so that all the locations could be compared. When the different between the installation angle and the ideal angle (equal to the latitude) was plotted against the production a simple curve was seen (Figure 15).

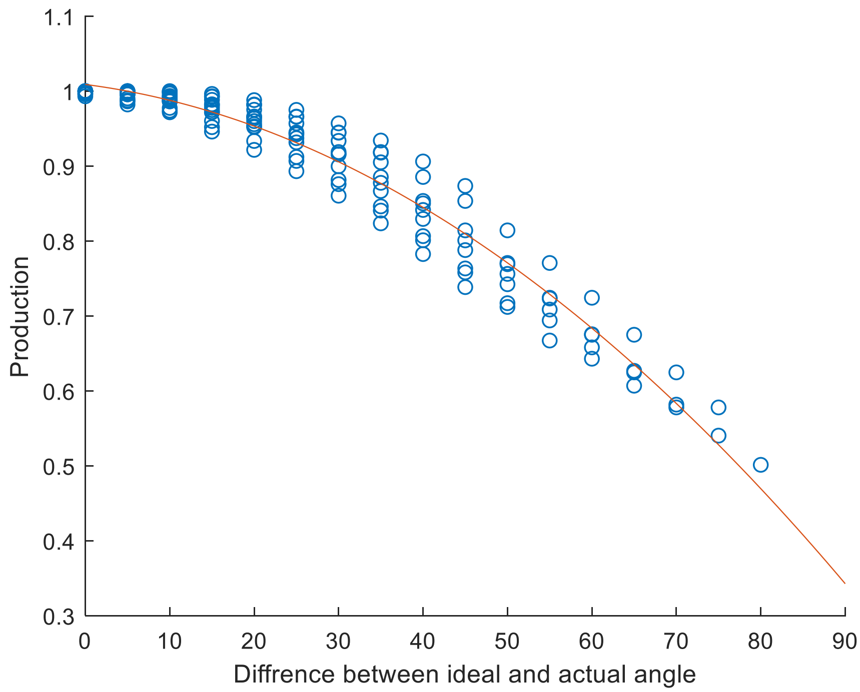


Figure 15 - Solar cell angle efficiency

The equation for this curve of efficiency (η) is

$$\eta = 1.008926 - 0.00146x - 0.0001x^2 \quad (4.1.2)$$

where x is ||latitude|-angle|

The equation was changed from the Matlab one to

$$\eta = 1 - 0.00146x - 0.0001x^2 \quad (4.1.3)$$

This is so that the curve goes through 1 on the y axel as it should.

After the University of Southern Queensland project conference, where this project was presented, it was brought to my attention the direction at which the solar panel also affect their efficiency. This is something that had been overlooked up until this point but it was decided to include it after the project conference.

To get the most out of the panels they should be directed towards the equator so in the southern hemisphere that is north and in the northern hemisphere that is south. In the domestic installation solar panels are normally fixed to the most north-facing roof space and this may not always be exactly north so a de-rating factor needs to be found. Like before a 1kW system was tested but this time at different angles from the north. Figure 16 shows the results.

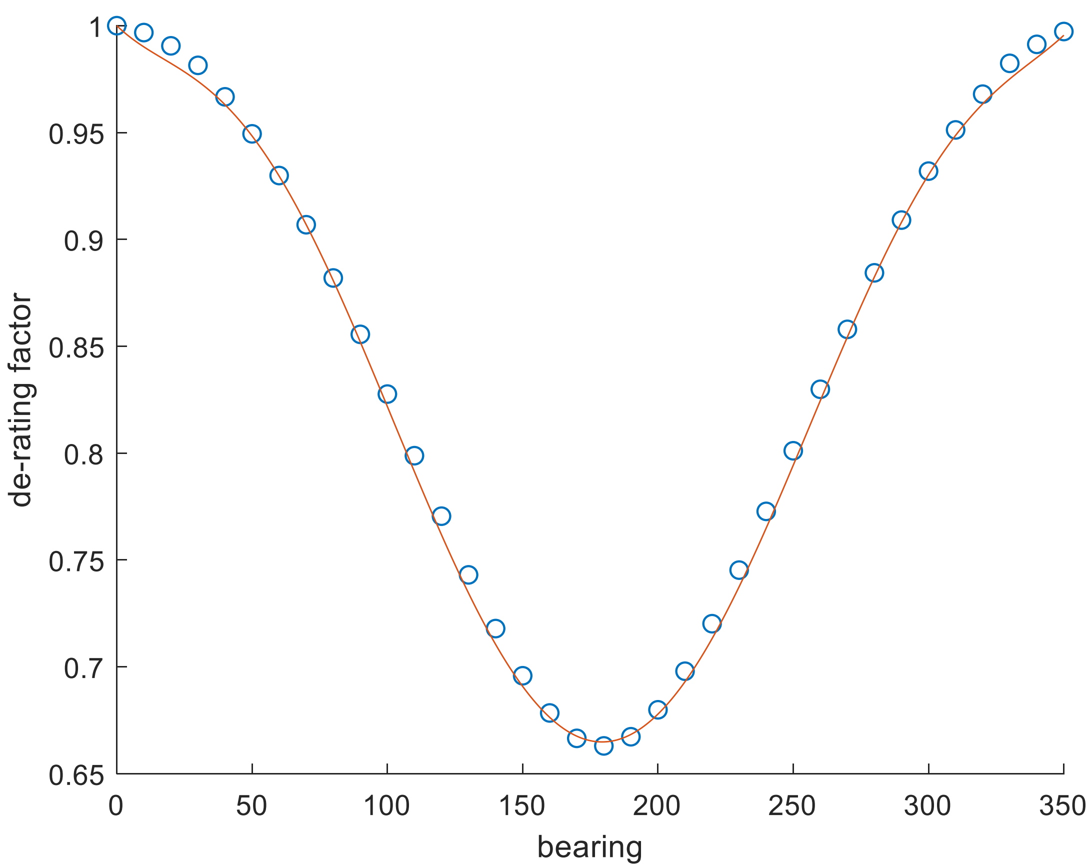


Figure 16 - Direction De-rating Factor

The blue dotes show the original data point and the orange line shows the equation created from these points which are as follows:

$$\eta = 1 - 0.001227x + 3.057 \times 10^{-5}x - 7.683 \times 10^{-7}x^2 + 5.382 \times 10^{-9}x^3 - 1.447 \times 10^{-11}x^5 + 1351 \times 10^{-14}x^6 \quad (4.1.3)$$

where η is the de-rating factor

x is the bearing of the installation.

The directional bearing is in line with convention and is demonstrated below

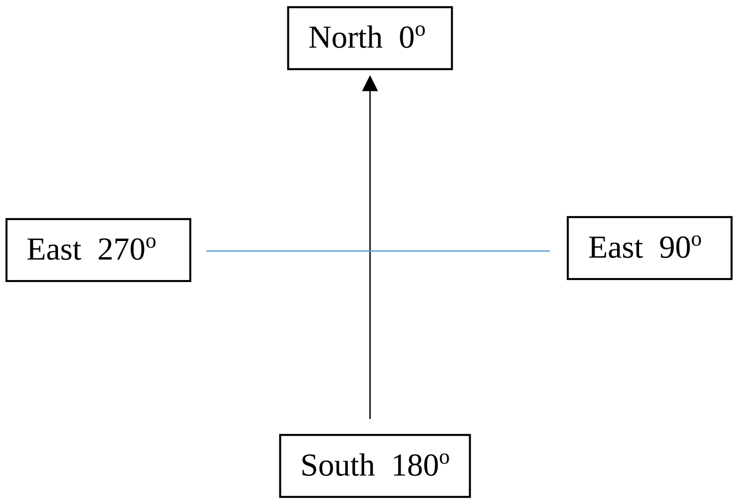


Figure 17- Bearing convention

This curve shows that if the panels are facing south only 67% of potential energy will be generated. The last step in modelling solar performance is modelling the solar output profile. The curve for the power output throughout the day from the solar panels looks very similar to a Gaussian curve when average out over a month (Figure 18).

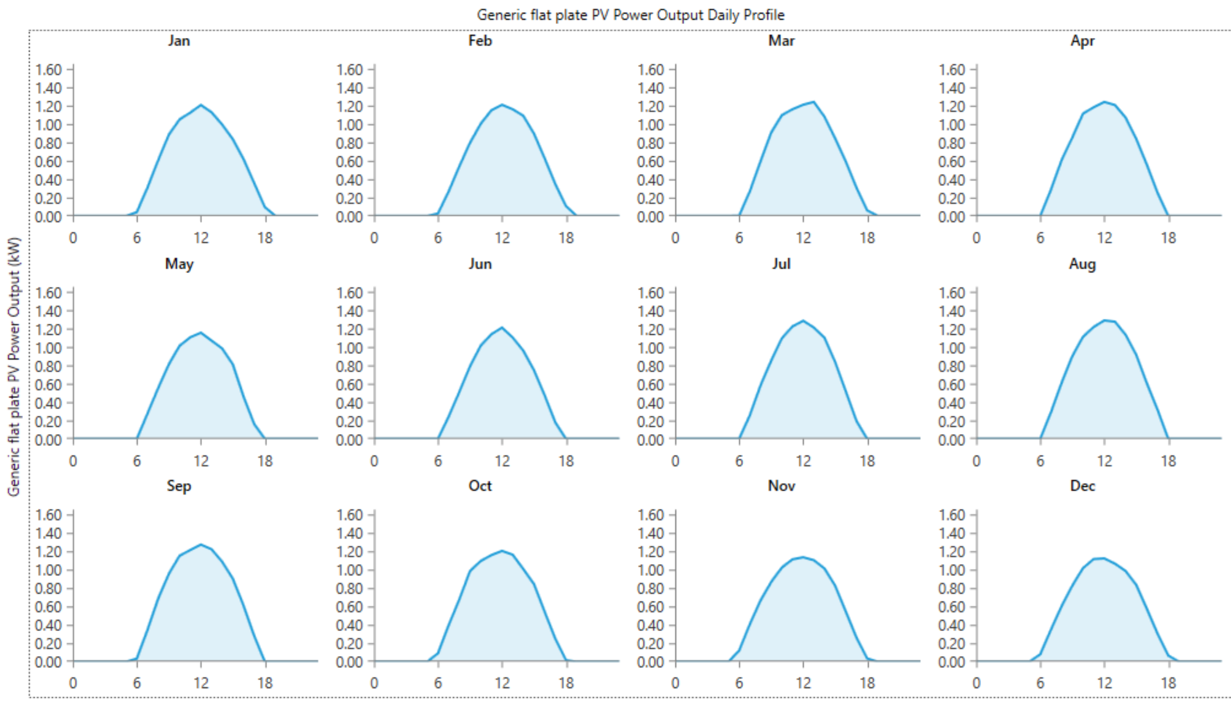


Figure 18 - Power Output Daily Profile (Homer Pro 2019)

Using the basic Gaussian formula this equation was developed to show the daily output profile.

$$Output(h) = 0.8P \times \exp\left(-\frac{(h-N)^2}{\mathrm{D}}\right) \quad (4.1.3)$$

Where P is peak or maximum output (kW)

h is the hour of the day

N is the time of solar noon

D is the time in hours between sunrise and sunset

This gave what closely resembled actual solar radiation (Figure 19). Variables could easily be changed to find a different curve for a different location.

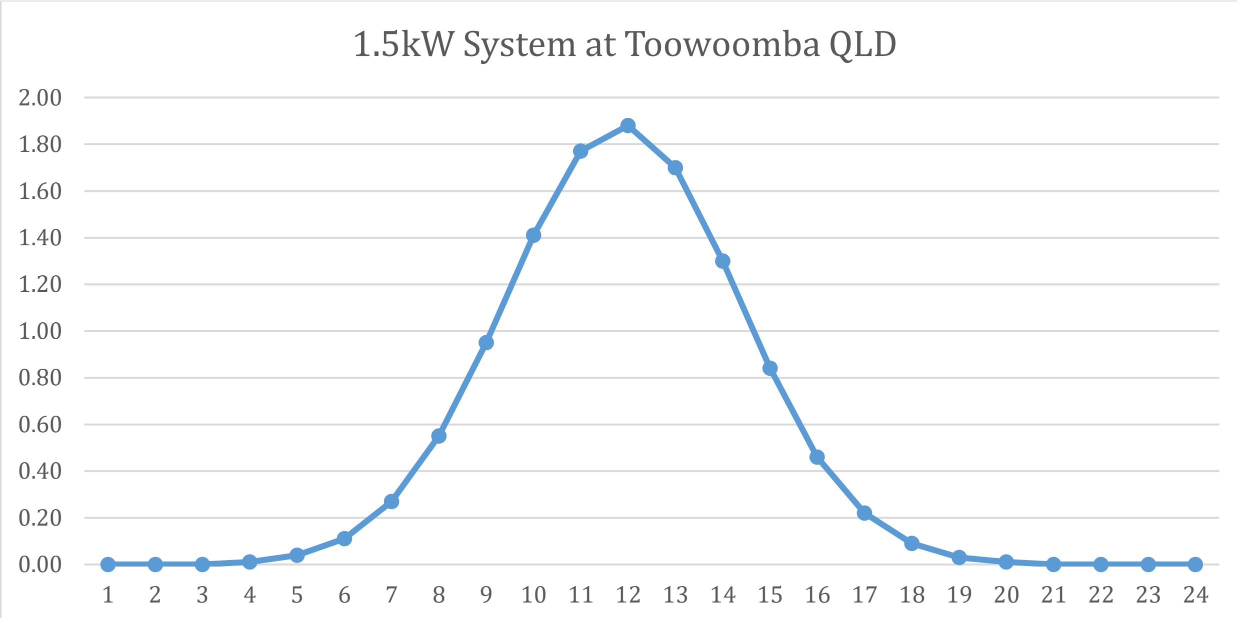
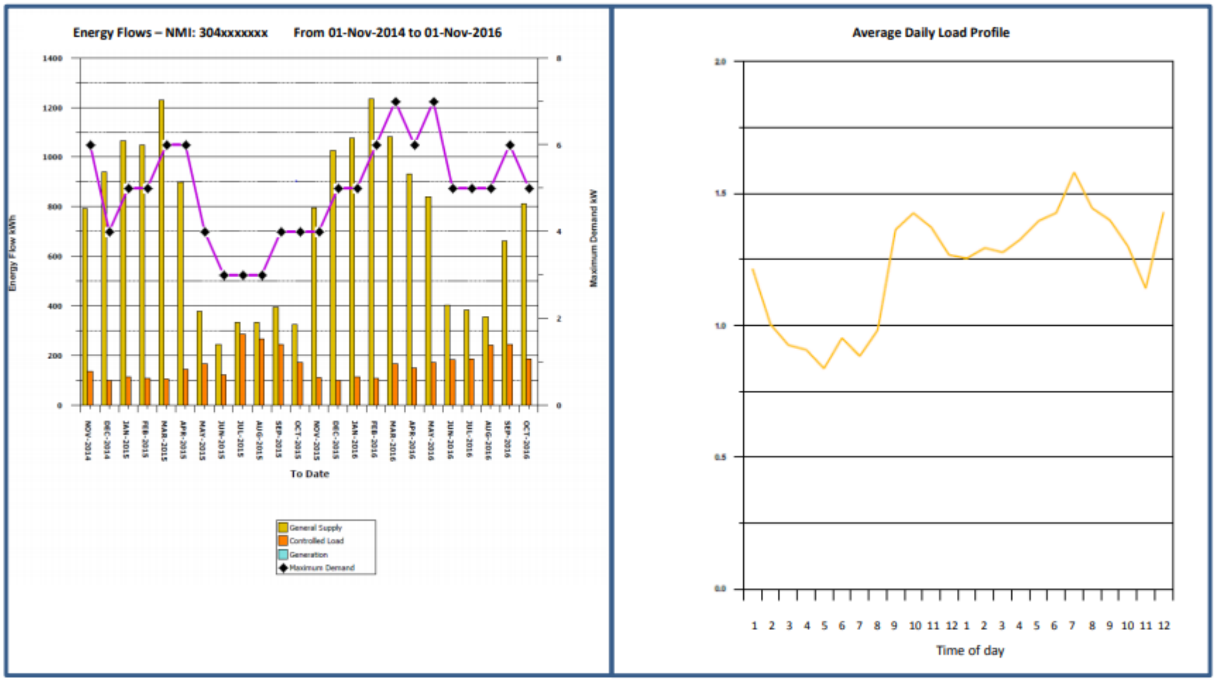


Figure 19 - 1.5kW Solar System at Toowoomba Generation Curve

The time of sunrise, sunset and noon are calculated using the National Oceanic & Atmospheric Administration (2011) equations (2.6.1) – (2.6.5). It was noticed that using equation 4.1.3 that on some occasions the model showed solar generation outside of daylight hours which is not possable. To solve this an IF statement was used to set solar generation to 0 outside of daylight hours.

