University of Southern Queensland

Faculty of Health, Engineering & Sciences

# Off-grid Solar Power Design and Battery Storage Optimisation

A dissertation submitted by

Jason Hooper

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# Abstract

Battery storage for solar applications have reduced in price over the years as more manufacturers begin to enter the market and manufacture batteries for residential use. This is undoubtedly a result of increased costs related to staying on grid as well as demand for solar panels have brought a decrease to their cost with an increase to the quality of the panels. This project sets out to analyse five locations across Queensland across three different load sizes, whilst comparing existing components, with the new battery technology from Enphase Energy, for either grid connected or off grid systems, which is dependent on the size of the system, location and components used. In this paper, detailed research was conducted for existing technology, as well as past projects involving renewable energy, focusing on off-grid solar power design and battery storage optimisation. Across the extensive literature reviewed, which was utilised for their relevance as well as being peer reviewed and cross referenced, the idea to model systems using HOMER Pro® and NREL SAM® was constructed in order to analyse techniques involved for each system to meet the load profiles. This was done to not only undergo an extensive analysis that focused on LCOE, ROI, system output, initial capital and NPC but also compare and contrast between the two programs to fully optimise the system using shade analysis and manual battery dispatch strategies. The result of this analysis and additional optimisation, resulted in the following optimised systems for each location. Brisbane had a 13.0 kW system with a single Tesla Powerwall 2 AC battery (13.5 kWh), Toowoomba had a 6.6 kW system with two Trojan SIND 041245 batteries (17.8 kWh), Hervey Bay had a 13.0 kW system with a single Tesla Powerwall 2 AC battery (13.5 kWh), Barcaldine had a 6.6 kW system with 8 Trojan SIND 041245 batteries (71.0 kWh) and is completely off grid, lastly Cairns had a 13.0 kW system with 6 Trojan SIND 041245 batteries (53.3 kWh) and utilises feed-in tariffs.

These results were filtered through the HOMER Pro® program and then subsequently the NREL SAM® program to apply realistic impacts on the efficiency of the system and to perform a full optimisation. All were performed using the Jinko Solar Eagle 60P (JMK260PP-60) panels, in which was optimised from the available solar panels throughout the process based on cost per kWh. The components analysed were 8 solar panels, 3 inverters and 10 batteries. The results suggest that even with modifications to the battery throughput and extending the lifetime, the best systems are those still connected to the grid. Additionally, taking advantage of solar credits available for the solar panels, can greatly reduce / offset the costs associated with buying a system with a battery system. Future work related to this topic can range from an analysis on the environmental impacts of replacing the components on a large scale, implementing alternative techniques like water cleaning the solar panels in which increases efficiency, obtaining an optimised system and testing for an extended period, obtaining actual load data to properly reflect realistic loads instead of a simulated load and as well additional analysis into azimuth angle and tilt angle for the solar panel arrays to determine if any further optimisation could be found. Finally, performing an additional optimisation after the RECs expire in 2030 would be vital as there wouldn’t be any solar credits available to offset the initial capital of the system.

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Jason Hooper

Student Number: [redacted]

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# Glossary

| | |
|---|---|
| AC | Alternating Current |
| ACCC | Australian Competition and Consumer Commission |
| AEMO | Australian Energy Market Operator |
| BMS | Battery Management System |
| CEC | Clean Energy Council |
| CET | Clean Energy Target |
| COE | Cost of Electricity |
| CPI | Consumer Price Index |
| DHI | Direct Horizontal Irradiance |
| DNI | Direct Normal Irradiance |
| DOE | Department of Energy |
| FiT | Feed-in Tariff |
| GDP | Gross Domestic Product |
| GHI | Global Horizontal Irradiance |
| GST | Goods and Service tax |
| GW | Gigawatts |
| HJT | Heterojunction technology |
| HOMER | Hybrid Optimization of Multiple Energy Resources |
| HSGSLG | Home based Solar power Generation, Storage, and Localised energy Grids |
| HV | High Voltage |
| Impp | Maximum Power Point Current |
| Isc | Short Circuit Current |
| KCL | Kirchhoff's Current Law |
| KVL | Kirchhoff's Voltage Law |
| kWh | kilowatt-hours |
| LCOE | Levelized Cost of Electricity |

| | |
|---|---|
| LID | Light Induced Degradation |
| MG | Microgrid |
| MOSFET | Metal Oxide Semiconductor Field-Effect Transistors |
| MPPT | Maximum Power Point Tracking |
| MW | Megawatts |
| NEG | National Energy Guarantee |
| NEM | National Electricity Market |
| NOCT | Normal Operating Cell Temperature |
| NPC | Net Present Cost |
| NPV | Net Present Value |
| NREL | National Renewable Energy Laboratory |
| O&M | Operation and Maintenance |
| Pmax | Maximum Power Point |
| PSoC | Partial State of Charge |
| PV | Photovoltaic |
| REC | Renewable Energy Certificates |
| RET | Renewable Energy Target |
| ROI | Return on Investment |
| SAM | System Advisor Model |
| SoC | State of Charge |
| SSTC | Small-scale Technology Certificates |
| STC | Standard Test Conditions |
| T&C | Terms and Conditions |
| UI | User Interface |
| USQ | University of Southern Queensland |
| Vmpp | Maximum Power Point Voltage |
| Voc | Open Circuit Voltage |

# Chapter 1. Introduction

## 1.1 Idea Initiation, Aims and Motivations

Renewable energy is an important aspect in the current climate of consumer electricity demand and supply. With the ever-rising cost of electricity tariffs in order to keep up with the high demand of electricity per household, there needs to be an alternative sought in order to mitigate not only the financial stress on Australian residents, but also the strain on the network itself and allow residents to go completely off-grid. Photovoltaic (PV) solar power is having a positive impact not only in Australia, but around the world, with majority of households taking advantage of excess electricity, and selling it back to the grid for a reduction in their electricity bill. Therefore, **the problem** being addressed in this project is whether there is any feasible choice for Australian residents to implement battery banks with the rising cost of electricity and introduction of new technologies, whilst taking into consideration load profiles that represent the typical daily usage of **three** different households across **five locations**. Financial analysis will be of concern when optimising the microgrid systems, with emphasis on the levelized cost of electricity (LCOE) and renewable fraction. Results will be presented for ease of access to information, and to ensure future use of data maintains its integrity beyond submission of this project.

As seen in Figure 1, since 2007 / 2008 power prices have substantially risen, as a result of either higher network costs or increases in retailer margins (ACCC 2017 p.6). Considering the exponential growth of solar energy globally which has surpassed 100 gigawatts (GW) in 2018 (Munsell, M 2018), there will be an expected 1 trillion Watts of installed solar globally by 2023 (International Energy Agency 2018). As of September 2018, there are 1.95 million PV installations in Australia, with a combined capacity over 10.14 GW (Australian PV Institute Solar Map 2018). Noted in Appendix D.1 there has been a significant rise in solar power installation within Australia and is considered the best consumer energy product on the market. The current technology has many different types and configurations available that suit any circumstances for residential and commercial settings. With the rising costs of electricity, and the introduction of battery storage systems like the Tesla Powerwall 2 and the new Alternating Current (AC) battery from Enphase Energy, it is becoming more affordable for consumers to couple the solar power with battery storage to have the ability to go off-grid and be sustainable without relying on an electricity provider. The introduction of Tesla's Powerwall in 2015, as well as the giant battery storage in South Australia in 2017 by Tesla, has allowed the market to grow substantially. This growth as noted by the Clean Energy's Council (CEC) 2018 report, shows that 12 % of the total 172,000 solar systems installed across Australia were coupled with battery storage (Clean Energy Council 2018a). Just two years prior, there was 5% installed with batteries, the total tally comes to 28,000 battery systems installed in Australia as noted in SunWiz's Battery Market Report (SunWiz 2018).