2. Load Modelling

Homer Pro has a standard residential load curve built-in that was used in this modelling. But as seen before from the Australian Bureau of Statistics (2013) survey there are a lot of things that affect energy usage in a household. Because of this the modelling allows for users to enter a custom load curve if they wish. In Queensland if you have a smart meter connected to your house it is possible to request this data and get your own load profile for your house. An example of this data can be seen in Figure 20.



- The above graph describes usage of load profile over a specified time period.
- The vertical axis on the left indicates energy flow measured in kilo watt hours.
- The vertical axis on the right indicates maximum demand measured in kilo watts.
- The horizontal axis indicates time periods.
- This is the total consumption measured against each meter installed per time period.

- The above graph describes the average daily load over a 24 hour time period.
- The vertical axis on the left indicates average consumption measured in kilo watt hours at a particular time of day.
- The horizontal axis indicates time of day.

Figure 20- Example of Load Profile Data (Ergon 2018b)

3. Battery Modeling

I selected 5 different battery models for modelling in Table 13. Allowances were also made in the model to have custom battery inputted by the user.

Table 13 - Battery Models

	Tesla Powerwall	LG Chem 6.5kWh	LG Chem 9.8kWh	6X BAE PVV 550	6X BAE PVV 1050
Price	13999	7203.91	8920	3235	6215
kWh	13.5	6.5	9.8	6.96	13.74
Usable kWh	13.5	5.9	8.8	4.872	9.618
Output Power (VA)	5000	4200	5000	1072.8	2064
Type	Li-Ion	Li-Ion	Li-Ion	Lead-Acid	Lead-Acid
Efficiency	0.9	0.95	0.95	0.9	0.9
Warranty (years)	10	10	10	3	3

To model the battery performance first the load curve with just the house load and solar is calculated. From this, it can be determined when there is excess energy in a system that would normally go back into the grid, that could be captured. As all new feed-in tariffs are lower than general-purpose tariffs it is more beneficial to store the energy and use it in your own house than to sell it back to the grid only to buy more energy later. As can be seen in Figure 21 from 8 am to 4 pm there is an excess of energy.

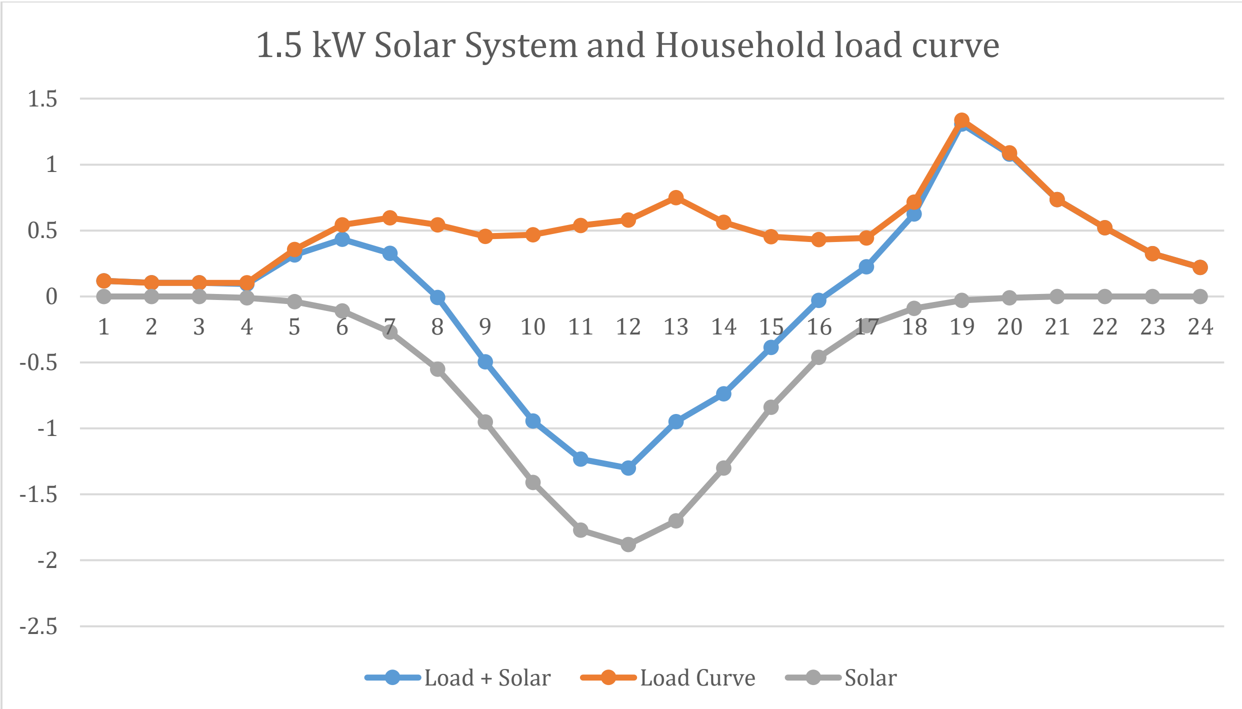


Figure 21-1.5 kW Solar System and Household load curve

Using IF statements in the excel model I could calculate the charging or discharging rate. Batteries have different charge and discharge rates so when this rate it hit the battery will not be able to receive any more energy and the battery rate is capped out sending the excess back into the grid. Figure 22 shows the process of the IF statements used in excel to calculate the state of charge.

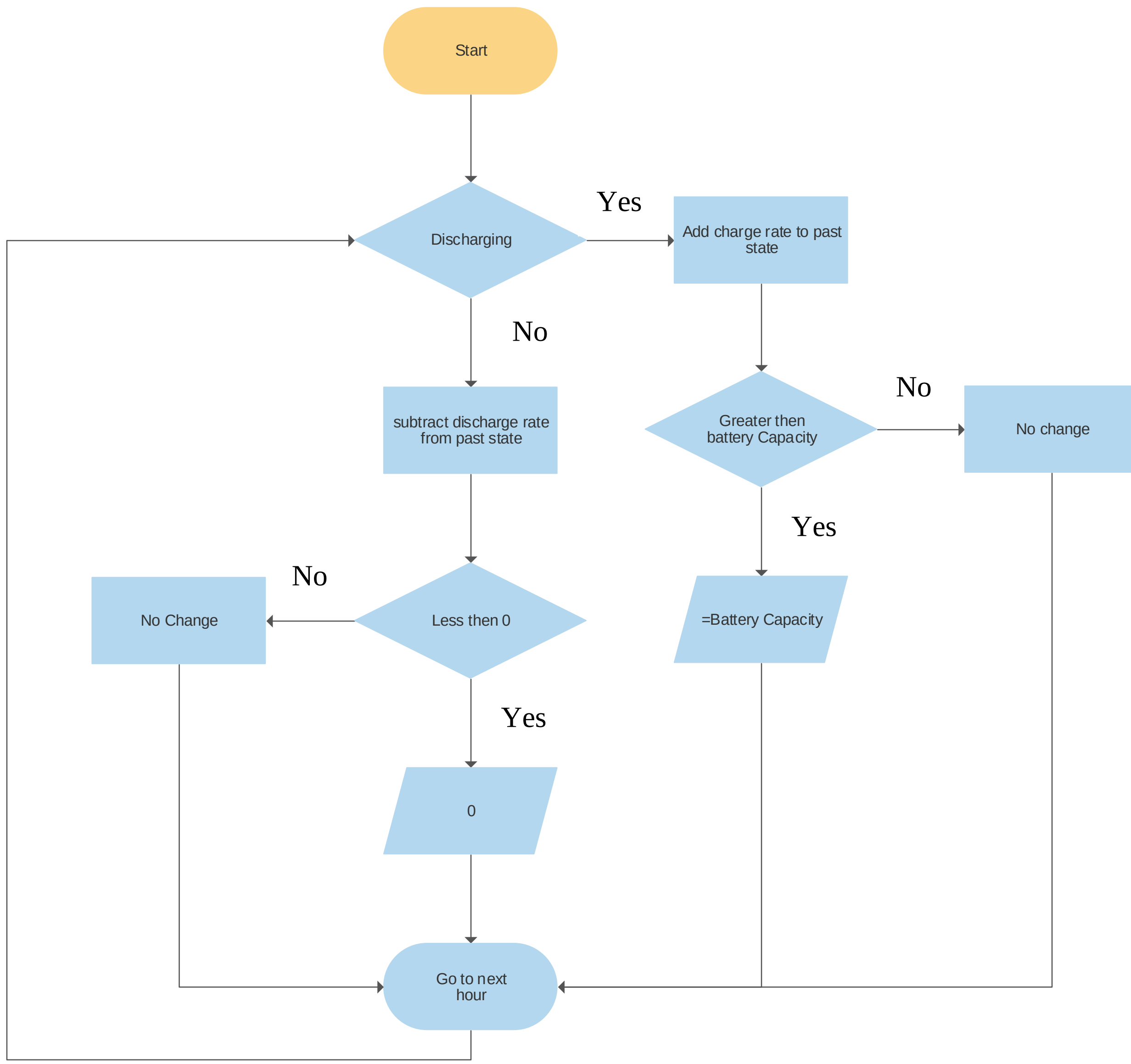


Figure 22 - Battery Model IF statement

The battery charge level is started at 0% and this loop is run over a 4 day period. By doing this the model is able to find a steady-state for the battery model. When the model was first created the loop only ran for a 2 day period and with the battery at half charge initial state. After running a few tests of the model with different input value it was quickly discovered that a longer time period would be needed for the battery to reach its steady-state. The initial state was set to 0 to simplify the model and extra days were added until a steady state was found for all the different combustions of systems.

From the battery modelling and solar modelling a new load profile can be found (Figure 23).

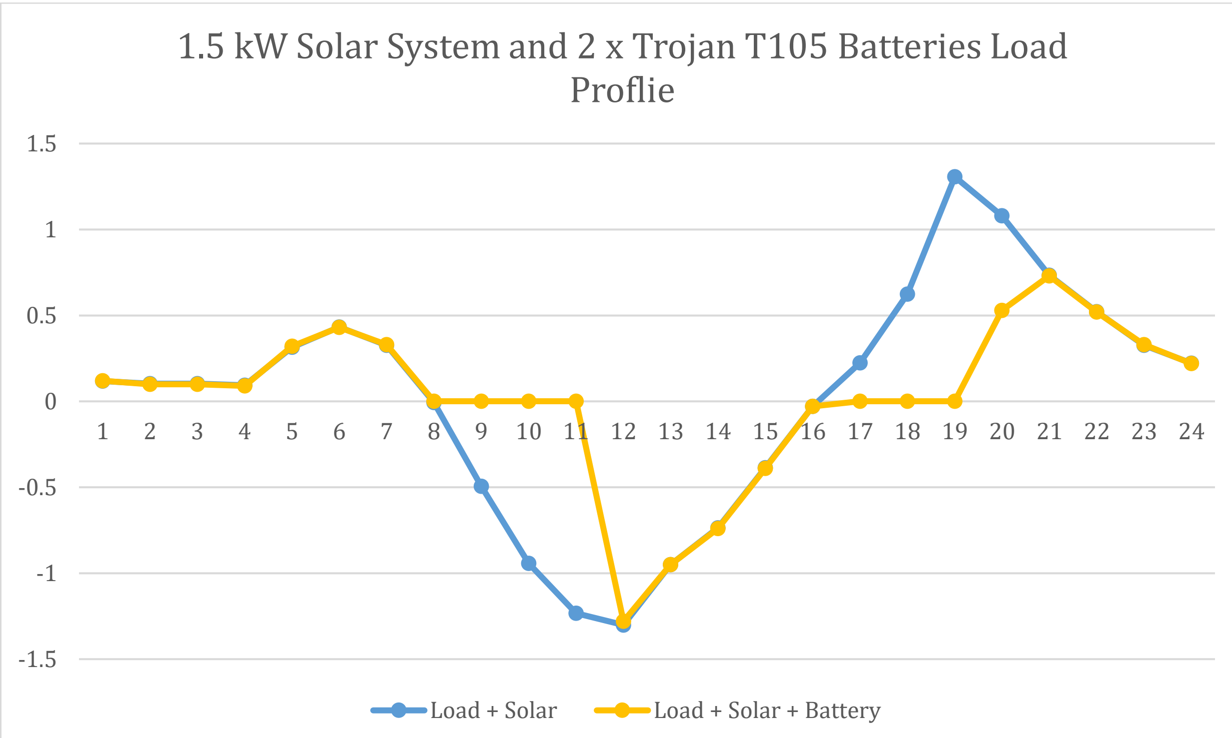


Figure 23 - 1.5 kW Solar System and 2 x Trojan T105 Batteries Load Profile

As can be seen some of the excess energy has been shifted and used during the peak time at 7 pm.

4. Financial Modelling

Finance is always a consideration for a household looking to invest in solar and battery storage options. Because of this, it is important that there is financial modelling included in this projects model. Financial factors this project looked to calculate in the model were yearly cost, net present cost, cost of energy and savings.

As mentioned in the literature review (page 9) there are different tariffs available to households. The general tariff, called tariff 11 by Ergon Energy is the most commonly used and the default for households. The other common type of tariff in use is the Time of Day tariff, called tariff 33 by Ergon energy. This kind of tariff is used for hot water systems. When constructing the model both of these tariffs where included. Figure 24 shows where this tariff information can be entered into the model, they are labelled General and Hot Water.

10	**Energy Usage**	**General Tariff (kWh)**	**Hot Water Tariff (kWh)**	**Total**	
11	Q1	2579	0	2579	Time of Day Tariff Normally used for Hot Water
12	Q2	2579	0	2579	
13	Q3	2579	0	2579	
14	Q4	2579	0	2579	
15	Average	2579	0		
16	Total	10314	0	10314	
17					
18	Load curve	Built in			
19					
20	**Tariff Price**	**$**			
21	General	0.428816			
22	Hot Water	0.2105			
23	Service fee	0.88949			
24	feed-in	0.07842			

Figure 24 - Model tariff and energy usage section

Because the two tariffs have different prices and represent a different percentage of the energy usage, to get a closer approximation of the price the household will pay after solar and battery installation, the user is asked to separate their energy usage into the two tariff categories for each quarter. An approximation of the yearly cost can be found with this information using the following equation:

$$Yearly\ Cost = 365(Grid \times \frac{E_{11}}{E} \times T_{11} + Grid \times \frac{E_{33}}{E} \times T_{33} - FI \times T_{FI} + SF) \quad (4.4.1)$$

Where $Grid$ is the kWh/day from the grid

E_{11} is general tariff usage (kWh)

E is the total energy used (kWh)

E_{33} is hot water tariff usage (kWh)

T_{11} is the tariff 11 price ($/kWh)

T_{33} is the tariff 33 price ($/kWh)

FI is the kWh/day feed into the grid

T_{FI} is the feed-in tariff price ($/kWh)

SF is the service fee ($/day).

The net present cost (NPC) is the next key financial value needing to be calculated in the model. This is a key indicator of whether or not the system is making or losing the owner money. The equation used to find the NPC is:

$$NPC = Initial\ Cost + \sum_{t=1}^{N} \frac{Cash\ Flow}{(1+i)^t} \quad (4.4.2)$$

Where N lifetime of the project (years)

t time period (1 to N)

i is the discount rate.

The NPC equation allows for the change in the value of money. If payments can be deferred to a later date, that money can be used to generate interest before having to make the payment, in turn lessening the value of that payment. Also if the household is not able to receive earnings until a later date those earnings are worthless then if they were paid earlier.

Cost of energy (COE) or cost per kWh is another indicator on how a solar and battery system is doing compared to without. COE is calculated using the following equation:

$$COE = \frac{NPC}{Total\ Load\ Served} \quad (4.4.3)$$

Where $Total\ Load\ Served$ is the total kWh used over the life of the project.

COE gives the user a dollars per kWh value and this can easily be compared to your general tariff to see if the household is spending more or less for their energy then before the installation of a solar and battery system.

The last financial value calculated in the model is savings. This is a very simple value and is just the original energy cost per year with no solar or battery minus the new energy cost per year with solar or battery storage. This is just a quick comparison for the household to show them how much they would save per year with a solar and battery system installed

5. User Interface

The user interface is the area on the model where the user can interact with the model and enter their individual location, energy usage, tariff prices, solar setup and battery selection (Figure 25).

Home Solar and Battery Model

Location				
Latitude	-33.85	Intrust rate	100%	Enter The location of your house here
Longitude	151.22			
Time Zone	10			
State	NSW			

Energy Usage	**General Tariff (kWh)**	**Hot Water Tariff (kWh)**	**Total**	
Q1	2579	0	2579	Time of Day Tariff Normally used for Hot Water
Q2	2579	0	2579	
Q3	2579	0	2579	
Q4	2579	0	2579	
Average	2579	0		
Total	10314	0	10314	
Load curve	Built in			

Tariff Price	**$**
General	0.428816
Hot Water	0.2105
Service fee	0.88949
feed-in	0.07842

Solar System				
Angle of installation	30	degrees		At what angle will the panels be mounted
Direction of installation	10	degress	0=North 180=south	The best angle is equal to the Latitude

Battery		Qty
6X BAE PVV 1050		3
Price	$ 6,215.00	$ 18,645.00
Usable kWh	9.62	28.854
Output Power (VA)	2064	6192
Type	Lead-Acid	Lead-Acid
Efficiency	0.9	0.9
Warranty	3	3

Figure 25 - User Interface

The yellow part on the model indicate areas of the model designed for the user to interact with and change values of. The more information the model is able to gather the more accurate it can be in predicting system performance. However, the more sections that are added could create confusion and complication for the user. This could result in errors in the predictions made by the model and this would not be a good outcome for the user. It is believed the model has found a good compromise between detail and ease of use. Due to time constraints and lack of ethics approval, it was not posable to get feedback from users of the model at this stage but it is something that I would like to be done in the future to improve the ease of use of the model.

Along with the user interface is the results section. The results section shows the models predictions on solar and battery performance (Figure 26).

Results

kW	Solar Generation kWh/Day	Mean output kW	Grid (kWh/day)	Feed-in (kWh/day)	Battery High-Low	Grid (kWh/day)	Feed in (kWh/day)
1.5	5.84	0.24	22.15	0.00	2.88	22.15	0.00
2	7.79	0.32	20.11	0.00	3.02	20.11	0.00
3	11.68	0.49	17.89	-1.84	3.18	16.23	-0.18
4	15.57	0.65	17.10	-5.14	2.38	12.47	-0.51
5	19.47	0.81	16.52	-8.63	1.39	8.75	-0.86
7	27.26	1.14	15.75	-16.01	0.61	1.57	-1.60
10	38.94	1.62	15.09	-27.55	5.07	1.51	-13.97

kW	Cost Solar	Battery	Payback (Years) Solar only	NPC (10 years)	Payback (Years) Solar and Batt	NPC (10 year
1.5	$ 3,020.00	$ 18,645.00	3.16	$ 38,928.28	22.65	$ 57,573.30
2	$ 3,180.00	$ 18,645.00	2.49	$ 36,064.12	17.11	$ 54,709.14
3	$ 3,640.00	$ 18,645.00	2.17	$ 32,733.85	11.81	$ 49,373.33
4	$ 4,080.00	$ 18,645.00	2.15	$ 31,109.62	9.14	$ 44,150.10
5	$ 4,440.00	$ 18,645.00	2.13	$ 29,663.67	7.50	$ 38,899.36
7	$ 6,950.00	$ 18,645.00	2.88	$ 29,026.84	6.06	$ 30,570.17
10	$ 9,490.00	$ 18,645.00	3.33	$ 27,459.95	6.13	$ 29,658.95

kW	Energy Cost Original	Solar Yearly	Saving	Cost per kWh	Solar and Battery Yearly	Savings	Cost per kWh
1.5	$ 4,747.59	$ 3,791.27	$ 956.32	$ 0.38	$ 3,791.27	$ 956.32	$ 0.56
2	$ 4,747.59	$ 3,471.97	$ 1,275.62	$ 0.35	$ 3,471.98	$ 1,275.62	$ 0.53
3	$ 4,747.59	$ 3,071.79	$ 1,675.80	$ 0.32	$ 2,860.04	$ 1,887.55	$ 0.48
4	$ 4,747.59	$ 2,853.84	$ 1,893.75	$ 0.30	$ 2,262.11	$ 2,485.49	$ 0.43
5	$ 4,747.59	$ 2,663.17	$ 2,084.43	$ 0.29	$ 1,669.71	$ 3,077.88	$ 0.38
7	$ 4,747.59	$ 2,330.92	$ 2,416.68	$ 0.28	$ 525.29	$ 4,222.31	$ 0.30
10	$ 4,747.59	$ 1,897.30	$ 2,850.29	$ 0.27	$ 160.90	$ 4,586.69	$ 0.29

Figure 26 - Model Results Section

The results section show the predicted solar generation and battery performance as well as the key financial indicator mentioned in the financial modelling section above. The orange highlighted square shows the best performing system for that category when compared with other systems that are just solar or solar and battery. The green highlighted squares shows the best performing system for that category when compared with systems that are just solar and solar and battery. This allows the user to quickly see at a glance which system is performing the best in the category most important to them.

The model also includes some graphical comparisons that can be seen in Figure 27.

Figure 27 - Model graphical comparisons

These graphs look at some of those key indicator mentioned before in the financial modelling section and allow the user to easily compare visually what system is better for them.

5. Results and Discussion

1. Excel Model Comparison

After creating the excel model test werre then done to see how it compared to the Homer Pro simulation.

The Solar model is very similar to the Homer Pro simulation. Figure 28 shows these two profiles

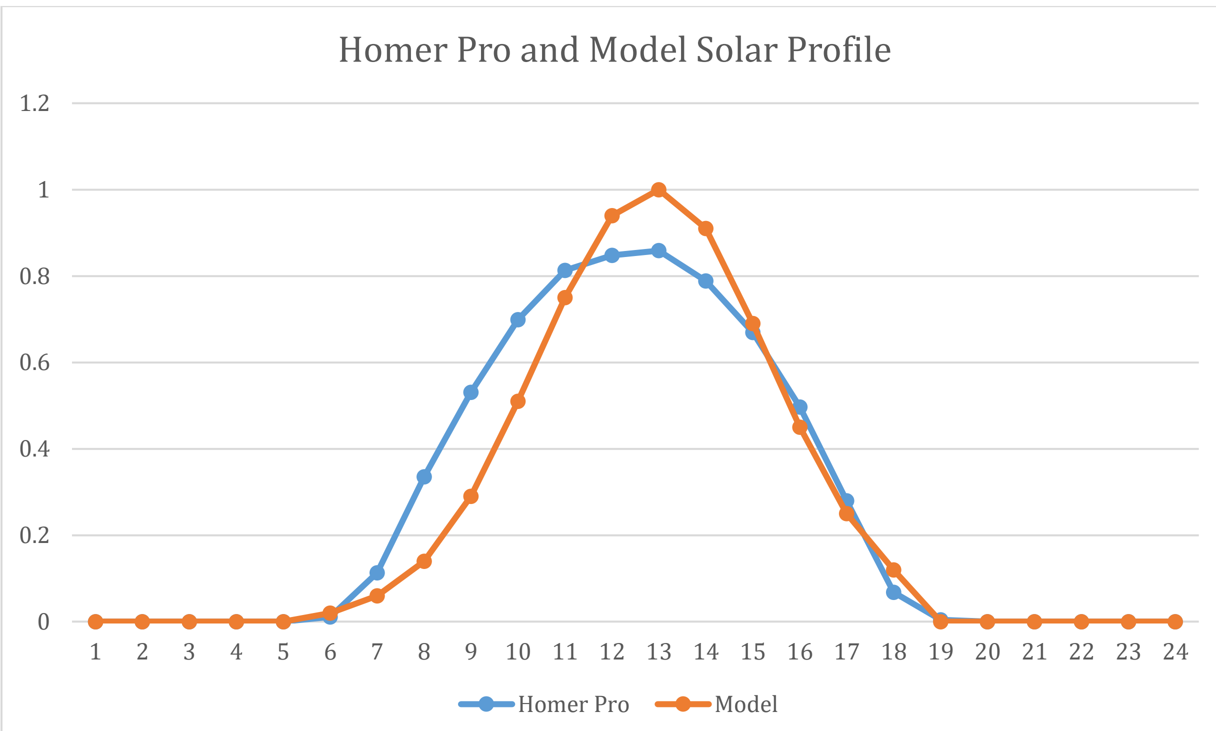


Figure 28 - Homer Pro and Model Solar Profile

The model curve is a bit more aggressive and steeper than the Homer Pro curve. The two peeks are happening at the same point on the curves. The area under the curve, or the kWh per day, is 6% less of the Homer Pro curve. The error of individual data points is on average 21% and at its most 100%. This maximum error happens at 6 am and 9 pm and only represents a difference, depending on the system size, of between 0.004kW and 0.03kW.

The battery model in excel, when compared to Homer Pro, came very close as can be seen below (Figure 29).

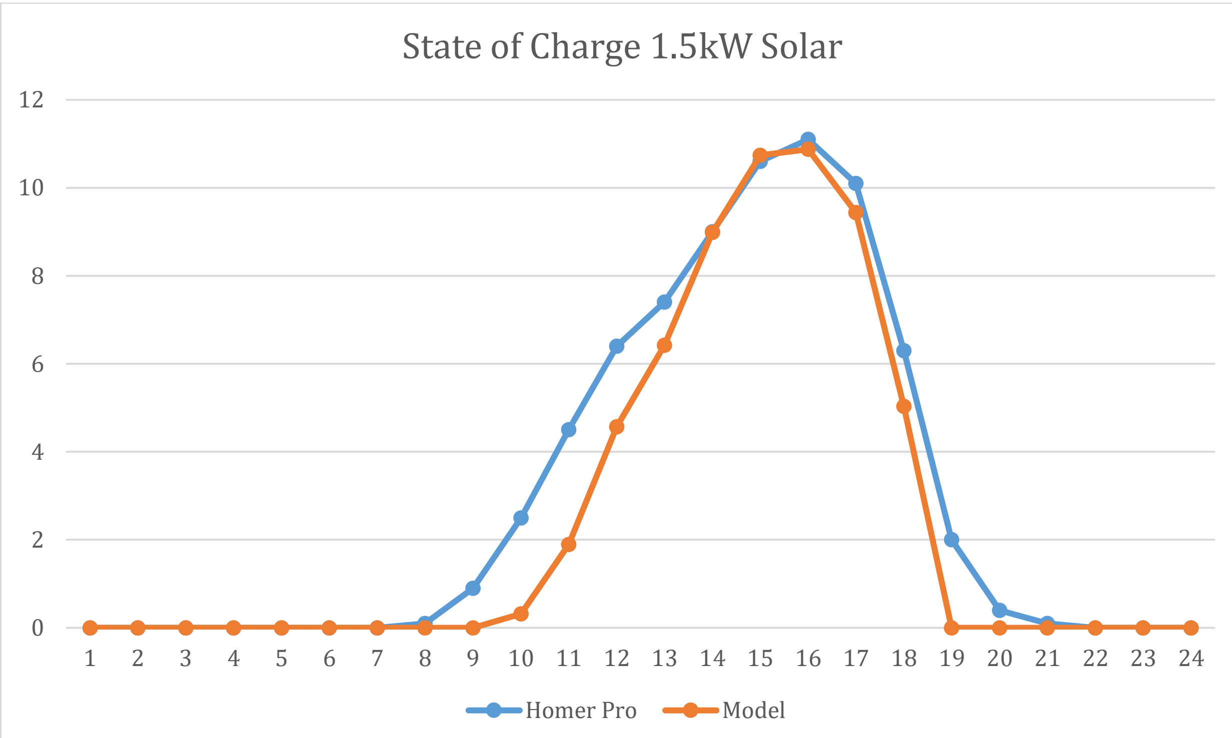


Figure 29 - State of Charge 1.5kW Solar and Tesla Powerwall

The excel model is very similar to the Homer Pro simulation. The area under both curves is within 18% of each other. The stepper curve from the solar model above (Figure 28) is caried over here. As can be seen that the Homer Pro curve is more gradual and the excel model's steeper. The peak of the two curves are within 2%, this is good as it shows that both models are showing the battery charge to about the same level each day and discharging again. So the same amount of energy in both models is going in and out of the battery. The results are even better when the battery is paired with a larger solar system (Figure 30).

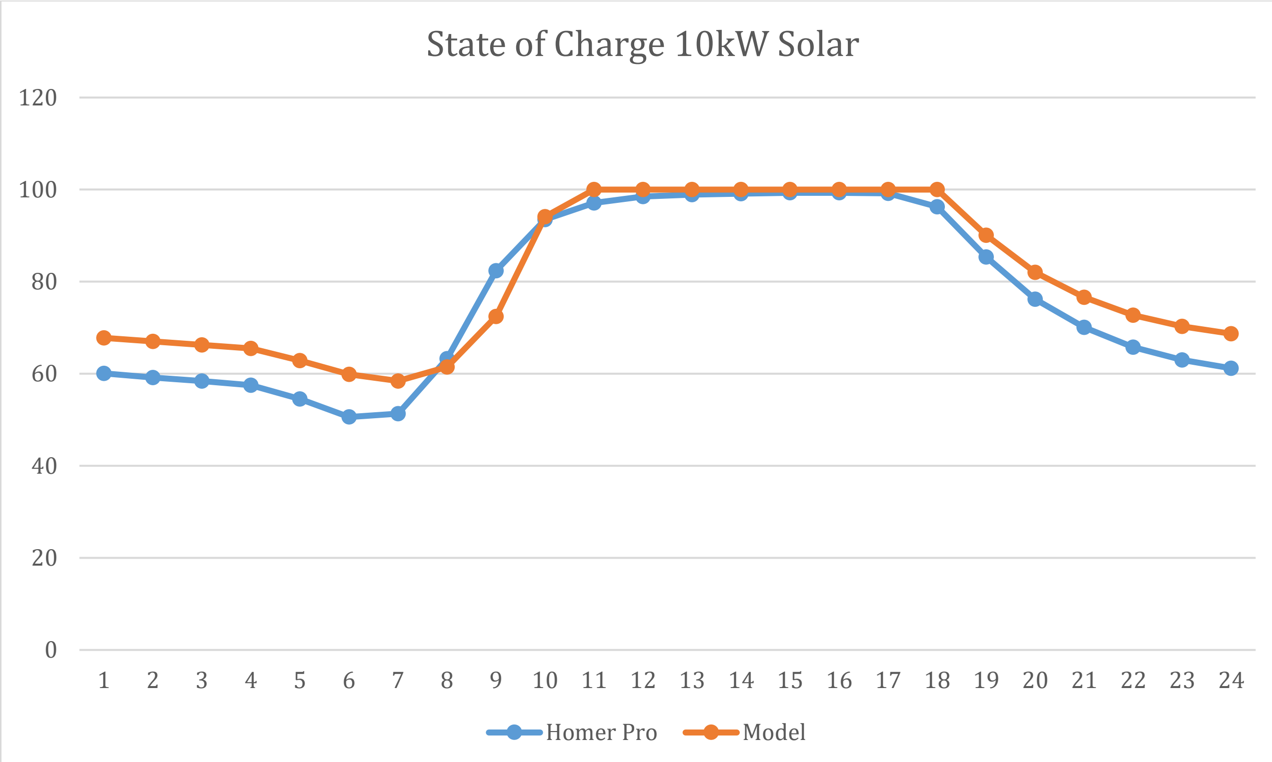


Figure 30- State of Charge 10kW Solar and Tesla Powerwall

The error between individual points only gets up to 18% but again the peak is very close at 1%. This is very good for the excel model. The battery will begin to discharge if left to sit and hence why the Homer model never reaches 100% capacity instead hovering around 99% the whole time.