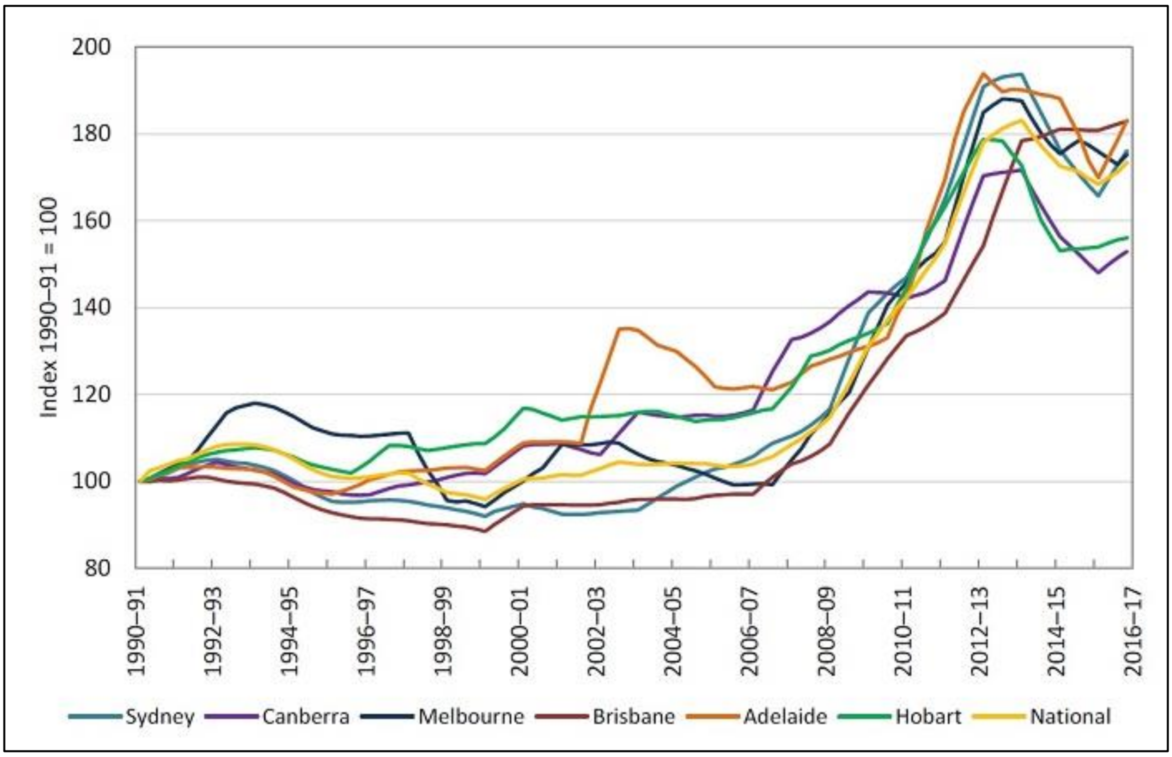


Figure 1: Consumer price index Australia (ACCC 2017 p.12)

US based technology company Enphase Energy is looking to capitalize on this spike in percentage, with introducing its own solar and storage solution to the Australian market. With a 400% increase in stocks since 2017, and with a 19% increase in November 2018 (Chatsko, M 2018). Enphase in 2019 will have a new supply deal with solar module leader SunPower, as well plans to supply new storage devices. These devices will expand upon the current capacity of 1.2 kilowatt-hours (kWh) available per device and bring about a 20% increase in full year revenue compared to previous years (Chatsko, M 2018). To ensure customers achieve a feasible and sustainable solution, this project aims to analyse and research the current available off-grid / grid connected options, as there is a small percentage of models / projects detailing such circumstances for Australian households. This will be done for multiple different scenarios, where locations and load profiles will be varied, with emphasis on the inclusion of battery storage to create sustainable microgrid (MG) systems. Expanding on the research of battery storage and solar optimisation, this project will also be optimising the inverters used, this will allow a full system to be analysed; a factor missing from literature reviewed.

Discussions will also include techniques that have the potential to be improved, the best product based on all costs associated with the system, in which range from implementation to long term investment. This will all be done with sustainability in mind, as well as the vision for the future of the products and the current electricity market, in which all will be discussed with appropriate solutions presented for Home based Solar power Generation, Storage, and Localised energy Grids (HSGSLG). All work will be completed with the microgrid simulation software Hybrid Optimization of Multiple Energy Resources (HOMER) Pro® version 3.12 by

Homer Energy, as well as the National Renewable Energy Laboratory’s (NREL) System Advisor Model (SAM®) software version 2018.11.11, which is developed by NREL and funded by the U.S Department of Energy (DOE). This provides a global standard for optimising systems which is capable of running multiple different parameters and model accordingly, comparison will be conducted to ensure accurate optimisation has occurred. MATLAB® version R2016a will be used throughout to ensure calculations are accurate within the simulation.

## 1.2 Project Objectives

The objectives for the project are as follows, repeated in Appendix A on page 150.

- Investigate current techniques related to off-grid / grid connected solar power systems, emphasis on battery banks for off-grid solutions.
- Research techniques used for the installations of localised energy grids and provide available alternatives to achieve maximum power generation and storage.
- Develop a model using HOMER Pro® software, NREL’s SAM® software and MATLAB®, to simulate the analysis of generation / storage / consumption, this will allow a thorough optimisation to occur.
- Analyse results and provide the best optimised solution for a small, medium and large household regardless of season with varying locations.
- Provide conclusion that details a comparison between techniques and performance in efficiency and capacity for each scenario / load profile and identify techniques that have potential for improvement.
- Recommend the best products, most sustainable, the ideal system as well as the best Return on Investment (ROI) and economic investment within a reasonable time expectancy based on results.
- Time permitting investigate other household utilities that could further optimise electricity usage (solar hot water thermal storage), as well as the impact on the network and environment of residential properties going off-grid.

These objectives have been created in regard to the aims and feasibility of the project as well as the ideology of the project itself, the use of software referenced in the objectives is essential to completing this project within the timeline and to the scope mentioned in the aims of the project discussed previously.

## 1.3 Justification and Feasibility

Previous work in solar off-grid systems regarding residential use, has been all related to selling excess electricity back to the grid to offset electricity bills, due to high penetration of the PV installed. As noted in the CEC 2018 report, these seems to be a switching paradigm from typical grid connected systems to distributed renewable generation. Such renewable generation systems require coupling with an energy storage solution to mitigate its power generation variability that will ensure a stable and reliable off-grid operation (Stroe, D-I, Zaharof, A & Iov, F 2018 p.464). Studies done thus far have related to grid connected PV battery systems for residential houses in Australia, where optimal sizing algorithms were done in regard to finding the correct battery and PV systems (Li, J 2018 p.1246) in order to minimise total annual cost of electricity. These were done using genetic algorithms, in which many researchers are concerned that electricity prices and components covered a broad spectrum of different houses and demand profiles (Li, J 2018 p.1247) and weren't individualised. Additionally, previous optimisations were only concerned with the fact that the optimisation has a positive effect on residential home electricity prices which is obvious, and not the individual components, in which capital price and return on investment would typically be the deciding factor for homeowners in a real situation. On page 1253 of the referenced report, revealed that the battery model used didn't include leakage or derating factors, which is considered detached and doesn't reflect real world results, that batteries might fail and produce realistic results, and have failed to go into much detail in regard to an optimal system, beyond traditional PV systems. Evaluation of rooftop solar generation has been effective for the past decade, where the conclusion from multiple sources show an increased size of solar PV will reduce the annual electricity consumption (Ren, Z, Grozev, G & Higgins, A 2016 p.329). This project will be important on expanding prior studies done with PV solar, but including optimisation with inverters and battery banks for a home microgrid for off-grid capabilities, which has been missing from previous literature for some time, especially concerning projects in Australia. As per Shephard, S in 2016, a sensitivity analysis was conducted on one location in which concluded the largest PV only connection was chosen to be the optimal system for all load profiles (Shephard, S 2016).

Based on current research and development of technology, the exclusion of modifying inverters and only concluding on a PV only system, has left a gap in knowledge in regard to various tariffs used, locations analysed and the sizing of inverters and battery banks for off grid capability. Additionally, Shephard, S found that the higher the powered PV the better the economic results, due to changing the evening and hot water peak load. Even though this does reflect with a lower demand required and a larger renewable fraction, with the inclusion of new battery banks it is much more suitable to store the excess electricity from the large systems to meet these demands in a more realistic approach. Instead of relying on the household to change / modify the peak load as majority of the time, extenuating circumstances won't allow a major change that will affect the peak load substantially. Additionally, the future work recommended in the project by Shephard, S will be more fleshed out throughout this current project, especially concerning the optimal configuration found in that project compared to this project 3 years later. The other recommendations by Shephard, S 2016 that have been intertwined within the current project objectives are:

- Environmental impact and economic viability of PV and battery systems, especially concerning the replacement of these components over their lifetime

- Impact of battery throughput and how it would need to be increased before batteries be economically sound
- Electricity usage, grid costs and Operation and Maintenance (O&M) prices change over the project lifetime to reflect real results
- Climate, solar irradiance, azimuth angle will be adjusted accordingly for optimisation
- Systems simulated within the realm of the 2013 CEC guidelines for an optimal system

The use of the Hybrid Optimization of Multiple Energy Resources (HOMER) Pro® in this project and various others researched has been the deciding factor to be used for this project that is being undertaken, with the inclusion of NREL's System Advisor Model (SAM®) the work completed here will be able to be utilised to provide a fully optimised system for each location being tested.

## 1.4 Compliance and Standards

Standards and appropriate compliance from the CEC will be used throughout this project, the specific standards that dictate the installation of PV solar arrays, including the guidelines associated with accreditation are as follows:

- "AS 4509 Stand-alone power systems
- AS 4086 Secondary batteries for SPS
- AS \ NZS 5033 Installation of photovoltaic (PV) arrays" (Clean Energy Council 2018b)

An assumption has been made that all home-based localised grids (panel, inverter, storage) will be fully accredited and compliant to the standards in Australia and be installed by a qualified installer. If any alternative strategies related to installations that result in better efficiency of the PV system is discovered during this project, this will be researched and discussed accordingly.

## 1.5 Ethics and Consequential effects

All work completed has been done with human ethics in mind, and as per the University of Southern Queensland's promoting ethical conduct of research, they require all staff and students to ensure that there is approval before any research is done regarding human subjects (USQ 2018). All work and data analysed for this project has been done so without human subjects or surveys, any data used has been anonymised to ensure ethics integrity is upheld. The ethical standards and requirements published by Engineers Australia has been used to ensure that relevant codes are enforced. The consequences of the project results are the chosen decision in components used for customer household PV and battery systems that will best work for their circumstances. As there is no physical testing of components a health and safety hazard is at a minimum.