The load profile seen by the grid of both models can be seen in Figure 31. The excel model in this configuration sells 1kWh more back to the grid and also buys 0.4kWh more for the gird then the Homer Pro model.

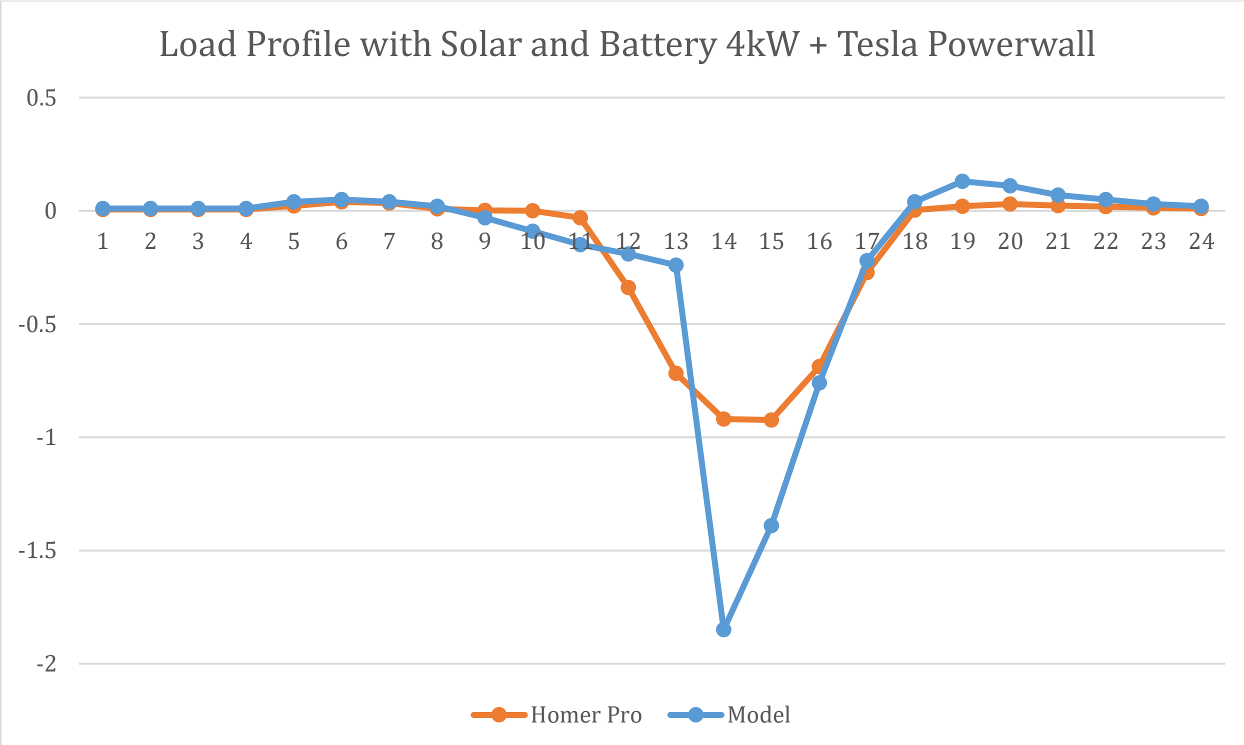


Figure 31- Load Profile with Solar and Battery 4kW + Tesla Powerwall

Over a year using the current Ergon tariffs, this is a difference of $7 more profit for the Homer Pro model. This is an error of 8%.

2. Optimisation

5 different households energy usage sizes were tested in both Homer Pro and the excel model. the 5 different sizes were informed by the Australian Bureau of Statistics (2013) survey and they are shown in Table 14

.

Table 14 - Household energy usage sizes

kWh/week	kWh/day
200	28.57
160	22.86
125	17.86
100	14.29
75	10.71

Because all households are different and looking for different things out of their solar and battery system this study will look at 4 different optimisation factors, as listed below.

1. Net Present Cost
2. Payback Period
3. Savings
4. Peak Leveling

The first 3 looks at different ways of financially optimizing the system and the last looks at optimizing the system from an electrical viewpoint.

For all of the following tests the direction of the panels was north and it was installed at its ideal angle.

a. Net Present Cost

Net Present Cost is the cost of the system over its lifetime taking into account interest rates. In this study the system's life is set to 10 years. It was decided to have a system life of 10 years because the length of the warranty of the lithium-ion batteries was 10 years and after 10 years it is more then likely that solar panels would need some maintenance to keep them running at their peak.

This is something that has not been included in the model at this time. Table 15 to Table 17 show the best net present cost for the location of Toowoomba, Sydney and Adelaide at their relevant tariff prices, all at an interest of 1% which is equal to Australia's current cash rate.

Table 15 – NPC Toowoomba (-27.56, 151.95) Tariff 0.25298

kWh/week	Solar size kW	Net Present Cost
200	10	$18,131.42
160	10	$14,509.44
125	10	$11,434.91
100	10	$9.266.88
75	10	$7,185.63

Table 16 - NPC Sydney (-33.85, 151.22) Tariff 0.331118

kWh/week	Solar size kW	Battery	Net Present Cost
200	10	3X 6XBAE PVV 550	$20,259.36
160	10		$17,488.39
125	10		$13,620.25
100	10		$10,910.40
75	10		$8,361.12

Table 17 - NPC Adelaide (-34.93, 138.60) Tariff 0.428816

kWh/week	Solar size kW	Battery	Net Present Cost
200	10	3X 6XBAE PVV 550	$20,508.43
160	10	3X 6XBAE PVV 550	$18,361.26
125	10		$16,031.36
100	10		$12,796.30
75	10		$9,661.85

Across all locations and house size a solar system size of 10 kW is optimum. The feed-in tariff was kept the same for all locations, at $0.07842/kWh. As can be seen because of the high tariff prices in Sydney and Adelaide it became viable based on the net present cost to invest in the smallest and cheapest of the batteries in the model. It should be noted however that this battery did only have a 3-year warranty and the model currently assumes the battery will last 10 years. With a warranty under 10 years, it is more than likely replacement or repair of the battery would be needed. This extra cost is not currently included in the model. If included it would be expected that a system without a battery would be the most viable based on net present cost. This does show however if power prices do increase in the future and battery prices drop, adding a battery to your solar system will become more viable.

b. Payback Period

The payback period is the time it would take to pay back the cost of the system with the savings made from its installation. In the model the payback period is calculated as follows:

$$Payback\ (years) = \frac{Cost}{yearly\ savings} \tag{5.2.1}$$

Table 18 to Table 20 show the minimum payback period for the same locations used above.

Table 18 – Payback Period Toowoomba (-27.56, 151.95) Tariff 0.25298

kWh/week	Solar size	Years
200	5	3.8
160	5	4.18
125	5	4.65
100	5	5.05
75	5 3	5.53 6.03

Table 19- Payback Period Sydney (-33.85, 151.22) Tariff 0.331118

kWh/week	Solar size	Years
200	3	2.98
160	3	3.36
125	5	3.83
100	5	4.23
75	5 3	4.72 4.94

Table 20 - Payback Period Adelaide (-34.93, 138.60) Tariff 0.428816

kWh/week	Solar size	Years
200	3	2.32
160	3	2.63
125	3	3.03
100	3	3.44
75	5 3	3.96 4.01

The 75 kWh/week bracket shows the 3 and 5 kW solar systems to show how close the payback periods are, about half a year at the most. This is a very different result to the net present cost optimisation which favoured the biggest solar system. The payback period optimisation favours a mid-range solar system with the inclusion of a battery doubling the payback period on average. This is reflective of the prices for solar systems listed in Table 9 shown earlier. The Lead-Acid batteries that only had 3 years warranty struggled to have the system with their inclusion paid back under 4 years short of their 3-year warranty. A solar system of under 2 kW when paired with lithium-ion were not able to pay back the system in under 10 years, the length of the lithium-ion battery warranty.

c. Savings

Optimisation based on saving looks at achieving the largest savings in dollars compared to the households original energy costs. This is for a household that is not concerned with how much the system is going to cost. Table 21 to Table 23 show the maximum savings for the different locations used above.

Table 21 - Savings Toowoomba (-27.56, 151.95) Tariff 0.25298

kWh/week	Solar size kW	Battery	Savings per Year
200	10	>15kWh	$2,788.33
160	10	>10kWh	$2,539.49
125	10	>9kWh	$2,270.50
100	10	>6.6kWh	$2,051.83
75	10	>5kWh	$1,832.70

Table 22 - Savings Sydney (-33.85, 151.22) Tariff 0.331118

kWh/week	Solar size kW	Battery	Savings per Year
200	10	>15kWh	$3,655.78
160	10	>10kWh	$3,166.44
125	10	>9kWh	$2,737.01
100	10	>6.6kWh	$2,429.71
75	10	>5kWh	$2,120.72

Table 23- Savings Adelaide (-34.93, 138.60) Tariff 0.428816

kWh/week	Solar size kW	Battery	Savings per Year
200	10	>15kWh	$4,622.17
160	10	>10kWh	$3,943.65
125	10	>9kWh	$3,349.60
100	10	>6.6kWh	$2,921.89
75	10	>5kWh	$2,493.11

To get the maximum savings the largest solar system is needed so that the greatest generation is achieved. Also, the purchase of energy needs to minimize. To minimize this a battery large enough to supply the energy need of the household outside of solar generation hours is needed. The optimum solution for each location was the same as it is not dependent on tariff price or solar radiation. The amount saved per year did change in the different locations but the system components were the same. Like in the net present cost optimisation the 10 kW solar system was that best.

d. Peak Leveling

Peak levelling looks at achieving the closest to flatline as possible for the load profile. Figure 32 shows an example of peak levelling on a 200kWh per week household using solar and battery.

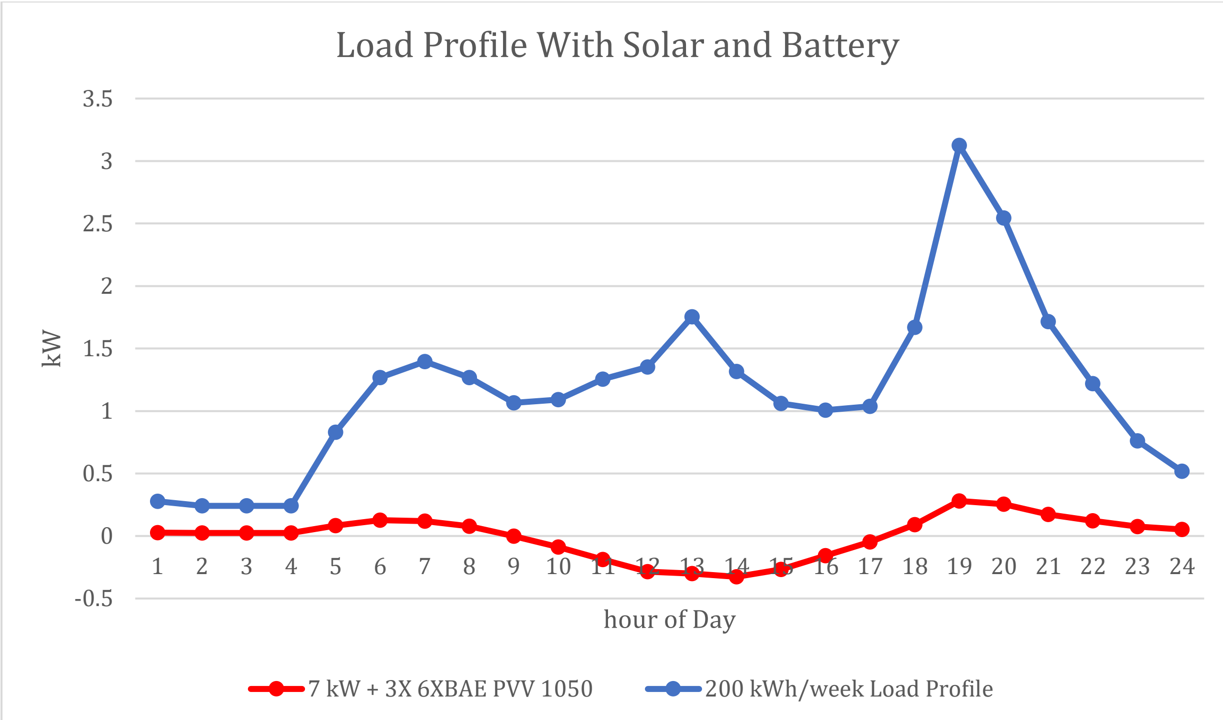


Figure 32 - Peak Leveling Example

The difference between the high point and the low point is now only 0.61 kW instead of 2.847kW on the original load profile. This levelling puts the less amount of stress on the grid as it does not have to quickly ramp up and ramp down production. Table 24 to Table 26 show the optimized results for peak levelling.

Table 24 – Peak Leveling Toowoomba (-27.56, 151.95) Tariff 0.25298

kWh/week	Solar size kW	Battery	Load difference (kW)
200	7	3x 6xBAE PVV 1050	0.62
160	4	LG Chem 9.8kWh	1.05
125	4	LG Chem 9.8kWh	0.8
100	3	LG Chem 9.8kWh	0.66
75	3	2x 6xBAE PVV 1050	0.26

Table 25 - Peak Leveling Sydney (-33.85, 151.22) Tariff 0.331118

kWh/week	Solar size kW	Battery	Load difference (kW)
200	7	3x 6xBAE PVV 1050	0.62
160	4	LG Chem 9.8kWh	1.03
125	4	LG Chem 9.8kWh	0.77
100	3	LG Chem 9.8kWh	0.66
75	3	2x 6xBAE PVV 1050	0.26

Table 26 - Peak Leveling Adelaide (-34.93, 138.60) Tariff 0.428816

kWh/week	Solar size kW	Battery	Load difference (kW)
200	7	3x 6xBAE PVV 1050	0.61
160	4	LG Chem 9.8kWh	1.09
125	4	LG Chem 9.8kWh	0.67
100	3	LG Chem 9.8kWh	0.68
75	2	2x 6xBAE PVV 1050	0.25

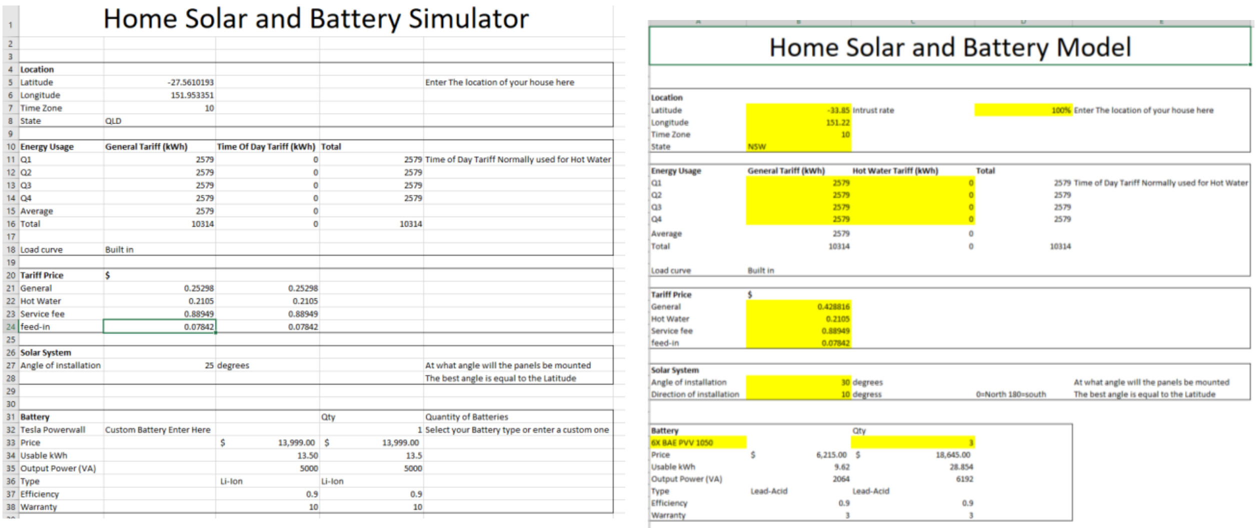
This optimisation criterion created the most variation between households. In this criteria there is more of a balancing act between the solar battery and load. Too much generation and the load profile drops below the 0 lines and the household is sent energy back into the grid increasing their load difference. Too small a solar system and the household will not generate enough to cover the peak period at night. If the battery selected is too small then the energy generated will not be able to be captured and used later during peak times.

6. Conclusions

1. Summary of Outcomes

One of the main objectives of this project was to create a model that a household could use to determine the best solar and battery storage system for them. After review of the model created in excel against professional software Homer Pro in the excel model comparison section it was determined that the excel model created came very close to the Homer Pro simulation results. Homer Pro does run 1000s of simulations and averages the results, this resulted in more gentler curves shown in Figure 28 to Figure 31 compared to the steeper curves from the excel model. After review of the differences between the Homer Pro and excel model it was found that there was an average error of just under 2%. And when the cost over a year was calculated the difference was only $7.

Over the length of the project continual review and improvement of the model has been conducted. One of the most notable has been the user interface where the layout was simplified and highlighted sections added to show the user were to enter their information (Figure 33).



	Home Solar and Battery Simulator				
1					
2					
3					
4	**Location**				
5	Latitude	-27.5610193			Enter The location of your house here
6	Longitude	151.953351			
7	Time Zone	10			
8	State	QLD			
9					
10	**Energy Usage**	**General Tariff (kWh)**	**Time Of Day Tariff (kWh)**	**Total**	
11	Q1	2579	0	2579	Time of Day Tariff Normally used for Hot Water
12	Q2	2579	0	2579	
13	Q3	2579	0	2579	
14	Q4	2579	0	2579	
15	Average	2579	0		
16	Total	10314	0	10314	
17					
18	Load curve	Built in			
19					
20	**Tariff Price**	$			
21	General	0.25298	0.25298		
22	Hot Water	0.2105	0.2105		
23	Service fee	0.88949	0.88949		
24	feed-in	0.07842	0.07842		
25					
26	**Solar System**				
27	Angle of installation	25	degrees		At what angle will the panels be mounted
28					The best angle is equal to the Latitude
29					
30					
31	**Battery**			Qty	Quantity of Batteries
32	Tesla Powerwall	Custom Battery Enter Here		1	Select your Battery type or enter a custom one
33	Price		$ 13,999.00	$ 13,999.00	
34	Usable kWh		13.50	13.5	
35	Output Power (VA)		5000	5000	
36	Type		Li-Ion	Li-Ion	
37	Efficiency		0.9	0.9	
38	Warranty		10	10	

Home Solar and Battery Model					
Location					
Latitude	-33.85	Intrust rate		100%	Enter The location of your house here
Longitude	151.22				
Time Zone	10				
State	NSW				
Energy Usage	**General Tariff (kWh)**	**Hot Water Tariff (kWh)**	**Total**		
Q1	2579	0		2579	Time of Day Tariff Normally used for Hot Water
Q2	2579	0		2579	
Q3	2579	0		2579	
Q4	2579	0		2579	
Average	2579	0			
Total	10314	0		10314	
Load curve	Built in				
Tariff Price	$				
General	0.428816				
Hot Water	0.2105				
Service fee	0.88949				
feed-in	0.07842				
Solar System					
Angle of installation	30	degrees			At what angle will the panels be mounted
Direction of installation	10	degress	0=North 180=south		The best angle is equal to the Latitude
Battery		Qty			
6X BAE PVV 1050		3			
Price	$ 6,215.00	$ 18,645.00			
Usable kWh	9.62	28.854			
Output Power (VA)	2064	6192			
Type	Lead-Acid	Lead-Acid			
Efficiency	0.9	0.9			
Warranty	3	3			

Figure 33 - User Interface Comparison

The University of Southern Queensland project conference, which ran on September 2019, was also a good opportunity to receive some feedback on the project. It was brought to my attention that I had not included the direction of installation of the solar panels only the angle and assumed the panel was always facing north. Because of this feedback, I was able to include this into the model this and can be seen in section 4.1 Solar Modelling (page 30). More work still can be done to improve the models' performance and accuracy, these areas will be highlighted below under further work.

The other key objective of the project was to find an optimized solution for different sized household loads across Australia. Initially, the project intention was to optimize based on one set of criteria but it was decided to expand the project to optimize solar and battery storage to several criteria. As all households have different budgets and needs for their energy generation it was felt that this would be inclusive of more Australia households. The solar and battery storage systems were optimized for the net present cost (NPC), payback period, savings and peak levelling and all are coved in section 5.2 Optimisation (page **Error! Bookmark not defined.**). The summary of the results is as follows:

Optimisation due to NPC found that the largest solar system size tested of 10kW was the optimum system across all locations tested. Location with higher tariffs like Sydney and Adelaide did find, on a household with high demand, (greater than 160kWh/week) that the cheapest battery option did become more cost-effective than a system without a battery.

Payback period optimisation found that 5 to 3 kWh solar systems were the fastest to payback. The difference between the 5 to 3 kWh systems was only about half a year in the payback period.

Savings optimisation also found that a 10kWh solar system was the best for all load sizes and locations. This time however a battery was included in all solution with the size of the battery varying form greater then 15kWh for a 200kWh/week load down to 5kWh for a 75kWh/week load.

Peek levelling optimisation found the greatest very variation in system types across load sizes. Results where relative similar across locations with the Adelaide 75kWh/week load the only variation to the other location requiring a 2 kW solar system instead of a 3kW. All system required a battery of some type in order to achieve the best levelling. The solar system size varied from 7kWh for a 200kWh/week load down to 3 or 2kWh for a 75kWh/week load.

2. Further Work

Up until this point, the excel model has only been compared against Homer Pro that only simulates the performance of solar and battery storage systems. The fact the excel model came very close to the same predictions that Homer Pro did, a professional-grade software is promising. It also indicates that this excel model could come close to real-world results. Homer Pro is one of the most widely used software tools in the industry for evaluating microgrid projects (Sinha & Chandel 2014), So it would be expected that its results are close to that seen in the real world.

Some features that could be included in the model in the future are individual modelling of solar generation for each quarter of the year. Each quarter has different weather conditions that affect the load and the generation from solar. Currently, the model does ask the user to provide useful information for each quarter. But this is then just averaged out to find an average load profile for the year. A solar generation profile is found using the average sunset and sunrise times for the year giving a yearly average generation profile.

The direction of the panel will also affect the timing of the generation profile. A panel that is facing east will see the sun before a panel facing more west. This will mean an east-facing panel will start generating before a west-facing panel. Currently, the model does take into consideration the efficacy drop due to direction of installation but it does not take into consideration the effect on the timing of the generation profile This is something that could be worked on in the future. It would also be interesting to see what effect this had on the optimized solution. A west-facing panel could see peak generation shifted later in the day closer to peak usage.

The effect of age is also something that could be worked on in the future. As solar panels age, they will becomes less and less effective and the same is true for batteries. They will not just stop working as soon as they hit the end of their warranty period. Being able to slowly decrease the efficacy of component over their life and past their warranty would be a good addition to the model. There are also some financial factors that could be added to the model in the future. A simple inclusion would be to allow extra labour and installation cost. Every house is different so it is more than likely that labour and resources, like cable, will vary from house to house.

It would also be good if the model could include an allowance for rebates and other government programs. Nationally the federal government runs the Small-Scale Renewable Energy Scheme SRES (Clean Energy Council 2018). The SRES award households small-scale technology certificates (STC) that then can be sold. The price of STC is based on supply and demand-driven market. Being able to predict the sale price of STCs in the excel model would be a challenge but something that could be looked into in the future.

With changes in technology and prices of components continually changing the model would have to be continually updated in the future to keep it up to date and relevant.

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Appendix A

Project Specification Version 1

ENG4111/4112 Research Project

Project Specification

For: Peter Becker

Title: Optimisation of battery and Solar on a house

Major: Power

Supervisor: Paul Wen

Enrolment: ENG4111 on campus S1 2019

ENG4112 on campus S1 2019

Project Aim: To develop equations to determine the optimum battery and solar set up for different types of houses in different locations across Australia.

Programme: Version 1 , 1/5/2019

1. Review existing data on solar and battery to determine the factors contributing to their efficiency (environmental, installation, Tariffs etc.)
2. Examine the relevant standard to see how they may impact solar and battery performance.
3. Use Homer software to evaluate different kind of houses, locations and solar and battery setups.
4. Use Mathlab software and previously collected data from review and Homer to develop equations for determining optimum battery and solar setup.
5. Use created equations to create an excel document that could be easily used by people to determine the optimum setup for their house.
6. Test Excel document against Homer using own house to see if the excel document gives the optimum solution.

If time and resources permit:

7. Gather data from a number of real houses to get a better view of how accurate excel document is.
8. Review the excel document and make changes to improve its accuracy based on previous results.

Project Specification Version 2

ENG4111/4112 Research Project

Project Specification

For:	Peter Becker
Title:	Home based Solar and Battery Optimisation
Major:	Power
Supervisor:	Paul Wen
Enrolment:	ENG4111 on campus S1 2019
	ENG4112 on campus S2 2019
Project Aim:	To develop equations to determine the optimum battery and solar set up for different types of houses in different locations across Australia.
Programme:	**Version 2 , 2/10/2019**

1. Review existing data on solar and battery to determine the factors contributing to their efficiency (environmental, installation, Tariffs etc.)
2. Examine the relevant standard and literature to see how different factors may impact solar and battery performance.
3. Use Homer software to evaluate different kind of houses, locations and solar and battery setups.
4. Use Mathlab software and previously collected data from review and Homer to develop equations for determining optimum battery and solar setup.
5. Use created equations to create an excel document that could be easily used by people to determine the optimum setup for their house.
6. Compare Excel document against Homer to see if the excel document is performing correctly.
7. Find and optimize the solution for different sized household loads across Australia

If time and resources permit:

8. Gather data from a number of real houses to get a better view of how accurate excel document is.
9. Review the excel document and make changes to improve its accuracy and performance.

Appendix B

1. Resources

- Homer Pro Software (Z-block computers)
- Computer and Internet Access

I have organized with university security to have access to Z-block computers on level 3 after hours

2. Risk Assessment

The project will all be done using simulations through computer software so there is no major safety risk like would be seen with real electrical work. Mostly risk I will encounter as listed in the table below along with their control measure.

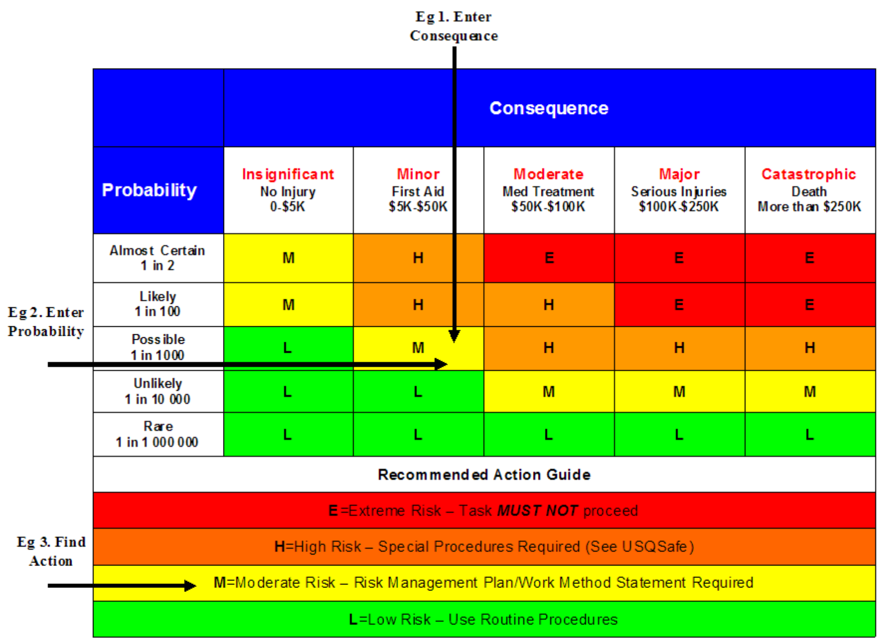

Figure 34- Risk Assessment Matrix (University of Southern Queensland 2018)

Risk/Hazard	Risk Assessment			Control
	Consequence	Probability	Rating	
Not Finishing the project on time	Fail and re-enrol (Minor)	Possible	Moderate	Developed Methodology and project timeline to keep me on track
Unable to access software	Fail and re-enrol (Minor)	Unlikely	Low	Needed software is available on all computers in Z-block it is unlikely this will change during the year
Loss of Data	Fail and re-enrol (Minor)	Possible	Moderate	Have data saved in 3 locations (USB, Laptop, Google Drive) and back up once a week or at the completion of a major task

3. Project Timeline

I am currently running on time I feel but I feel I could do with a little bit of a buffer next Semester. I will be doing 3 subject plus my project. My exams for semester 1 end up being early in the exam block so I will start back on project work sooner than expected and hopefully I can give myself at least a 1-week buffer. My timeline is below

Phase 1	**Preparation**
1A	*Literature Review*
1B	Project Specification
1C	Resource Check
1D	Progress Report
Phase 2	**Simulation and Equation Creation**
2A	Run Simulations with Homer with different housing types and locations. Collected and evaluate the results
2B	Use Matlab to create optimisation equations and test against homer results
2C	Use equations to develop excel document
2D	Test excel document homer using own house as a reference and evaluate the accuracy
Phase 3	**Dissertation**
3A	Write up draft dissertation and submit for supervisor review and feedback.
3B	Attend Project Conference at University and present current results.
3C	Write up final dissertation with supervisor feedback and get proofread by a family member
3D	Get dissertation Printed and submitted