# Chapter 2. Literature Review

## 2.1 Electricity Market and Demand

Following the events of 2016 which resulted in a power outage to South Australia, a significant concern has been raised into the operation of Australia's National Electricity Market (NEM). As detailed in the 2017 report by the Australian Energy Market Operator (AEMO), the fault that occurred was a result of extreme weather conditions across a small timespan (AEMO 2017 p.32). The increased flow on interconnectors to counteract the loss from the weather event, resulted in immediate overcompensation that tripped both transmission circuits powering half the demand at the time of the fault (AEMO 2017 p.32). The NEM interconnects 5 regional market jurisdictions, in which involve wholesale generation that is generated via High Voltage (HV) transmission lines from generators (AEMO 2018).

As per the Australian Competition and Consumer Commission (ACCC) and Figure 1, retail prices for electricity have been up more than 60% since 2008 (ACCC 2017 p.6), as noted in Figure 2 between 2007 and 2017 electricity prices had a compounding annual growth rate of 8 % which is more than twice that for wages and Consumer Price Index (CPI). With the Clean Energy Target (CET) dumped by the Australian government in 2017 in favour for the National Energy Guarantee (NEG), which purpose was intended to assist investment certainty and bring more generation capacity online, thus reducing electricity costs (ACCC 2017 p.86). This intended purpose was to ensure electricity companies provided a set percentage of their power from coal, gas, batteries and hydro pumped generation (Igguiden, T 2017).

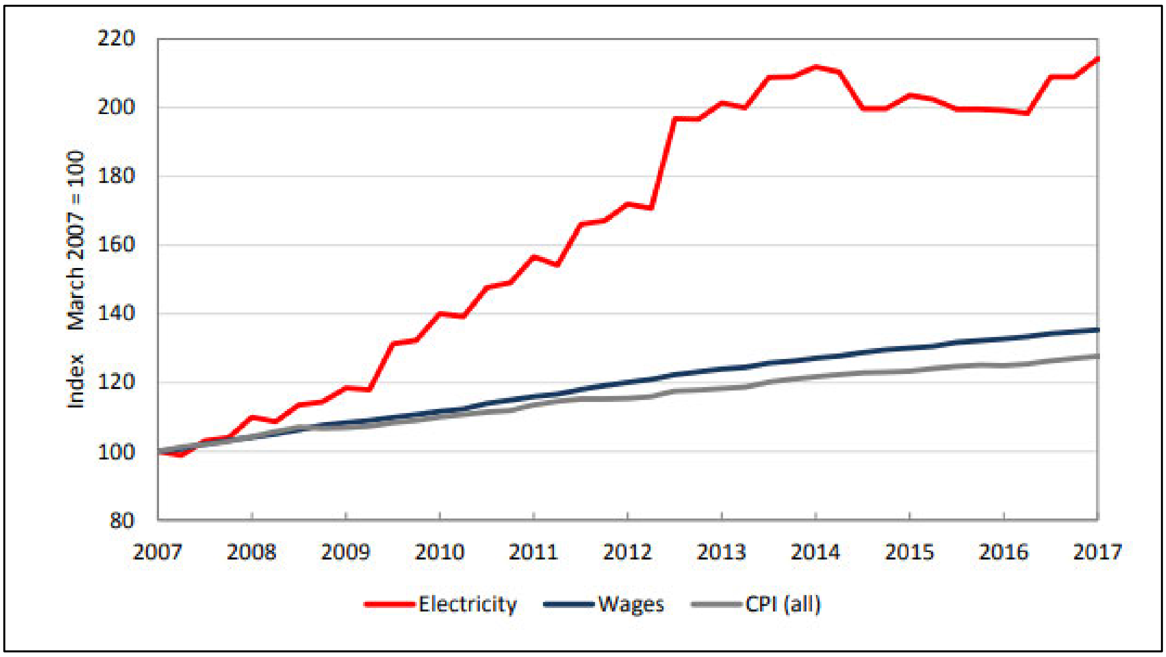


Figure 2: CPI for electricity compared with other sectors and wage growth (ACCC 2017 p.13)

Subsequently the Renewable Energy Target (RET) was back benched, in which subsidies for renewables for residential homes will begin to be phased out by 2030 (Yaxley, L & Sweeney, L 2018). With around 55,000 Megawatts (MW) of electricity generation capacity (Abbot, M & Cohen, B 2018 p.65), the major resource for fuel in Australia is coal. From 1970 to 2000, the volume of electricity generated in Australia grew around / was greater than that of electricity's real Gross Domestic Product (GDP). In addition, increase in air condition use nationally, resulted in maximum demand to grow substantially more than overall electricity demand (Abbott, M & Cohen, B 2018 p.65).

While reforms have been made in the industry to deliver on both benefits and costs, it is still incomplete, with considerable concern with respect to the security of supply and resilience of transmission and distribution networks (Abbot, M & Cohen, B 2018 p.70). However, there has been an increase of investment in the renewable energy capacity, as a result of government incentives upon the first introduction of renewable generation (Energy.gov.au 2018). One of the most changing aspects of renewable generation is the addition of battery banks for storage, where the cost ($ / kWh) is expected to decline sharply over the next 10 years (Hayward, J.A and Graham, P.W. 2017 p.23), and be reduced by 68% by 2035. One of these rises in investment could be contributed to climate change, in which has dominated policy debates in the energy market for the 21st century (Abbott, M & Cohen, B 2018 p.70). Regardless, even when policy measures are implemented, there is an amount of uncertainty remaining as to the likely long-term environment in which would require investors to further invest to ensure security in supply and pricing (Abbott, M & Cohen, B 2018 p.71). As a result of problems in the operation of the NEM, and the government's inability to reach a consensus on the renewable sector, there is now a significant tipping point that could see more Australian homeowners move to off-grid solutions due to solar feed-in tariff rates not being enough to offset the rising cost of electricity.

### 2.1.1 Tariffs

Tariffs will be used to initially analyse how much electricity costs are for the households being tested, as well as selling back to the grid if there are existing solar panels at the property. This will allow a baseline to compare against, once battery storage optimisation has been simulated in the available models. All tariffs used will include the relevant Goods and Service tax (GST) and will include any available feed-in tariffs (FiT). Companies that will be included in this project will be: AGL, Alinta Energy, Ergon Energy and Origin Energy.

All prices seen in the below table are the most updated and relevant prices as of the 10th of March 2019. Feed-in tariffs in Australia are a rate paid for electricity fed back into the grid (Martin, N & Rice, J 2013 p.697), state run schemes allow households to get an incentive for feeding electricity back into the grid. There are two types of tariffs, net feed-in (export metering) credits the homeowner only for surplus energy that is produced, whereas gross feed-in pays for each kWh produced by the grid connected system. Here in Queensland the tariff used is a net feed-in (Zahedi, A 2010 p.3253). If tariffs span a minimum to maximum value, averages will be taken for the simulation.

Table 1: AGL Rates (source: AGL 2017)

| **Tariff Type** | **Supply/Usage** | **Cost (cents / kWh)** | **Supply charge (cents / day)** |
|---|---|---|---|
| Single Rate | All Usage | 28.60 | 110.0 |
| Solar feed-in | All Usage | 10.6 to 20.0 | 7.7 |

Table 2: Alinta Energy Rates (source: Alinta Energy 2018)

| **Tariff Type** | **Supply/Usage** | **Cost (cents / kWh)** | **Supply charge (cents / day)** |
|---|---|---|---|
| Single Rate | All Usage | 20.185 | 108.90 |
| Solar feed-in | All Usage | 11.0 | 11.28 |

Table 3: Ergon Energy Rates (source: Ergon Energy 2018a-d)

| **Tariff Type** | **Supply/Usage** | **Cost (cents / kWh)** | **Supply charge (cents / day)** |
|---|---|---|---|
| Single Rate | All Usage | 27.83 | 97.84 |
| Solar feed-in | All Usage | 9.369 | 14.07 |

Table 4:Origin Energy Rates (source: Origin Energy 2018a, b)

| **Tariff Type** | **Supply/Usage** | **Cost (cents / kWh)** | **Supply charge (cents / day)** |
|---|---|---|---|
| Single Rate | All Usage | 26.620 | 124.003 |
| Solar feed-in | All Usage | 14.0 | 6.974 |

### 2.1.2 Household Usage

The varying house sizes in this project will be small, medium and large. The locations that will be used to ensure different solar irradiance, weather data and demand is compared are Brisbane, Toowoomba, Hervey Bay, Barcaldine and Cairns. The Australian Government Energy Made Easy Home Energy Usage calculator, defines the following (EnergyMadeEasy 2018):

- Small: 2 people, no pool
- Medium: 3 people, no pool
- Large: 5+ people, plus pool

This shows a benchmark of annual usage throughout the seasons, as obtaining actual load profiles for this project was unachievable, and to ensure ethics are upheld the load profiles that match the households above will be simulated. MATLAB® was used to find the average annual usage (see Appendix E on page 158) for each of the sites taken from seasonal data based on the Home Energy Usage tool.