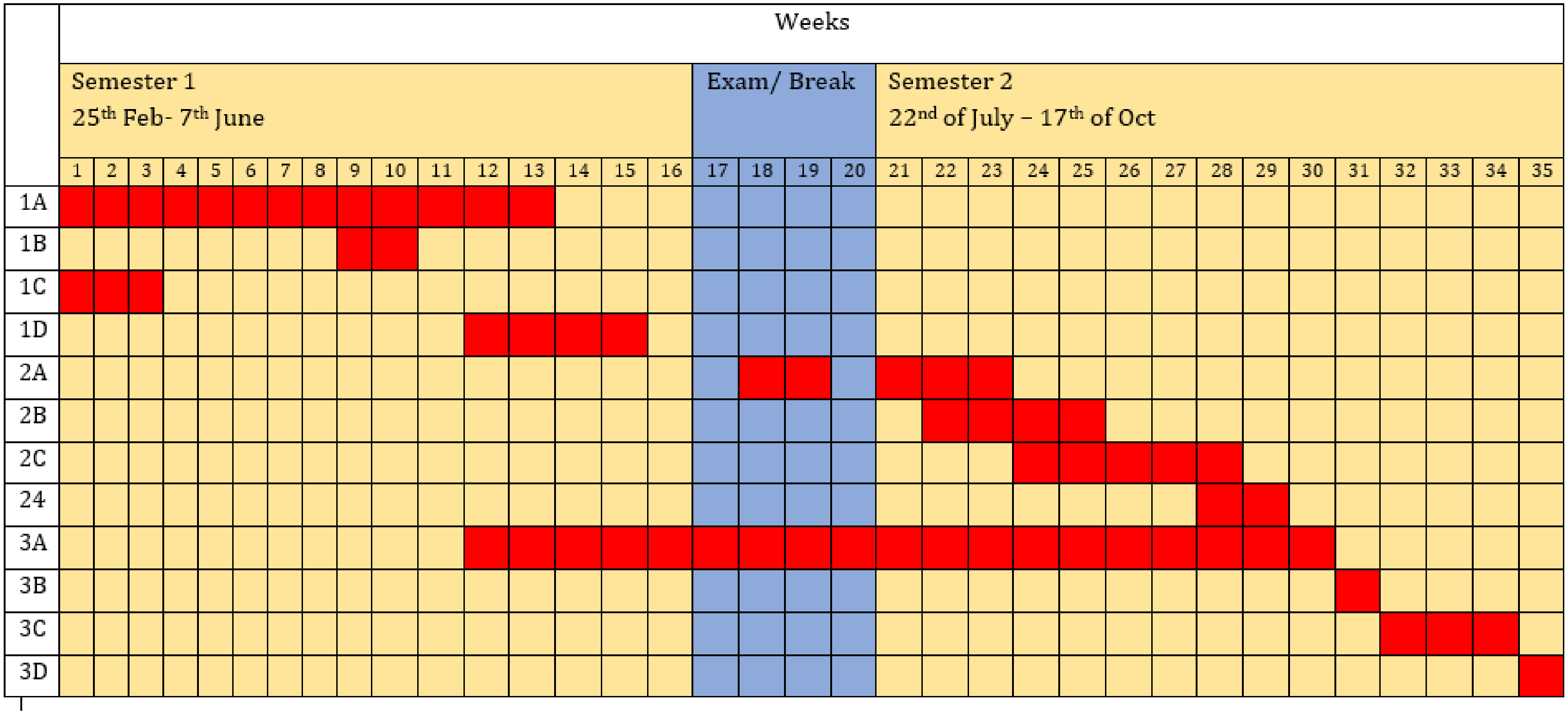

Figure 35 - Project Timeline

Appendix C – Raw Data

Table 27 - Solar Generation Homer Pro data

Lat	Long	Mean Output	Mean Output	Production	Max Output	Hours of Op
		kW	kWh/d	kWh/yr	kW	hrs/yr
-15	145	0.183	4.4	1606	0.795	4355
-20	145	0.189	4.54	1656	0.824	4402
-25	145	0.189	4.54	1656	0.824	4402
-30	145	0.185	4.43	1617	0.842	4384
-35	145	0.175	4.19	1530	0.867	4376
-40	145	0.161	3.86	1409	0.87	4374
-43	147	0.139	3.33	1215	0.882	4372
-25	150	0.182	4.36	1593	0.82	4383
-30	150	0.184	4.42	1614	0.848	4375
-35	150	0.158	3.79	1384	0.853	4372
-20	140	0.188	4.51	1645	0.789	4368
-25	140	0.175	4.21	1537	0.808	4382
-30	140	0.173	4.14	1512	0.834	4378
-35	140	0.168	4.04	1473	0.858	4375
-15	135	0.183	4.38	1600	0.786	4324
-20	135	0.188	4.52	1650	0.797	4348
-25	135	0.191	4.58	1672	0.827	4361
-30	135	0.183	4.38	1600	0.84	4409
-35	135	0.173	4.16	1518	0.855	4372

-15	130	0.179	4.3	1569	0.78	4402
-20	130	0.192	4.61	1682	0.799	4412
-25	130	0.19	4.57	1668	0.834	4378
-30	130	0.187	4.48	1636	0.845	4373
-15	125	0.191	4.59	1675	0.779	4379
-20	125	0.185	4.44	1621	0.782	4368
-25	125	0.193	4.64	1693	0.814	4382
-30	125	0.186	4.48	1634	0.814	4370
-20	120	0.202	4.85	1770	0.788	4402
-25	120	0.195	4.68	1707	0.826	4383
-30	120	0.19	4.55	1662	0.849	4375
-35	120	0.171	4.11	1500	0.857	4372
-20	115	0.203	4.87	1779	0.804	4357
-25	115	0.19	4.55	1660	0.819	4402
-30	115	0.177	4.24	1549	0.85	4384

Table 28 - Solar Model Coefficients

	p	p_{10}	p_{01}	p_{20}	p_{11}	p_{02}	p_{30}
Mean Output kW	-51.98191984	0.325776	1.651602	-0.00553	-0.00907	-0.01961	1.52E-06
Mean output kWh/d	-1252.066161	8.095172	39.78788	-0.13186	-0.22316	-0.47233	-3.05E-05
Production kWh/yr	-444504.3912	2981.471	14149.04	-46.5964	-81.432	-168.162	-0.00773
Max Output kW	27.38089499	-0.21581	-0.82173	0.008209	0.008065	0.009792	4.41E-05
Hours of Op hrs/yr	-112479.5058	-2472.72	3051.845	16.37763	63.0182	-28.3016	0.071256

	yp_{21}	p_{12}	p_{03}	p_{40}	p_{31}	p_{22}	p_{13}	p_{04}
Mean Output kW	8.19E-05	8.02E-05	0.000103	-1.01E-07	-9.91E-08	-3.34E-07	-2.34E-07	-2.04E-07
Mean output kWh/d	0.001911	1.95E-03	0.002488	-2.81E-06	-2.23E-06	-7.78E-06	-5.64E-06	-4.91E-06
Production kWh/yr	0.676995	0.708379	0.886721	-0.00098	-0.0008	-0.00276	-0.00204	-0.00175
Max Output kW	-9.62E-05	-8.01E-05	-5.29E-05	1.45E-07	-1.57E-07	3.25E-07	2.46E-07	1.09E-07
Hours of Op hrs/yr	-0.20495	-0.51901	0.10746	-0.0006	-0.00102	0.000464	0.001369	-0.00013

Table 29 - Solar Production in kWh per year at different angles of installation

Latitude	10	15	20	25	30	35	40	45
Angle								
0	1514.066	1570.691	1570.691	1557.452	1464.777	1377.281	1179.891	1038.96
5	1528.019	1603.437	1603.437	1597.956	1510.104	1420.766	1223.068	1077.782
10	1533.83	1627.579	1627.579	1629.641	1545.457	1456.302	1258.587	1111.029
15	1531.565	1643.071	1643.071	1652.489	1571.848	1484.019	1286.808	1138.298
20	1521.313	1650.067	1650.067	1666.602	1589.568	1504.102	1308.09	1159.66
25	1503.345	1648.607	1648.607	1671.781	1598.855	1516.855	1322.627	1175.175
30	1477.993	1638.809	1638.809	1667.987	1599.991	1521.798	1330.797	1185.021
35	1445.176	1620.64	1620.64	1655.529	1593.051	1518.384	1332.557	1189.442
40	1405.09	1594.058	1594.058	1634.516	1578.177	1506.958	1327.598	1188.276
45	1357.97	1559.1	1559.1	1604.923	1555.373	1487.667	1315.992	1181.245
50	1303.98	1515.954	1515.954	1566.809	1524.604	1461.141	1297.839	1168.255
60	1179.513	1408.245	1408.245	1467.164	1439.474	1388.122	1243.899	1125.215
65	1109.257	1343.409	1343.409	1406.637	1386.632	1341.319	1208.436	1096.209
70	1036.086	1271.643	1271.643	1338.773	1327.027	1287.69	1167.148	1062.306
75	961.2585	1195.045	1195.045	1263.98	1260.556	1227.289	1120.102	1023.393
80	892.0576	1113.524	1113.524	1184.427	1187.6	1161.682	1067.349	979.5413
85	828.6274	1030.671	1030.671	1100.01	1110.304	1091.103	1010.162	930.8016
90	768.8203	953.4847	953.4847	1014.496	1028.551	1015.223	948.7693	878.3253

Table 30 - Solar Performance at different directions

Bearing	Production kWh
180	1070.121
190	1077.042
200	1097.391
210	1126.535
220	1162.418
230	1202.901
240	1247.263
250	1293.012
260	1339.455
270	1384.721
280	1427.415
290	1467.257
300	1504.223
310	1535.344
320	1562.37
330	1585.64
340	1599.98
350	1609.676
0	1614.086
10	1608.865
20	1598.868
30	1584.132
40	1560.337
50	1532.391
60	1500.905
70	1463.745
80	1423.535
90	1380.944
100	1335.831
110	1289.313
120	1243.632
130	1199.303
140	1158.739
150	1123.097
160	1095.005
170	1075.824

Appendix D – Excel Formula

The full excel document can be found at this URL

https://1drv.ms/x/s!AoUyLRZqySpfkkDbtU1Xx_Cn0Wng?e=8dTarI

Below is a copy of some of the formula used in the excel model

Table 31 - User Input Screen Formula

Home Solar and Battery Model

Location				
Latitude	-33.85	Intrust rate	0.01	Enter The location of your house here
Longitude	151.22			
Time Zone	10			
State	NSW			

Energy Usage	General Tariff (kWh)	Hot Water Tariff (kWh)	Total	
				Time of Day Tariff Normally used for Hot Water
Q1	=(200/7)*90.25	0	=SUM(B11:C11)	
Q2	=B11	0	=SUM(B12:C12)	
Q3	=B12	0	=SUM(B13:C13)	

Q4	=B13	0	=SUM(B14:C14)
Average	=AVERAGE(B11:B14)	=AVERAGE(C11:C14)	
Total	=SUM(B11:B14)	=SUM(C11:C14)	=SUM(B16:C16)
Load curve	Built in		

Tariff Price	**$**
General	0.428816
Hot Water	0.2105
Service fee	0.88949
feed-in	0.07842

Solar System				
Angle of installation	30	degrees		At what angle will the panels be mounted
Direction of installation	10	degress	0=North 180=south	The best angle is equal to the Latitude

Battery		Qty
LG Chem 9.8kWh		1
Price	=IF(BT=Battery!$B$1,Battery!B2,IF(BT=Battery!$C$1,Battery!C2,IF(BT=Battery!$D$1,Battery!D2,IF(BT=Battery!$E$1,Battery!E2,IF(BT=Battery!$F$1,Battery!F2,IF(BT=Battery!$G$1,Battery!G2))))))	=B33*$C$32
Usable kWh	=IF(BT=Battery!$B$1,Battery!B4,IF(BT=Battery!$C$1,Battery!C4,IF(BT=Battery!$D$1,Battery!D4,IF(BT=Battery!$E$1,Battery!E4,IF(BT=Battery!$F$1,Battery!F4,IF(BT=Battery!$G$1,Battery!G4))))))	=B34*$C$32
Output Power (VA)	=IF(BT=Battery!$B$1,Battery!B5,IF(BT=Battery!$C$1,Battery!C5,IF(BT=Battery!$D$1,Battery!D5,IF(BT=Battery!$E$1,Battery!E5,IF(BT=Battery!$F$1,Battery!F5,IF(BT=Battery!$G$1,Battery!G5))))))	=B35*$C$32
Type	=IF(BT=Battery!$B$1,Battery!B6,IF(BT=Battery!$C$1,Battery!C6,IF(BT=Battery!$D$1,Battery!D6,IF(BT=Battery!$E$1,Battery!E6,IF(BT=Battery!$F$1,Battery!F6,IF(BT=Battery!$G$1,Battery!G6))))))	=B36
Efficiency	=IF(BT=Battery!$B$1,Battery!B7,IF(BT=Battery!$C$1,Battery!C7,IF(BT=Battery!$D$1,Battery!D7,IF(BT=Battery!$E$1,Battery!E7,IF(BT=Battery!$F$1,Battery!F7,IF(BT=Battery!$G$1,Battery!G7))))))	=B37
Warranty	=IF(BT=Battery!$B$1,Battery!B8,IF(BT=Battery!$C$1,Battery!C8,IF(BT=Battery!$D$1,Battery!D8,IF(BT=Battery!$E$1,Battery!E8,IF(BT=Battery!$F$1,Battery!F8,IF(BT=Battery!$G$1,Battery!G8))))))	=B38

Table 32 - Results Screen Formula

Results

	Solar Generation				Battery		
kW	kWh/Day	Mean output kW	Grid (kWh/day)	Feed-in (kWh/day)	High-Low	Grid (kWh/day)	Feed in (kWh/day)
1.5	=Solar!Y16	=Solar!AB16	=Load!V$259	=Load!V$261	=Load!V$265	=Load!V$246	=Load!V$249
2	=Solar!Y17	=Solar!AB17	=Load!X$259	=Load!X$261	=Load!X$265	=Load!X$246	=Load!X$249
3	=Solar!Y18	=Solar!AB18	=Load!Z$259	=Load!Z$261	=Load!Z$265	=Load!Z$246	=Load!Z$249
4	=Solar!Y19	=Solar!AB19	=Load!AB$259	=Load!AB$261	=Load!AB$265	=Load!AB$246	=Load!AB$249
5	=Solar!Y20	=Solar!AB20	=Load!AD$259	=Load!AD$261	=Load!AD$265	=Load!AD$246	=Load!AD$249
7	=Solar!Y21	=Solar!AB21	=Load!AF$259	=Load!AF$261	=Load!AF$265	=Load!AF$246	=Load!AF$249
10	=Solar!Y22	=Solar!AB22	=Load!AH$259	=Load!AH$261	=Load!AH$265	=Load!AH$246	=Load!AH$249

	Cost		Payback (Years)		Payback (Years)		
kW	Solar	Battery	Solar only	NPC (10 years)	Solar and Battey	NPC (10 years)	
1.5	=IF($B$8=Solar!$S$4,Solar!S5,IF($B$8=Solar!$T$4,Solar!T5,IF($B$8=Solar!$U$4,Solar!U5,IF($B$8=Solar!$V$4,Solar!V5,IF($B$8=Solar!$W$4,Solar!W5,IF($B$8=Solar!$X$4,Solar!X5,IF($B$8=Solar!$Y$4,Solar!Y5,IF($B$8=Solar!$Z$4,Solar!Z5,0))))))))	=$C$33	=I17/$K$27	=$I17+J27*'Discount	=(I17+J17)/N27	=$I17+$J17+M27*'Discount	