Table 5: Annual Consumption per day (source: EnergyMadeEasy 2018)

| Location | Postcode | Small (kWh) | Medium (kWh) | Large (kWh) |
|---|---|---|---|---|
| **Brisbane** | 4000 | 12.62 | 14.84 | 29.54 |
| **Toowoomba** | 4350 | 12.63 | 13.32 | 28.14 |
| **Hervey Bay** | 4655 | 12.63 | 14.84 | 29.54 |
| **Barcaldine** | 4725 | 19.41 | 22.78 | 24.32 |
| **Cairns** | 4870 | 17.54 | 20.05 | 21.59 |

The data that has been used is from a collective 8000 households across Australia in the 2017 period (EnergyMadeEasy 2018), this was used to calculate the average household energy on the Energy Made Easy calculator (EnergyMadeEasy 2018).

## 2.2 Solar Panels

Solar panels are an active part of renewable generation, they are the most cost-effective solutions to ensuring households can save on their electricity bill. Solar panels are constructed of cells known as photovoltaic cells, which are subsequently known as modules when electrically connected in which forms the panel. The cells are made up of semiconductors, in which the current market has two different types, **monocrystalline** and **polycrystalline** silicon cells (Aldous, S 2000 p.2). As seen in Figure 3, a solar cell consists of a positive type (P-type) and negative type (N-type), in which is doped with Boron and has three electrons in its outer shell instead of four (Aldous, S 2000 p.3), this creates a P/N cell junction which acts as a diode. Photons (Sunlight) hits the solar cell and the energy frees the electron-hole pairs. The cell's electric field causes a voltage, DC power is produced, and the basic functionality of a solar cell is observed (see Appendix D.1, Figure 70). Due to its reflective material, silicon requires an antireflective coating to be applied to the top of the cell to reduce reflection losses to around 5% (Aldous, S 2000 p.4), an additional glass cover plate is used to protect the cell from the elements. The equivalent circuit for the PV cell can be seen on the following page in Figure 4.

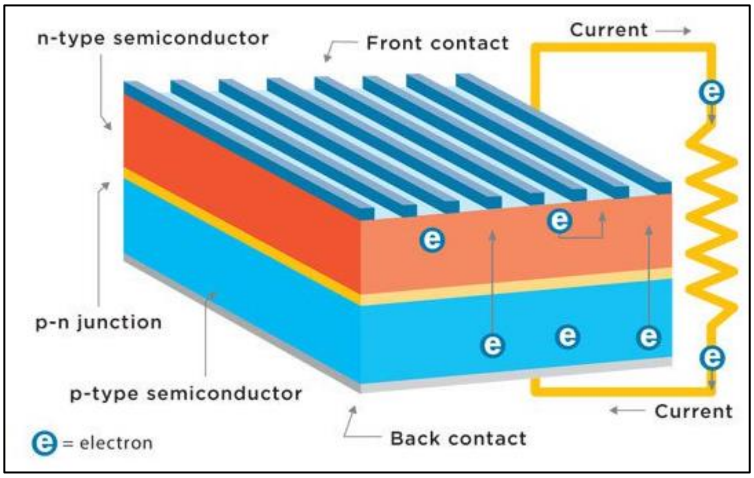


Figure 3: Cell construction (source: Southern tier solar works N.Y)

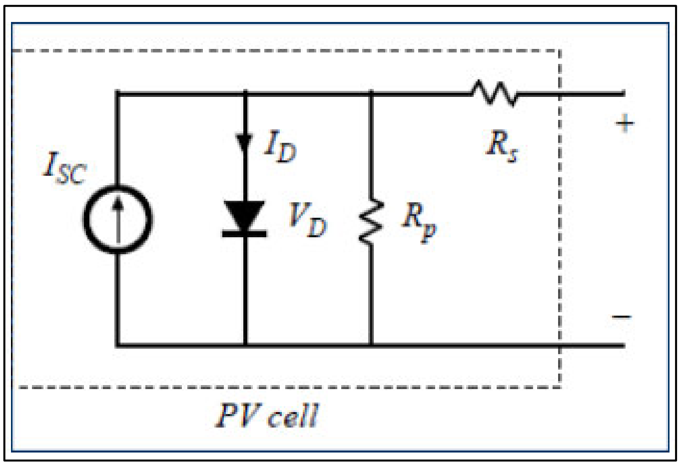


Figure 4: PV cell equivalent circuit (Mandour, R & Elamvazuthi, I 2013 p.663)

The circuit contains a current source with a diode, shunt resistance and series resistance, the diode current is responsible for producing the nonlinear IV curve of the PV cell that is mentioned in section 2.2.4 on page 20.

Kirchhoff's Current Law (KCL) of the above circuit results in:

$$0 \;= I_{sc} - I_D - \frac{V_D}{R_p} - I_{PV} \qquad 1$$

$$I_D \;= I_o\left(e^{\frac{V_D}{V_T}} - 1\right) \qquad 2$$

Applying Kirchhoff's Voltage Law (KVL) results in:

$$V_{PVcell} = V_D - R_s I_{PV} \qquad 3$$

Where,

$I_{SC}$ = short circuit current of PV cell

$I_D$, $V_D$ = Diode current, Diode voltage

$I_o$ = P / N junction reverse saturation current

$I_{PV}$, $V_{PV}$ = PV current, PV voltage

$R_S$ , $R_P$ = Series resistance , Parallel resistance

### 2.2.1 Types of Solar Panels

Monocrystalline (crystal silicon) and Polycrystalline are both types of solar cells constructed from crystalline silicon. Both are very similar in performance however Monocrystalline is created from a single crystal structure that is placed in a vat of molten silicon (Sendy, A 2017), known as Czochralski method. Polycrystalline (Multicrystalline) is a newer technology that rather than drawing the silicon seed up as is done with Monocrystalline the vat of silicon is left to cool, this is what forms the distinctive appearance of Polycrystalline (Sendy, A 2017) as seen below comparing the two panels in Figure 5.

Table 6: Advantages and disadvantages panel types

| Panel Type | Advantages (Sendy, A 2017) | Disadvantages (Sendy, A 2017) |
|---|---|---|
| Monocrystalline | Space efficient, long lifespan | More expensive |
| | Better performance in shade | Polycrystalline cheaper |
| Polycrystalline | Simpler and cost effective | Efficiency: 14% to 16% |
| | High temperature coefficient | Lower purity, lower space efficiency |
| | | Performance affected by shade |

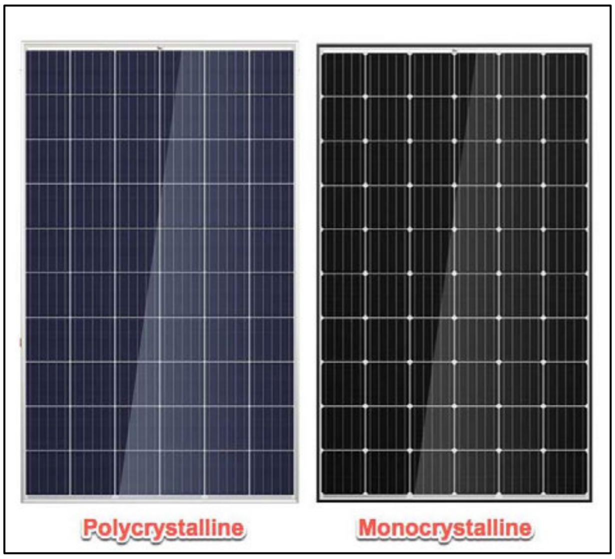


Figure 5: Polycrystalline and Monocrystalline solar panels (SolarQuotes 2009)

Apart from the choice of Monocrystalline or Polycrystalline for panels, depending on the manufacturer a panel can be either N-type or P-type. The typical format that has been used for the past three decades is a P-type solar cell. P-type solar cell is where the base of cell is positive and attracts the negatively charged electrons to it (Brakels, R 2017) due to being doped with Boron. P-type solar cells have reached their maximum efficiency, N-type is becoming more popular as manufacturing costs reduce further and efficiency increases (Svarc, J 2018a), due to not being prone to the Boron-Oxygen defect (MacDonald, D 2012 p.1).

Growth of N-type and P-type ingots have been a major factor into the popularity of P-type over N-type in recent years. Parallel or series connection is another important aspect to consider when solar panels are installed. A series string of panels installed in two different orientations will result in a significant power loss and as per AS5033 (clause 2.1.6), running two parallel strings of panels in different orientation is allowed (Cavanagh, M 2018). As per how parallel connections work in the electrical environment, different orientations will only affect the voltage slightly as current is added instead of voltage, so power loss is minimal.

### 2.2.2 Factors Impacting Solar Panels

There are a variety of factors that should be first considered in which will have a detrimental effect on the efficiency of the system if the overlooked, these have been taken from multiple resources, including: dkaSolarcentre 2017, Dinçer, F & Meral, ME 2010, O'regan, B & Grätzel, M 1991.

- Insolation and irradiance
- PV array tilt and azimuth angle (orientation)
- Weather, soiling, shading
- Light Induced Degradation (LID) resistance, panel reflection, output yields
- Quality of product, maintenance and physical size

**Insolation and Irradiance**

Insolation is related to the amount of electromagnetic energy (solar radiation) incident on the surface of the earth (Apricus N.Y). It is measured in kWh / m$^2$ / day and is the amount of solar energy that strikes a square metre of the earth in a single day (Apricus N.Y):

$$E\left(\frac{kWh}{day}\right) = R * A * H * PR \qquad 4$$

**E** – Power output (kWh / day)**,** **R** – Solar panel efficiency (%), **A** – Total panel area (m$^2$), **H** – Annual average solar insolation, **PR** – performance ratio (coefficient for losses (ranges between 0.5 and 0.9)).

Irradiance is the instantaneous solar power per unit area (David, L 2015) and changes throughout the day. Measured in kilowatts per square metre, and directly affects the power generated by a solar PV system at a given moment (David, L 2015). Three aspects of irradiation that make up the whole concept is Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI) and both when combined (Kipp&Zonen 2013) below, calculate the Global Horizontal Irradiance (GHI):

$$GHI = DNI * cos(\theta) + DHI \qquad 5$$

$\boldsymbol{\theta} -$ Solar zenith angle (vertically above location = 0$^o$, horizontal = 90$^o$)

As defined by the US department of Energy (NREL 2018), zenith angle is the angle between the direction of interest (the sun) and that at which is directly overhead. BOM data and appropriate NASA solar radiation data will be utilised for each location that is being analysed for this project.

### PV Array tilt and Azimuth angle (orientation)

The array tilt and orientation are vital in optimising a full solar system, if it isn't optimised correctly, massive losses can accumulate before even reaching the inverter. In Australia due to being in the Southern Hemisphere, true North facing panels will typically give the greatest energy output. Optimum tilt angle is site specific as it depends on the daily, monthly, and yearly path of the sun (Yadav, AK & Chandel, SS 2013 p.503). When panels are installed, they are orientated towards the equator, but slight variations in orientation can achieve maximum solar power output. As discussed previously, the position of the sun in the sky is given by the zenith angle ($\theta$) and the angular position at solar noon is declination (Yadav, AK & Chandel, SS 2013 p.503). Monthly average daily solar radiation on a titled surface ($H_T$) is as follows:

$$HT = (H_B + H_D + H_R) \tag{6}$$

$H_B$ = beam solar radiation

$H_D$ = diffuse radiation

$H_R$ = ground reflected radiation

Models in MATLAB® have previously been developed for studies that calculate the solar energy for varying inclinations of a PV module (Nfaoui, M & El-Hami, K 2018 p.540). As discussed earlier, orientation is an important factor for the efficiency of the module, Table 7 shows the difference roof orientation makes to power losses.

Table 7: Roof orientation power loss (SolarMarket 2018a)

| **Roof orientation** | **Power losses (%)** |
|---|---|
| North | 0 |
| North East / North West | 7 |
| East / West | 15 |
| South | 38 |

The basic rule of thumb for maximum annual energy availability is a surface slope equal to the latitude of the area, and the surface should face the equator (Handoyo, EA, Ichsani, D & Prabowo 2013). Anything else as seen in Table 7, will result in losses. As defined previously, Azimuth angle as seen below is the compass direction from which the sunlight is coming (PVEducation 2019). In general, at sun rise the angle is 90° and 270° at sunset.

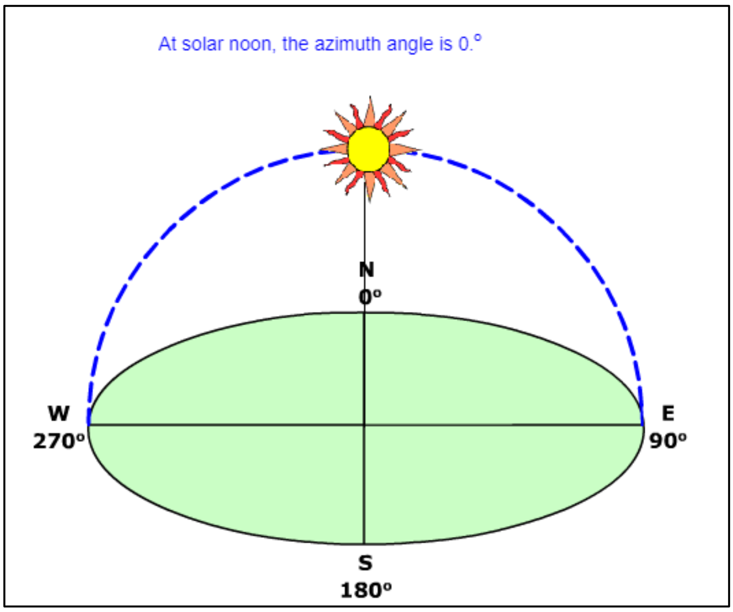


Figure 6: Azimuth angle at noon (PVEducation 2019)

The azimuth is calculated as follows:

$$\sin(azimuth\ angle) = \frac{\sin(\omega)\cos(\delta)}{\cos(\alpha)} \tag{7}$$

Where,

α = elevation angle

ω = hour angle

$\delta$ = declination angle (rads)

As noted in the journal by Nfaoui, M & El-Hami, K 2018, and Radhika, S.K. Suman 2015, shows that varying azimuth angle (whilst tilt angle remains at 20°), a 20° increase from 120° to 140° results in an increase solar output on average of 200 kWh per month. But there is a point where angle change will result in losses (120° to 240°) of around 2 kWh per month (Radhika, S.K. Suman 2015 p.5109). This is all relative to the location tested, and results will vary substantially per location.

**Weather, soiling and shading**

The weather effect on solar panels directly influences the panel's operating efficiency, often efficiency figures quoted in the datasheets by PV manufacturers are for a clean laboratory environment at 25 °C and standard air density. This is often not appropriate as field studies suggest that actual output could be reduced by as much as 60% due to soiling (dust and polluted climate) (Ghazi, S & Ip, K 2014 p.1). A study done in the UK concerning dry dust covers saw that even a small number of fine particles could reduce light transmittance by 11% (Ghazi, S & Ip, K 2014 p.50).

Standard test conditions (STC) have room temperature at 25 °C and solar irradiance of 1000 W / $m^2$, however solar spectrum through the atmosphere varies based on locality and climate conditions such as water vapour, $CO_2$ and dust particles. Throughout the year's studies have been done on the soiling of panels and their effect. Bird droppings, water stains, traffic pollutants and agricultural dust on solar cells are one of the few variables that seen an increase cell temperature of up to 10°C (Ghazi, S & Ip, K 2014 p.51). Variable humidity has a significant influence on the deposition of solid particles on the glass surface of the array (Ghazi, S & Ip, K 2014 p.55), where a correlation has been determined between humidity and solar output.

Additionally, efficiency suffers with large rainy days and low amounts of solar radiation (resulting in a system that is almost non-functioning). The humidity levels that influence PV outputs are any higher than 80%, precipitation more than 12 mm of rain per day, as well as wind speed lower than 30 km/hr will all result in poor efficiency (Ghazi, S & Ip, K 2014 p.56). In the study by Ghazi, S & Ip, K 2014 there was almost zero PV output when the weather conditions were poor, and precipitation was evident. Hence it is obvious that annual rain fall, humidity, temperature and wind speed of the local area for each location will be used. In recent years, hydrophilic coatings for the cell's glass have been innovated to minimise the effect of weather conditions (Ghazi, S & Ip, K 2014 p.59), however these weather effects are still prominent throughout the market (Ghazi, S & Ip, K 2014 p.59). Majority of panels are best operated at 25°C, if the ambient temperature is higher the panels output declines (Clean Energy Council 2018c p.14) based on the panel's temperature coefficient.

### Light Induced Degradation (LID) resistance and Panel reflection

Solar panels are designed to absorb light, however some cases it might reflect light, resulting in losses throughout the solar output. Anti-reflective coating applied to the glass panel, can increase up to 5% absorption at the panel (SolarChoice 2013). Typically, the irradiance that isn't absorbed and converted to electricity will convert to thermal energy and hence increase the arrays temperature resulting in an efficiency loss (Hosseini, R, Hosseini, N & Khorasanizadeh, H 2011 p.2993). A continuous film of water on the surface of the PV panel has shown to have lasting effects on the operation of the PV system, ensuring efficiency and output is maintained. First it reduces the reflection of the solar irradiance, and mostly reduces the panel temperature by absorbing heat generated by the panel (Hosseini, R, Hosseini, N & Khorasanizadeh, H 2011 p.2997).

This is all a result of the temperature of the water running over the panel surface that causes evaporation, additionally water collected at the lower end of the panel can be used as a utility for heating purposes (Hosseini, R, Hosseini, N & Khorasanizadeh, H 2011 p.2999). Silicon PV modules have a natural degradation due to the physical reactions through the P-N junctions of a PV module (Silver, H 2015). The initial degradation is known as power stabilisation and is a result of exposure to sunlight. Average percentage of power loss for the 1st year among all types of panels is around 3% (Silver, H 2015). Afterwards power degradation occurs at around 0.8% for the following years after the initial install.

**Output Yields**

Power output from solar panels vary between a variety of different available panels and locales. As seen on page 5 of the consumer review report from the CEC (Clean Energy Council 2018c p.4), shows the average daily production of common grid connected systems throughout Australia. A typical household as described in section 2.1.2 and Table 5 on page 9, across Australia consume around 18 kWh / day, the CEC recommends a 1 kW to 2 kW system will displace on average 25% to 40% of the average electricity bill (Clean Energy Council 2018c p.5).