				Rate'!$B$14		Rate'!$B$14	
2	=IF($B$8=Solar!$S$4,Solar!S6,IF($B$8=Solar!$T$4,Solar!T6,IF($B$8=Solar!$U$4,Solar!U6,IF($B$8=Solar!$V$4,Solar!V6,IF($B$8=Solar!$W$4,Solar!W6,IF($B$8=Solar!$X$4,Solar!X6,IF($B$8=Solar!$Y$4,Solar!Y6,IF($B$8=Solar!$Z$4,Solar!Z6,0))))))))	=$C$33	=I18/$K$28	=$I18+J28*'Discount Rate'!$B$14	=(I18+J18)/N28	=$I18+$J18+M28*'Discount Rate'!$B$14	
3	=IF($B$8=Solar!$S$4,Solar!S7,IF($B$8=Solar!$T$4,Solar!T7,IF($B$8=Solar!$U$4,Solar!U7,IF($B$8=Solar!$V$4,Solar!V7,IF($B$8=Solar!$W$4,Solar!W7,IF($B$8=Solar!$X$4,Solar!X7,IF($B$8=Solar!$Y$4,Solar!Y7,IF($B$8=Solar!$Z$4,Solar!Z7,0))))))))	=$C$33	=I19/$K$29	=$I19+J29*'Discount Rate'!$B$14	=(I19+J19)/N29	=$I19+$J19+M29*'Discount Rate'!$B$14	
4	=IF($B$8=Solar!$S$4,Solar!S8,IF($B$8=Solar!$T$4,Solar!T8,IF($B$8=Solar!$U$4,Solar!U8,IF($B$8=Solar!$V$4,Solar!V8,IF($B$8=Solar!$W$4,Solar!W8,IF($B$8=Solar!$X$4,Solar!X8,IF($B$8=Solar!$Y$4,Solar!Y8,IF($B$8=Solar!$Z$4,Solar!Z8,0))))))))	=$C$33	=I20/$K$30	=$I20+J30*'Discount Rate'!$B$14	=(I20+J20)/N30	=$I20+$J20+M30*'Discount Rate'!$B$14	
5	=IF($B$8=Solar!$S$4,Solar!S9,IF($B$8=Solar!$T$4,Solar!T9,IF($B$8=Solar!$U$4,Solar!U9,IF($B$8=Solar!$V$4,Solar!V9,IF($B$8=Solar!$W$4,Solar!W9,IF($B$8=Solar!$X$4,Solar!X9,IF($B$8=Solar!$Y$4,Solar!Y9,IF($B$8=Solar!$Z$4,Solar!Z9,0))))))))	=$C$33	=I21/$K$31	=$I21+J31*'Discount Rate'!$B$14	=(I21+J21)/N31	=$I21+$J21+M31*'Discount Rate'!$B$14	
7	=IF($B$8=Solar!$S$4,Solar!S10,IF($B$8=Solar!$T$4,Solar!T10,IF($B$8=Solar!$U$4,Solar!U10,IF($B$8=Solar!$V$4,Solar!V10,IF($B$8=Solar!$W$4,Solar!W10,IF($B$8=Solar!$X$4,Solar!X10,IF($B$8=Solar!$Y$4,Solar!Y10,IF($B$8=Solar!$Z$4,Solar!Z10,0))))))))	=$C$33	=I22/$K$32	=$I22+J32*'Discount Rate'!$B$14	=(I22+J22)/N32	=$I22+$J22+M32*'Discount Rate'!$B$14	
10	=IF($B$8=Solar!$S$4,Solar!S11,IF($B$8=Solar!$T$4,Solar!T11,IF($B$8=Solar!$U$4,Solar!U11,IF($B$8=Solar!$V$4,Solar!V11,IF($B$8=Solar!$W$4,Solar!W11,IF($B$8=Solar!$X$4,Solar!X11,IF($B$8=Solar!$Y$4,Solar!Y11,IF($B$8=Solar!$Z$4,Solar!Z11,0))))))))	=$C$33	=I23/$K$33	=$I23+J33*'Discount Rate'!$B$14	=(I23+J23)/N33	=$I23+$J23+M33*'Discount Rate'!$B$14	

	Energy Cost	**Solar**			**Solar and Battery**		
kW	Original	Yearly	Saving	Cost per kWh	Yearly	Savings	Cost per kWh
1.5	=((D16*(B16/D16))*B21)+((D16*(C16/D16))*B22)+B23*365	=(((K6*365*($B$16/$D$16))*$B$21)+((K6*($C$16/$D$16))*$B$22)+$B$23*365)+(L6*$B$24*365)	=I27-J27	=L17/($B$16*10)	=(((N6*365*($B$16/$D$16))*$B$21)+((N6*365*($C$16/$D$16))*$B$22)+$B$23*365)+(O6*$B$24*365)	=I27-M27	=N17/($B$16*10)
2	=I27	=(((K7*365*($B$16/$D$16))*$B$21)+((K7*($C$16/$D$16))*$B$22)+$B$23*365)+(L7*$B$24*365)	=I28-J28	=L18/($B$16*10)	=(((N7*365*($B$16/$D$16))*$B$21)+((N7*365*($C$16/$D$16))*$B$22)+$B$23*365)+(O7*$B$24*365)	=I28-M28	=N18/($B$16*10)
3	=I28	=(((K8*365*($B$16/$D$16))*$B$21)+((K8*($C$16/$D$16))*$B$22)+$B$23*365)+(L8*$B$24*365)	=I29-J29	=L19/($B$16*10)	=(((N8*365*($B$16/$D$16))*$B$21)+((N8*365*($C$16/$D$16))*$B$22)+$B$23*365)+(O8*$B$24*365)	=I29-M29	=N19/($B$16*10)
4	=I29	=(((K9*365*($B$16/$D$16))*$B$21)+((K9*($C$16/$D$16))*$B$22)+$B$23*365)+(L9*$B$24*365)	=I30-J30	=L20/($B$16*10)	=(((N9*365*($B$16/$D$16))*$B$21)+((N9*365*($C$16/$D$16))*$B$22)+$B$23*365)+(O9*$B$24*365)	=I30-M30	=N20/($B$16*10)
5	=I30	=(((K10*365*($B$16/$D$16))*$B$21)+((K10*($C$16/$D$16))*$B$22)+$B$23*365)+(L10*$B$24*365)	=I31-J31	=L21/($B$16*10)	=(((N10*365*($B$16/$D$16))*$B$21)+((N10*365*($C$16/$D$16))*$B$22)+$B$23*365)+(O10*$B$24*365)	=I31-M31	=N21/($B$16*10)

7	=I31		=(((K11*365*($B$16/$D$16))*$B$21)+((K11*($C$16/$D$16))*$B$22)+$B$23*365)+(L11*$B$24*365)	=I32-J32	=L22/($B$16*10)	=(((N11*365*($B$16/$D$16))*$B$21)+((N11*365*($C$16/$D$16))*$B$22)+$B$23*365)+(O11*$B$24*365)	=I32-M32	=N22/($B$16*10)
10	=I32		=((((K12*365*($B$16/$D$16))*$B$21)+((K12*($C$16/$D$16))*$B$22)+$B$23*365)+(L12*$B$24*365))	=I33-J33	=L23/($B$16*10)	=(((N12*365*($B$16/$D$16))*$B$21)+((N12*365*($C$16/$D$16))*$B$22)+$B$23*365)+(O12*$B$24*365)	=I33-M33	=N23/($B$16*10)

Table 33 - Sample of Load, Solar and Battery Modelling For 1.5 kW Solar System

=Solar!B5
Solar Gen
=-Solar!B114
=-Solar!B115
=-Solar!B116
=-Solar!B117
=-Solar!B118
=-Solar!B119
=-Solar!B120
=-Solar!B121
=-Solar!B122
=-Solar!B123
=-Solar!B124
=-Solar!B125
=-Solar!B126
=-Solar!B127
=-Solar!B128
=-Solar!B129
=-Solar!B130
=-Solar!B131
=-Solar!B132
=-Solar!B133
=-Solar!B134
=-Solar!B135
=-Solar!B136

=-Solar!B137
Load and Solar
=$K2-Solar!B114
=$K3-Solar!B115
=$K4-Solar!B116
=$K5-Solar!B117
=$K6-Solar!B118
=$K7-Solar!B119
=$K8-Solar!B120
=$K9-Solar!B121
=$K10-Solar!B122
=$K11-Solar!B123
=$K12-Solar!B124
=$K13-Solar!B125
=$K14-Solar!B126
=$K15-Solar!B127
=$K16-Solar!B128
=$K17-Solar!B129
=$K18-Solar!B130
=$K19-Solar!B131
=$K20-Solar!B132
=$K21-Solar!B133
=$K22-Solar!B134
=$K23-Solar!B135
=$K24-Solar!B136
=$K25-Solar!B137

Batt rate
=IF(ABS(V30)<USER!$C$35/1000,V30,IF(V30>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V31)<USER!$C$35/1000,V31,IF(V31>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V32)<USER!$C$35/1000,V32,IF(V32>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V33)<USER!$C$35/1000,V33,IF(V33>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V34)<USER!$C$35/1000,V34,IF(V34>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V35)<USER!$C$35/1000,V35,IF(V35>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V36)<USER!$C$35/1000,V36,IF(V36>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V37)<USER!$C$35/1000,V37,IF(V37>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V38)<USER!$C$35/1000,V38,IF(V38>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V39)<USER!$C$35/1000,V39,IF(V39>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V40)<USER!$C$35/1000,V40,IF(V40>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V41)<USER!$C$35/1000,V41,IF(V41>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V42)<USER!$C$35/1000,V42,IF(V42>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V43)<USER!$C$35/1000,V43,IF(V43>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V44)<USER!$C$35/1000,V44,IF(V44>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V45)<USER!$C$35/1000,V45,IF(V45>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V46)<USER!$C$35/1000,V46,IF(V46>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V47)<USER!$C$35/1000,V47,IF(V47>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V48)<USER!$C$35/1000,V48,IF(V48>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V49)<USER!$C$35/1000,V49,IF(V49>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V50)<USER!$C$35/1000,V50,IF(V50>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V51)<USER!$C$35/1000,V51,IF(V51>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V52)<USER!$C$35/1000,V52,IF(V52>0,USER!$C$35/1000,-(USER!$C$35/1000)))
=IF(ABS(V53)<USER!$C$35/1000,V53,IF(V53>0,USER!$C$35/1000,-(USER!$C$35/1000)))
Batt D1
0
=IF(V31>0,IF(V83-V58<0,0,V83-V58),IF((-((($P$1-V83)+V58)-$P$1))<$P$1,(-((($P$1-V83)+V58)-$P$1)),$P$1))
=IF(V32>0,IF(V84-V59<0,0,V84-V59),IF((-((($P$1-V84)+V59)-$P$1))<$P$1,(-((($P$1-V84)+V59)-$P$1)),$P$1))

=IF(V33>0,IF(V85-V60<0,0,V85-V60),IF((-((($P$1-V85)+V60)-$P$1))<$P$1,(-((($P$1-V85)+V60)-$P$1)),$P$1))
=IF(V34>0,IF(V86-V61<0,0,V86-V61),IF((-((($P$1-V86)+V61)-$P$1))<$P$1,(-((($P$1-V86)+V61)-$P$1)),$P$1))
=IF(V35>0,IF(V87-V62<0,0,V87-V62),IF((-((($P$1-V87)+V62)-$P$1))<$P$1,(-((($P$1-V87)+V62)-$P$1)),$P$1))
=IF(V36>0,IF(V88-V63<0,0,V88-V63),IF((-((($P$1-V88)+V63)-$P$1))<$P$1,(-((($P$1-V88)+V63)-$P$1)),$P$1))
=IF(V37>0,IF(V89-V64<0,0,V89-V64),IF((-((($P$1-V89)+V64)-$P$1))<$P$1,(-((($P$1-V89)+V64)-$P$1)),$P$1))
=IF(V38>0,IF(V90-V65<0,0,V90-V65),IF((-((($P$1-V90)+V65)-$P$1))<$P$1,(-((($P$1-V90)+V65)-$P$1)),$P$1))
=IF(V39>0,IF(V91-V66<0,0,V91-V66),IF((-((($P$1-V91)+V66)-$P$1))<$P$1,(-((($P$1-V91)+V66)-$P$1)),$P$1))
=IF(V40>0,IF(V92-V67<0,0,V92-V67),IF((-((($P$1-V92)+V67)-$P$1))<$P$1,(-((($P$1-V92)+V67)-$P$1)),$P$1))
=IF(V41>0,IF(V93-V68<0,0,V93-V68),IF((-((($P$1-V93)+V68)-$P$1))<$P$1,(-((($P$1-V93)+V68)-$P$1)),$P$1))
=IF(V42>0,IF(V94-V69<0,0,V94-V69),IF((-((($P$1-V94)+V69)-$P$1))<$P$1,(-((($P$1-V94)+V69)-$P$1)),$P$1))
=IF(V43>0,IF(V95-V70<0,0,V95-V70),IF((-((($P$1-V95)+V70)-$P$1))<$P$1,(-((($P$1-V95)+V70)-$P$1)),$P$1))
=IF(V44>0,IF(V96-V71<0,0,V96-V71),IF((-((($P$1-V96)+V71)-$P$1))<$P$1,(-((($P$1-V96)+V71)-$P$1)),$P$1))
=IF(V45>0,IF(V97-V72<0,0,V97-V72),IF((-((($P$1-V97)+V72)-$P$1))<$P$1,(-((($P$1-V97)+V72)-$P$1)),$P$1))
=IF(V46>0,IF(V98-V73<0,0,V98-V73),IF((-((($P$1-V98)+V73)-$P$1))<$P$1,(-((($P$1-V98)+V73)-$P$1)),$P$1))
=IF(V47>0,IF(V99-V74<0,0,V99-V74),IF((-((($P$1-V99)+V74)-$P$1))<$P$1,(-((($P$1-V99)+V74)-$P$1)),$P$1))
=IF(V48>0,IF(V100-V75<0,0,V100-V75),IF((-((($P$1-V100)+V75)-$P$1))<$P$1,(-((($P$1-V100)+V75)-$P$1)),$P$1))
=IF(V49>0,IF(V101-V76<0,0,V101-V76),IF((-((($P$1-V101)+V76)-$P$1))<$P$1,(-((($P$1-V101)+V76)-$P$1)),$P$1))
=IF(V50>0,IF(V102-V77<0,0,V102-V77),IF((-((($P$1-V102)+V77)-$P$1))<$P$1,(-((($P$1-V102)+V77)-$P$1)),$P$1))
=IF(V51>0,IF(V103-V78<0,0,V103-V78),IF((-((($P$1-V103)+V78)-$P$1))<$P$1,(-((($P$1-V103)+V78)-$P$1)),$P$1))
=IF(V52>0,IF(V104-V79<0,0,V104-V79),IF((-((($P$1-V104)+V79)-$P$1))<$P$1,(-((($P$1-V104)+V79)-$P$1)),$P$1))
=IF(V53>0,IF(V105-V80<0,0,V105-V80),IF((-((($P$1-V105)+V80)-$P$1))<$P$1,(-((($P$1-V105)+V80)-$P$1)),$P$1))
Batt D2
=IF(V30>0,IF(V106-V57<0,0,V106-V57),IF((-((($P$1-V106)+V57)-$P$1))<$P$1,(-((($P$1-V106)+V57)-$P$1)),$P$1))
=IF(V31>0,IF(V109-V58<0,0,V109-V58),IF((-((($P$1-V109)+V58)-$P$1))<$P$1,(-((($P$1-V109)+V58)-$P$1)),$P$1))
=IF(V32>0,IF(V110-V59<0,0,V110-V59),IF((-((($P$1-V110)+V59)-$P$1))<$P$1,(-((($P$1-V110)+V59)-$P$1)),$P$1))
=IF(V33>0,IF(V111-V60<0,0,V111-V60),IF((-((($P$1-V111)+V60)-$P$1))<$P$1,(-((($P$1-V111)+V60)-$P$1)),$P$1))
=IF(V34>0,IF(V112-V61<0,0,V112-V61),IF((-((($P$1-V112)+V61)-$P$1))<$P$1,(-((($P$1-V112)+V61)-$P$1)),$P$1))
=IF(V35>0,IF(V113-V62<0,0,V113-V62),IF((-((($P$1-V113)+V62)-$P$1))<$P$1,(-((($P$1-V113)+V62)-$P$1)),$P$1))
=IF(V36>0,IF(V114-V63<0,0,V114-V63),IF((-((($P$1-V114)+V63)-$P$1))<$P$1,(-((($P$1-V114)+V63)-$P$1)),$P$1))