Table 8: Average solar yield in Australia (kWh) (Clean Energy Council 2018c, p.4)

| City | 1 kW | 1.5 kW | 2.0 kW | 3.0 kW | 4.0 kW |
|---|---|---|---|---|---|
| **Adelaide** | 4.2 | 6.3 | 8.4 | 12.6 | 16.8 |
| **Brisbane** | 4.2 | 6.3 | 8.4 | 12.6 | 16.8 |
| **Cairns** | 4.2 | 6.3 | 8.4 | 12.6 | 16.8 |
| **Melbourne** | 3.6 | 5.4 | 7.2 | 10.8 | 14.4 |
| **Sydney** | 3.9 | 5.85 | 7.8 | 11.7 | 15.6 |

**Quality of Product and Maintenance**

Depending on manufacturer the quality of the build can vary, products may widely vary between solar output, efficiency, maintenance costs and lifetime expectancy. The modules that will be used for this project are those approved for building and ground mounted applications as per the CEC terms and conditions (Clean Energy Council 2018d, Clean Energy Council 2018e). The modules will also comply with CEC design and install guidelines set out in the Terms and Conditions (T&C). Upon reviewing the top 10 solar panel reviews (Svarc, J 2018a), the following panels will be used for this project in accordance with the approved list by the CEC. A wide variety of different solar panels with varying outputs and warranties have been included in the table below. Prices included in Table 10 are an estimate as the price varies per source and there is no universal price for solar panels at the current time of writing. Sources: LG 2018, SunPower Corporation 2018, RecGroup 2018a, RecGroup 2018b, HanwhaSolar 2018, TrinaSolar 2018, JinkoSolar 2018.

Table 9: Solar Panel Summary

| Manufacturer | Name | Model # | Efficiency (%) | Pmax (W) | Op Temp (°C) |
|---|---|---|---|---|---|
| LG | Neon 2 | LG340N1C-A5 | 19.8 | 340 | -40 to +90 |
| | | LG330N1C-A5 | 19.6 | 335 | |
| SunPower Corporation | X-Series | SPR-X22-370 | 22.7 | 370 | -40 to +85 |
| REC | TwinPeak 2 Series | REC275TP2 | 16.5 | 275 | -40 to +85 |
| | N-Peak | REC330NP | 19.8 | 330 | -40 to +85 |
| Hanwha Solar | Hanwha Solar | Q. PEAK BLK-G4.1 300 | 17.7 | 295 | -40 to +85 |
| Trina Solar | DuoMax | TSM-285PEG5 | 17.3 | 285 | -40 to +85 |
| Jinko Solar | Eagle 60P | JKM260PP-60 | 15.88 | 260 | -40 to +85 |

Op Temp = Operating Temperature

Table 10: Solar Panel information

| Manufacturer | Name | Model # | $/W | Warranty (years) | Cell type |
|---|---|---|---|---|---|
| LG | Neon 2 | LG340N1C-A5 | 1.133 | 25 | Mono / N-type |
| | | LG330N1C-A5 | 1.022 | | |
| SunPower Corporation | X-Series | SPR-X22-370 | 1.74 | 25 | Mono / N-type |
| REC | TwinPeak 2 Series | REC275TP2 | 0.78 | 20 | Poly / PERC |
| | N-Peak | REC330NP | 0.846 | 20 | Mono / N-type |
| Hanwha Solar | Hanwha Solar | Q. PEAK BLK-G4.1 300 | 0.9 | 12 | Mono / P-type |
| Trina Solar | DuoMax | TSM-285PEG5 | 0.824 | 10 | Poly |
| Jinko Solar | Eagle 60P | JKM260PP-60 | 0.49 | 10 | Poly |

Table 11: Solar Panel Electrical Specification

| Manufacturer | Name | Model # | Vmpp (V) | Impp (A) | Voc (V) | Isc (A) |
|---|---|---|---|---|---|---|
| LG | Neon 2 | LG340N1C-A5 | 34.5 | 9.86 | 41.1 | 10.53 |
| | | LG330N1C-A5 | 34.1 | 9.83 | 41.0 | 10.49 |
| SunPower Corporation | X-Series | SPR-X22-370 | 59.1 | 6.26 | 69.5 | 6.66 |
| REC | TwinPeak 2 Series | REC275TP2 | 31.5 | 8.74 | 38.2 | 9.52 |
| | N-Peak | REC330NP | 34.6 | 9.55 | 41.3 | 10.36 |
| Hanwha Solar | Q.Antum | Q. PEAK BLK-G4.1 300 | 32.19 | 9.17 | 39.48 | 9.70 |
| Trina Solar | DuoMax | TSM-285PEG5 | 32 | 8.91 | 38.6 | 9.36 |
| Jinko Solar | Eagle 60P | JKM260PP-60 | 31.1 | 8.37 | 38.1 | 8 |

### 2.2.3 Current Technology

Table 12: PV Technology

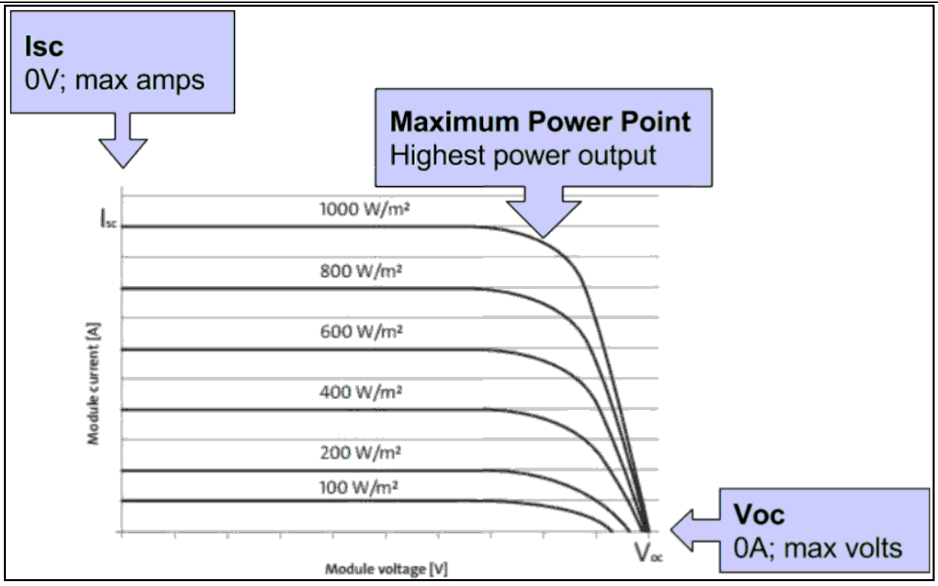
| Technology | Notes |
|---|---|
| Dual Glass Panels | Replaces traditional white EVA backing on panels, creates a double layer of glass that when compared against single layer glass is more stable (Svarc, J 2018a). Can enhance power output of panel by around 1.92% per module (Tang, T, Gan, C, Hu, Z, Niu, H, Si, J & Luo, X 2017). |
| PERC | Emerged as premium technology for both Mono and Poly cells. Uses passivation layers on rear of the cell to improve efficiency (Svarc, J 2018a). Panels available from Hanwha Solar (Q.Antum panels) have P-type PERC modules. |
| HJT | Panasonic is leading the way in HJT technology (Panasonic 2017), HJT cells use a common base of crystalline silicon with an additional thin film layer of amorphous silicon, done on either side of the cell. Compared against P/N junction cells, HJT have the potential to increase efficiency with lab results achieving 25% as noted in the journal by (Smith, DD, Reich, G, Baldrias, M, Reich, M, Boitnott, N & Bunea, G 2016). |
| Bifacial | Absorb light from both sides of the panel and in the right location and conditions can produce up to 27% more energy than traditional alternative cells (Svarc, J 2018a). Typically constructed of a glass front and clear rear polymer back sheet to encapsulate the cells. LG390NT commercial 72 cell is a new Bifacial panel on the market from LG. |

| | |
|---|---|
| Multiple wire Busbars | As seen on the cells, busbars are thin wires that run down each cell and carry electrons through the module. As PV cells have become more efficient, they in turn generate more current, with manufacturers moving from 3 busbars to 6 or even 12. LG have introduced using very thin round wires rather than flat busbars, doing so lowers electrical resistance and further increases efficiency, this is known as CELLO technology for LG panels (Svarc, J 2018a). |
| Split modules and half-cut cells | A recent innovation is using half cut cells rather than full size square cells, with the addition of moving the junction box to the centre of the module (Svarc, J 2018a). Doing so, splits the solar panel into 2 smaller panels of 50% capacity, with a parallel configuration instead of series. This increases performance due to much lower resistive losses, since each cell is half size, the width of the busbar can be reduced without impacting the power output (Svarc, J 2018a). |
| Smart Panels and Optimisers | A new technology that is becoming popular, and is able to be installed on existing panels, is integrated power optimisers. With a small chipset, they bypass individual shaded / soiled cells, in order to reduce temperature degradation (Svarc, J 2018b). Companies Tigo and SolarEdge manufacture add-on optimisers to existing panels. |

### 2.2.4 Important Panel Specifications

Table 13: Panel specifications

| Specification | Notes |
|---|---|
| Standard Test Conditions (STC) | Standard that each module is tested under, module temperature 25°C, atmospheric density 1.5, solar irradiance 1000 W / m$^2$. Voltage and current change based on temperature and intensity of light, in order to compare panels, all solar panels are tested with same conditions (Beaudet, A 2016). |
| Normal Operating Cell Temperature (NOCT) | Measured when solar panel is actively working and installed the location of choice. NOCT is realistic performance of the panels using actual world conditions and gives the customer power rating that is more realistic for the system being installed (Beaudet, A 2016). Irradiance 800 W / m$^2$, air temperature 20°C, wind speed 3.6 km / hr. |
| IV Curve | PV cells have a complex relationship between operating environment and the maximum power that the panel can produce. As seen below, when the solar cell is open circuit, current will be at its minimum and the voltage across the cell is at its maximum (open circuit voltage). At the other extreme, when the cell is short circuited the voltage is at its minimum, but current is at its maximum, which is the short circuit current (Isc). The curve therefore spans from the maximum short circuit current to maximum open circuit voltage, at the knee of the curve, the maximum power point is observed (MPP) (Miller, M 2010). |

| | |
|---|---|
| |  <br>Figure 7: Rated output of solar panels at different light intensities (Beaudet, A 2016)<br>This maximum power point reaches this point at Impp and Vmpp, typically the values of Vmpp and Impp can be estimated from the open circuit voltage and short circuit current, that is (0.8-0.9) Voc and (0.85-0.95) Isc respectively. |
| Open Circuit Voltage (Voc) | Open Circuit Voltage is the voltage of the solar panel that isn't connected to a load. This is important as it is the maximum voltage that the panel can produce under STC, and as such is used to determine how many solar panels that can be wired in series into the inverter (Beaudet, A 2016) as they essentially sum with one another. |
| Short Circuit Current (Isc) | This is the current output of a circuit that isn't connected to any load, it is measured with an ammeter across the positive and negative leads which are directly connected in series (Beaudet, A 2016). This is the highest current the panels will produce under STC. For transformer isolating inverters a DC breaker / isolator that is double pole will be required, and as per the Australian standards will need to be rated to 1.25 x Isc. |
| Maximum Power Point (Pmax) | Amount of power (measured in Watts) that the module produces at maximum efficiency, as seen in the above figure, it is at the knee of the IV curve and is where the combination of voltage and current results in the highest wattage (Beaudet, A 2016). When a solar array has a Maximum Power Point Tracking (MPPT) inverter, this is the point that the electronics attempt to maximize the power output. |
| Maximum Power Point Voltage (Vmpp) | Actual voltage of the module when connected to a load and when the power output is the greatest. It is the voltage that is necessary to see in order to obtain full power output that the panel is specified (Beaudet, A 2016). In real world the actual Vmpp will vary over a day and will consider temperature, shading and soiling of the panel surface, and thus rarely achieve its maximum power point voltage seen under STC. |

| | |
|---|---|
| Maximum Power Point Current (Impp) | Actual current output of the module when connected to a load at the point when maximum power point is measured. As mentioned with maximum power point voltage it is the actual current that is necessary to achieve the maximum power point when connected to MPPT devices (Beaudet, A 2016). |
| Temperature Coefficient | All solar cells have a temperature coefficient, typically monocrystalline solar cells have a coefficient of - 0.5%/°C. This means a solar panel will lose half of one percent of its power for every degree the temperature rises (TindoSolar 2019). Majority of solar panels are all rated at 25°C, so any temperature above will degrade the panel and result in losses based on this coefficient. |

## 2.3 Inverters

Inverters (converters) are the next stage when solar panels are being installed at residential homes, sizing the right inverter will ensure that the solar system is operating as efficiently as possible. DC is created at the panel, depending on the type of battery bank (DC or AC coupled) an inverter is used to convert it from DC to AC and is used on the load, selling back to the grid or being stored in the battery bank. Off grid applications for microgrids, require an additional DC to DC converter between the array and batteries as well an inverter with a built-in charger (Worden, J & Zuercher-Martinson, M 2009).

In an inverter, power from the PV array is inverted to AC power via a set of solid-state switches – Metal Oxide Semiconductor Field-Effect Transistors (MOSFET) or insulated-gate bipolar transistor (IGBT) that flip DC power back and forth, creating AC power (Worden, J & Zuercher-Martinson, M 2009). As noted in section 2.2 on page 9, MPPT is a method used to remain on the maximum power point of a PV array. Inverter will use this to ensure that the MPP is extracted at all times in order to maintain high efficiency (EnergySavingTrust N.Y).

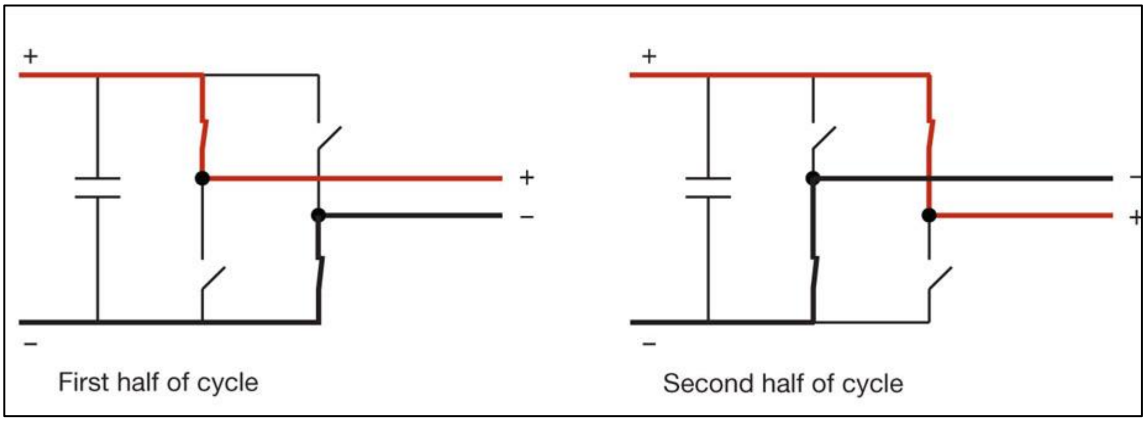


Figure 8: H-bridge operation in a single-phase inverter (Worden, J & Zuercher-Martinson, M 2009)

### 2.3.1 Types of Inverters

**Standard String Inverter**

Most common type for residential use, majority of inverters available on the market are string. Generally, a single inverter is only required per installation, and is named due to the string connection that solar panels form. Lifetime of an inverter is typically 10 years and full solar system failures are believed to be a result from inverter failure (Ristow, A, Begovic, M, Pregelj, A & Rohatgi, A 2008).

Table 14: String Inverter (Advantages / disadvantages)

| Advantages (SolarMarket 2018b) | Disadvantages (SolarMarket 2018b, Harb, S, Kedia, M, Zhang, H & Balog, RS 2013) |
|---|---|
| Hundreds of approved inverters, easy to find an inverter to suit system | String inverters don’t allow for battery pack integration, separate battery inverter is required |
| Technology more reliable and efficient | May require an additional energy management system to increase efficiency depending on manufacturer |
|  | DC voltage can be as high as 600 V, creating a hazardous system voltage |
|  | Require replacement at least once for a typical 25-year power output guarantee from the panels |

A major downside of string inverters is that even if one panel is shaded / soiled the output of every panel on the string is reduced to that panels’ output (Zipp, K 2016) as a result of the cabling topology. To mitigate effects of shading, power optimisers can be installed at the module level (on each panel), when the solar panel already comes with a power optimiser this is known as a Smart Module (Zipp, K 2016).

Technology has developed where string inverters have additional add-ons that can control hot water systems, and batteries all in the one component (RedShiftSolar 2018). SolarEdge manufacturer is leading the way with DC optimisers.

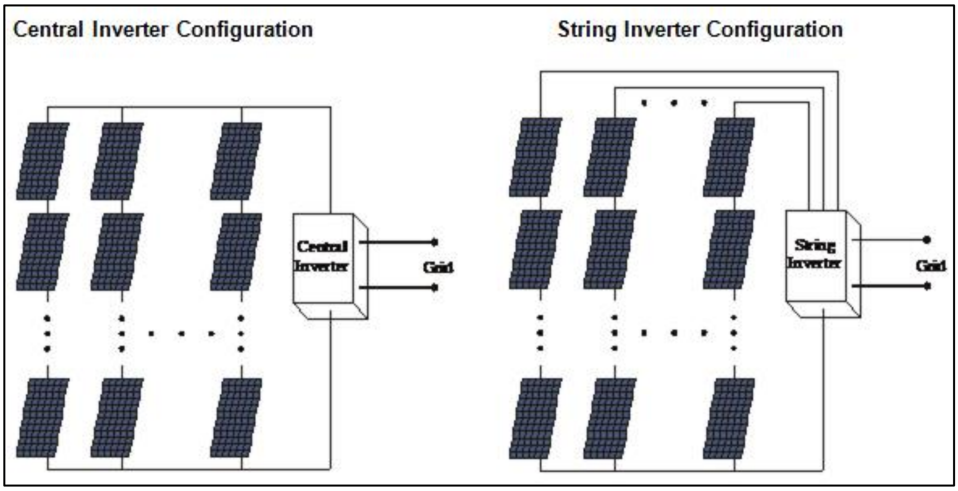


Figure 9: Central vs String inverter (Gnanajothi, G 2012)

### Off Grid Inverter

Similar to the standard string inverters but require powerful battery inverters with inbuilt chargers than can be set up as either AC or DC coupled systems as discussed in section 2.4 on page 33. Modern flexible off-grid inverters are known as interactive inverters and are commonly used to create hybrid grid-tie systems. Used typically in rural settings they can function indefinitely using only the sun to provide useable power. Requires large amp-hour battery cells, large cabling systems, fault protection and isolators. This is usually a large investment initially but return on investment will correct itself and provide many years of reliable service (RedshiftSolar 2018).