=IF(V37>0,IF(V115-V64<0,0,V115-V64),IF((-((($P$1-V115)+V64)-$P$1))<$P$1,(-((($P$1-V115)+V64)-$P$1)),$P$1))
=IF(V38>0,IF(V116-V65<0,0,V116-V65),IF((-((($P$1-V116)+V65)-$P$1))<$P$1,(-((($P$1-V116)+V65)-$P$1)),$P$1))
=IF(V39>0,IF(V117-V66<0,0,V117-V66),IF((-((($P$1-V117)+V66)-$P$1))<$P$1,(-((($P$1-V117)+V66)-$P$1)),$P$1))
=IF(V40>0,IF(V118-V67<0,0,V118-V67),IF((-((($P$1-V118)+V67)-$P$1))<$P$1,(-((($P$1-V118)+V67)-$P$1)),$P$1))
=IF(V41>0,IF(V119-V68<0,0,V119-V68),IF((-((($P$1-V119)+V68)-$P$1))<$P$1,(-((($P$1-V119)+V68)-$P$1)),$P$1))
=IF(V42>0,IF(V120-V69<0,0,V120-V69),IF((-((($P$1-V120)+V69)-$P$1))<$P$1,(-((($P$1-V120)+V69)-$P$1)),$P$1))
=IF(V43>0,IF(V121-V70<0,0,V121-V70),IF((-((($P$1-V121)+V70)-$P$1))<$P$1,(-((($P$1-V121)+V70)-$P$1)),$P$1))
=IF(V44>0,IF(V122-V71<0,0,V122-V71),IF((-((($P$1-V122)+V71)-$P$1))<$P$1,(-((($P$1-V122)+V71)-$P$1)),$P$1))
=IF(V45>0,IF(V123-V72<0,0,V123-V72),IF((-((($P$1-V123)+V72)-$P$1))<$P$1,(-((($P$1-V123)+V72)-$P$1)),$P$1))
=IF(V46>0,IF(V124-V73<0,0,V124-V73),IF((-((($P$1-V124)+V73)-$P$1))<$P$1,(-((($P$1-V124)+V73)-$P$1)),$P$1))
=IF(V47>0,IF(V125-V74<0,0,V125-V74),IF((-((($P$1-V125)+V74)-$P$1))<$P$1,(-((($P$1-V125)+V74)-$P$1)),$P$1))
=IF(V48>0,IF(V126-V75<0,0,V126-V75),IF((-((($P$1-V126)+V75)-$P$1))<$P$1,(-((($P$1-V126)+V75)-$P$1)),$P$1))
=IF(V49>0,IF(V127-V76<0,0,V127-V76),IF((-((($P$1-V127)+V76)-$P$1))<$P$1,(-((($P$1-V127)+V76)-$P$1)),$P$1))
=IF(V50>0,IF(V128-V77<0,0,V128-V77),IF((-((($P$1-V128)+V77)-$P$1))<$P$1,(-((($P$1-V128)+V77)-$P$1)),$P$1))
=IF(V51>0,IF(V129-V78<0,0,V129-V78),IF((-((($P$1-V129)+V78)-$P$1))<$P$1,(-((($P$1-V129)+V78)-$P$1)),$P$1))
=IF(V52>0,IF(V130-V79<0,0,V130-V79),IF((-((($P$1-V130)+V79)-$P$1))<$P$1,(-((($P$1-V130)+V79)-$P$1)),$P$1))
=IF(V53>0,IF(V131-V80<0,0,V131-V80),IF((-((($P$1-V131)+V80)-$P$1))<$P$1,(-((($P$1-V131)+V80)-$P$1)),$P$1))
Batt D3
=IF(V30>0,IF(V132-V57<0,0,V132-V57),IF((-((($P$1-V132)+V57)-$P$1))<$P$1,(-((($P$1-V132)+V57)-$P$1)),$P$1))
=IF(V31>0,IF(V135-V58<0,0,V135-V58),IF((-((($P$1-V135)+V58)-$P$1))<$P$1,(-((($P$1-V135)+V58)-$P$1)),$P$1))
=IF(V32>0,IF(V136-V59<0,0,V136-V59),IF((-((($P$1-V136)+V59)-$P$1))<$P$1,(-((($P$1-V136)+V59)-$P$1)),$P$1))
=IF(V33>0,IF(V137-V60<0,0,V137-V60),IF((-((($P$1-V137)+V60)-$P$1))<$P$1,(-((($P$1-V137)+V60)-$P$1)),$P$1))
=IF(V34>0,IF(V138-V61<0,0,V138-V61),IF((-((($P$1-V138)+V61)-$P$1))<$P$1,(-((($P$1-V138)+V61)-$P$1)),$P$1))
=IF(V35>0,IF(V139-V62<0,0,V139-V62),IF((-((($P$1-V139)+V62)-$P$1))<$P$1,(-((($P$1-V139)+V62)-$P$1)),$P$1))
=IF(V36>0,IF(V140-V63<0,0,V140-V63),IF((-((($P$1-V140)+V63)-$P$1))<$P$1,(-((($P$1-V140)+V63)-$P$1)),$P$1))
=IF(V37>0,IF(V141-V64<0,0,V141-V64),IF((-((($P$1-V141)+V64)-$P$1))<$P$1,(-((($P$1-V141)+V64)-$P$1)),$P$1))
=IF(V38>0,IF(V142-V65<0,0,V142-V65),IF((-((($P$1-V142)+V65)-$P$1))<$P$1,(-((($P$1-V142)+V65)-$P$1)),$P$1))
=IF(V39>0,IF(V143-V66<0,0,V143-V66),IF((-((($P$1-V143)+V66)-$P$1))<$P$1,(-((($P$1-V143)+V66)-$P$1)),$P$1))
=IF(V40>0,IF(V144-V67<0,0,V144-V67),IF((-((($P$1-V144)+V67)-$P$1))<$P$1,(-((($P$1-V144)+V67)-$P$1)),$P$1))

=IF(V41>0,IF(V145-V68<0,0,V145-V68),IF((-((($P$1-V145)+V68)-$P$1))<$P$1,(-((($P$1-V145)+V68)-$P$1)),$P$1))
=IF(V42>0,IF(V146-V69<0,0,V146-V69),IF((-((($P$1-V146)+V69)-$P$1))<$P$1,(-((($P$1-V146)+V69)-$P$1)),$P$1))
=IF(V43>0,IF(V147-V70<0,0,V147-V70),IF((-((($P$1-V147)+V70)-$P$1))<$P$1,(-((($P$1-V147)+V70)-$P$1)),$P$1))
=IF(V44>0,IF(V148-V71<0,0,V148-V71),IF((-((($P$1-V148)+V71)-$P$1))<$P$1,(-((($P$1-V148)+V71)-$P$1)),$P$1))
=IF(V45>0,IF(V149-V72<0,0,V149-V72),IF((-((($P$1-V149)+V72)-$P$1))<$P$1,(-((($P$1-V149)+V72)-$P$1)),$P$1))
=IF(V46>0,IF(V150-V73<0,0,V150-V73),IF((-((($P$1-V150)+V73)-$P$1))<$P$1,(-((($P$1-V150)+V73)-$P$1)),$P$1))
=IF(V47>0,IF(V151-V74<0,0,V151-V74),IF((-((($P$1-V151)+V74)-$P$1))<$P$1,(-((($P$1-V151)+V74)-$P$1)),$P$1))
=IF(V48>0,IF(V152-V75<0,0,V152-V75),IF((-((($P$1-V152)+V75)-$P$1))<$P$1,(-((($P$1-V152)+V75)-$P$1)),$P$1))
=IF(V49>0,IF(V153-V76<0,0,V153-V76),IF((-((($P$1-V153)+V76)-$P$1))<$P$1,(-((($P$1-V153)+V76)-$P$1)),$P$1))
=IF(V50>0,IF(V154-V77<0,0,V154-V77),IF((-((($P$1-V154)+V77)-$P$1))<$P$1,(-((($P$1-V154)+V77)-$P$1)),$P$1))
=IF(V51>0,IF(V155-V78<0,0,V155-V78),IF((-((($P$1-V155)+V78)-$P$1))<$P$1,(-((($P$1-V155)+V78)-$P$1)),$P$1))
=IF(V52>0,IF(V156-V79<0,0,V156-V79),IF((-((($P$1-V156)+V79)-$P$1))<$P$1,(-((($P$1-V156)+V79)-$P$1)),$P$1))
=IF(V53>0,IF(V157-V80<0,0,V157-V80),IF((-((($P$1-V157)+V80)-$P$1))<$P$1,(-((($P$1-V157)+V80)-$P$1)),$P$1))
Batt D4
=IF(V30>0,IF(V158-V57<0,0,V158-V57),IF((-((($P$1-V158)+V57)-$P$1))<$P$1,(-((($P$1-V158)+V57)-$P$1)),$P$1))
=IF(V31>0,IF(V161-V58<0,0,V161-V58),IF((-((($P$1-V161)+V58)-$P$1))<$P$1,(-((($P$1-V161)+V58)-$P$1)),$P$1))
=IF(V32>0,IF(V162-V59<0,0,V162-V59),IF((-((($P$1-V162)+V59)-$P$1))<$P$1,(-((($P$1-V162)+V59)-$P$1)),$P$1))
=IF(V33>0,IF(V163-V60<0,0,V163-V60),IF((-((($P$1-V163)+V60)-$P$1))<$P$1,(-((($P$1-V163)+V60)-$P$1)),$P$1))
=IF(V34>0,IF(V164-V61<0,0,V164-V61),IF((-((($P$1-V164)+V61)-$P$1))<$P$1,(-((($P$1-V164)+V61)-$P$1)),$P$1))
=IF(V35>0,IF(V165-V62<0,0,V165-V62),IF((-((($P$1-V165)+V62)-$P$1))<$P$1,(-((($P$1-V165)+V62)-$P$1)),$P$1))
=IF(V36>0,IF(V166-V63<0,0,V166-V63),IF((-((($P$1-V166)+V63)-$P$1))<$P$1,(-((($P$1-V166)+V63)-$P$1)),$P$1))
=IF(V37>0,IF(V167-V64<0,0,V167-V64),IF((-((($P$1-V167)+V64)-$P$1))<$P$1,(-((($P$1-V167)+V64)-$P$1)),$P$1))
=IF(V38>0,IF(V168-V65<0,0,V168-V65),IF((-((($P$1-V168)+V65)-$P$1))<$P$1,(-((($P$1-V168)+V65)-$P$1)),$P$1))
=IF(V39>0,IF(V169-V66<0,0,V169-V66),IF((-((($P$1-V169)+V66)-$P$1))<$P$1,(-((($P$1-V169)+V66)-$P$1)),$P$1))
=IF(V40>0,IF(V170-V67<0,0,V170-V67),IF((-((($P$1-V170)+V67)-$P$1))<$P$1,(-((($P$1-V170)+V67)-$P$1)),$P$1))
=IF(V41>0,IF(V171-V68<0,0,V171-V68),IF((-((($P$1-V171)+V68)-$P$1))<$P$1,(-((($P$1-V171)+V68)-$P$1)),$P$1))
=IF(V42>0,IF(V172-V69<0,0,V172-V69),IF((-((($P$1-V172)+V69)-$P$1))<$P$1,(-((($P$1-V172)+V69)-$P$1)),$P$1))
=IF(V43>0,IF(V173-V70<0,0,V173-V70),IF((-((($P$1-V173)+V70)-$P$1))<$P$1,(-((($P$1-V173)+V70)-$P$1)),$P$1))
=IF(V44>0,IF(V174-V71<0,0,V174-V71),IF((-((($P$1-V174)+V71)-$P$1))<$P$1,(-((($P$1-V174)+V71)-$P$1)),$P$1))

=IF(V45>0,IF(V175-V72<0,0,V175-V72),IF((-((($P$1-V175)+V72)-$P$1))<$P$1,(-((($P$1-V175)+V72)-$P$1)),$P$1))
=IF(V46>0,IF(V176-V73<0,0,V176-V73),IF((-((($P$1-V176)+V73)-$P$1))<$P$1,(-((($P$1-V176)+V73)-$P$1)),$P$1))
=IF(V47>0,IF(V177-V74<0,0,V177-V74),IF((-((($P$1-V177)+V74)-$P$1))<$P$1,(-((($P$1-V177)+V74)-$P$1)),$P$1))
=IF(V48>0,IF(V178-V75<0,0,V178-V75),IF((-((($P$1-V178)+V75)-$P$1))<$P$1,(-((($P$1-V178)+V75)-$P$1)),$P$1))
=IF(V49>0,IF(V179-V76<0,0,V179-V76),IF((-((($P$1-V179)+V76)-$P$1))<$P$1,(-((($P$1-V179)+V76)-$P$1)),$P$1))
=IF(V50>0,IF(V180-V77<0,0,V180-V77),IF((-((($P$1-V180)+V77)-$P$1))<$P$1,(-((($P$1-V180)+V77)-$P$1)),$P$1))
=IF(V51>0,IF(V181-V78<0,0,V181-V78),IF((-((($P$1-V181)+V78)-$P$1))<$P$1,(-((($P$1-V181)+V78)-$P$1)),$P$1))
=IF(V52>0,IF(V182-V79<0,0,V182-V79),IF((-((($P$1-V182)+V79)-$P$1))<$P$1,(-((($P$1-V182)+V79)-$P$1)),$P$1))
=IF(V53>0,IF(V183-V80<0,0,V183-V80),IF((-((($P$1-V183)+V80)-$P$1))<$P$1,(-((($P$1-V183)+V80)-$P$1)),$P$1))
discharging
=(V161-V158)*USER!$C$37
=(V162-V161)*USER!$C$37
=(V163-V162)*USER!$C$37
=(V164-V163)*USER!$C$37
=(V165-V164)*USER!$C$37
=(V166-V165)*USER!$C$37
=(V167-V166)*USER!$C$37
=(V168-V167)*USER!$C$37
=(V169-V168)*USER!$C$37
=(V170-V169)*USER!$C$37
=(V171-V170)*USER!$C$37
=(V172-V171)*USER!$C$37

=(V173-V172)*USER!$C$37
=(V174-V173)*USER!$C$37
=(V175-V174)*USER!$C$37
=(V176-V175)*USER!$C$37
=(V177-V176)*USER!$C$37
=(V178-V177)*USER!$C$37
=(V179-V178)*USER!$C$37
=(V180-V179)*USER!$C$37
=(V181-V180)*USER!$C$37
=(V182-V181)*USER!$C$37
=(V183-V182)*USER!$C$37
=(V184-V183)*USER!$C$37
load curve with batt
=ROUND(V30+V194,5)
=ROUND(V31+V195,5)
=ROUND(V32+V196,5)
=ROUND(V33+V197,5)
=ROUND(V34+V198,5)
=ROUND(V35+V199,5)
=ROUND(V36+V200,5)
=ROUND(V37+V201,5)
=ROUND(V38+V202,5)
=ROUND(V39+V203,5)
=ROUND(V40+V204,5)
=ROUND(V41+V205,5)
=ROUND(V42+V206,5)
=ROUND(V43+V207,5)
=ROUND(V44+V208,5)
=ROUND(V45+V209,5)

=ROUND(V46+V210,5)
=ROUND(V47+V211,5)
=ROUND(V48+V212,5)
=ROUND(V49+V213,5)
=ROUND(V50+V214,5)
=ROUND(V51+V215,5)
=ROUND(V52+V216,5)
=ROUND(V53+V217,5)
solar and batt grid
=SUMIF(V220:V243,">0")
solar and batt Feedin
=SUMIF(V220:V243,"<0")
Battery Max Charge
=MAX(V109:V132)
Battery Max Charge
=MIN(V109:V132)
Solar Only grid
=SUMIF(V30:V53,">0")
Solar Only feed in
=SUMIF(V30:V53,"<0")
max - min
=ABS(MAX(V220:V243)-MIN(V220:V243))