### Battery Backup Inverter

Battery inverters are responsible for the charging / discharging of the electricity stored in a solar battery, battery inverters are installed alongside a standard string inverter, which it will AC couple with. Battery inverters are bidirectional in nature, including both a charger and inverter, and feeds AC power back into switchboard instead of grid power if used in an off-grid setting (SolarMarket 2018b). A similar battery backup that works simultaneously with solar PV and battery banks, is a hybrid inverter (multi-mode inverter). It simultaneously manages inputs from both solar panels and battery bank, charging batteries with either solar or the electricity grid (depending on which is more economical) (Martin, J 2015) to combine both solar, battery inverter and grid tie inverter in one unit.

Table 15: Battery Backup (Advantages / Disadvantages)

| Advantages (SolarMarket 2018b) | Disadvantages (SolarMarket 2018b) |
|---|---|
| Good quality battery inverters are robust and hard wearing | Rules in regard to battery inverters can sometimes be complicated, approvals maybe required |
| Hybrid inverters present a more seamless and cost-effective solution | Battery inverter cost more than installing a hybrid inverter when initially purchasing the system |

## Micro Inverter

Recent years have seen the increase in popularity of microinverters, leading manufacturer Enphase Energy specialises in the development of microinverters for the solar market. They are a miniaturised inverter that work on a per-panel level (usually around 200W to 250W) and provide a very different approach to single string inverters in which has substantial efficiency benefits over the alternative. With the introduction of the IQ 7 series from Enphase, microinverters are becoming a more common choice when compared to string inverters, they work by individually converting DC electricity from each solar panel into AC electricity on the roof, with no need for a separate inverter (EnergySage 2019a). One of the major aspects of microinverters is that they cancel out the impacts of partial or complete shading. As noted below in Figure 10, the string of panels on the right are all reduced to 50% due to the last panel being soiled, on the left however using 4 microinverters results in only 1 module losing efficiency to 50%.

Table 16: Microinverters (Advantages / Disadvantages)

| **Advantages (SolarMarket 2018b)** | **Disadvantages (SolarMarket 2018b)** |
|---|---|
| Panel output collected individually; underperforming panel doesn't impact other panels | More expensive than standard string inverters at start of investment |
| Low voltage DC due to DC – AC conversion at the panel | New technology, small market |
| Installation is cheaper and easier as topology is simpler | Costly to replace as roof access is required, extreme heat due to positioning under panel |

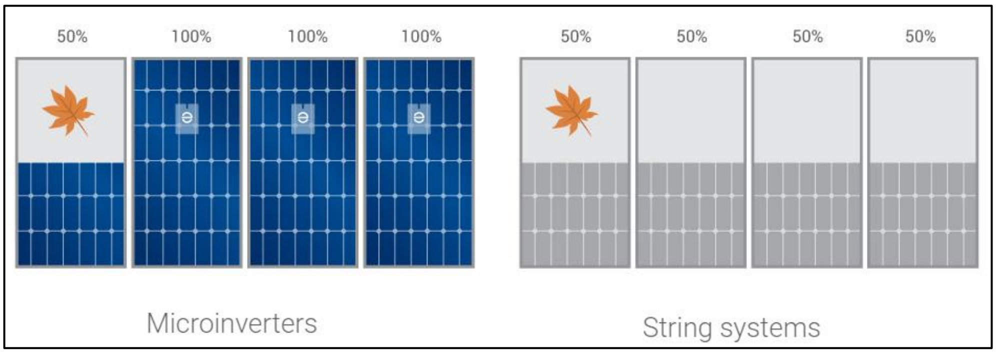


Figure 10: Microinverter vs String system (Enphase 2019a)

Additionally, microinverters provide MPPT at each panel, the lifetime of each microinverter is much higher than conventional inverters. Microinverter manufacturers offer lifetime warranties ranging from 20 – 25 years (Gnanajothi, G 2012). A study done in 2013 comparing a 6 kW string system and equivalent microinverter system showed that including all impacts on the cost of the PV system, the microinverter reached its break even cost quicker than the equivalent string inverter in the same operating environment (Harb, S, Kedia, M, Zhang, H & Balog, RS 2013 p.1).

The levelized cost of electricity (LCOE) was also calculated, over the system's lifetime the microinverter with consideration of light shade weighting factor, will take less than 3 years to reach the break-even cost with the same configuration of the string inverter (Harb, S, Kedia, M, Zhang, H & Balog, RS 2013 p.2889). The conclusion of the paper resulted in that the additional energy harvest found gave it an economic advantage over expected lifetime of the system, particularly when the cost of replacing the string inverter is considered (Harb, S, Kedia, M, Zhang, H & Balog, RS 2013 p.2890).

### 2.3.2 Factors Impacting Inverters

In PV systems, the inverter is responsible for the majority of failures, and thus most have been known to fail based on the aluminium electrolytic capacitors typically used in the DC bus (Ristow, A, Begovic, M, Pregelj, A & Rohatgi, A 2008 p.2581). Before installation, typical payback time and energy price per kWh is evaluated for a system, this is often assumed to work without interruptions. The most used index in reliability studies is the mean time between failures (MTBF), it is the mean average time period between system failures due to the random failures of one of its component parts (Ristow, A, Begovic, M, Pregelj, A & Rohatgi, A 2008 p.2581). A MTBF of 522 years has been reported for residential systems, which means in a year there would be 1 module of every 522 installed to fail. Inverters however are much less reliable, regardless of warranty length, due to the DC to AC switching or voltage levels exceed the limitations that the inverter is rated.

### 2.3.3 Current Technology

The current technology that is used in the market is as follows, all inverters mentioned below have compliance with CEC design and install guidelines set out in the terms and conditions. Typically, the inverter component represents around 20% of an entire PV system. Average warranty for grid connected inverters is around 10 to 20 years, with most around the 10-year mark. As per the solar choice comparison of solar inverters and due to the circumstances of this project, hybrid, battery and easily upgraded inverters that accept battery banks for off grid solutions will be analysed. Price range included is an estimate as the price varies per source and there is no universal price for the inverters at the current time of writing. The following inverters are currently the most used inverters in Australia, the following sources are used for the information presented on the following page in Table 17. (source: SolaXPower 2018, SolarEdge 2018, Fronius 2019, Redback 2019, Huawei 2019, SMA 2018a, Sungrow 2018 and Enphase 2019b).

Table 17: Current Inverter efficiency and price

| Manufacturer | Model | Type | Efficiency (%) | Price ($) |
|---|---|---|---|---|
| SolaX | X1-Hybrid | Hybrid | 97.8 | 1049.5 |
| SolarEdge | StorEdge SE5000-AUS / SE6000-AUS | Hybrid | 97.6 | 2,565.0 |
| Fronius | Symo | Hybrid | >90.0 | 1,939.0 |
| | Symo 10.0-3-M | Hybrid | 97.4 | 3,061.30 |
| Redback | Smart Hybrid | Hybrid | 97.6 | 3,844.50 |
| Huawei | Fusion Home SUN2000L | Hybrid | 98.5 | 2,147.19 |
| SMA | Sunny Boy Storage SBS2.5 | Battery Inverter | 96.8 | 2,101.10 |
| Enphase Energy | IQ7 | Micro | 96.5 | 302.45 |

Table 18: Electrical characteristics of Inverters

| Manufacturer | Model | Nominal output AC power (kW) | Max DC Input Power (kW) | Nominal DC operating voltage (V) | MPPT voltage range (V) | No. of MPP trackers | Total harmonic distortion (%) |
|---|---|---|---|---|---|---|---|
| SolaX | X1-Hybrid | 4.0-6.0 | 3.25-6.0 | 360 | 125-580 | 2 | <2 |
| StorEdge SE5000-AUS | StorEdge SE5000-AUS | 5.0 – 6.0 | 6.75 – 8.1 | 400 | N/A | N/A | <3 |
| Fronius | Symo | 2.5 – 5.0 | 5.0 – 8.0 | 595 | 200-800 | 1 | <3 |
| | Symo 10.0-3-M | 10.0 | 15.0 | 200 | 270-800 | 2 | 1.8 |
| Redback | Smart Hybrid | 4.6 | 6.0 | 500 | 125-500 | 2 | <3 |
| Huawei | Fusion Home SUN2000L | 2.0 – 5.0 | 3.0 – 7.5 | 495 | 120-480 | 2 | <3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SMA | Sunnyboy Storage SBS2.5 | 2.5 | 2.65 | 500 | 100-500 | 2 | N/A |
| Enphase Energy | IQ7 | 0.25 / panel | 0.235 to 0.350 per panel | 230 | 184 – 276 | N/A | N/A |

Table 19: Technical Data for Inverters

| Manufacturer | Model | Operating Temperature (°C) | Cooling | Features |
|---|---|---|---|---|
| SolaX | X1-Hybrid | -20 to +60 | Forced | Multiple work modes, Wi-Fi port |
| SolarEdge | StorEdge SE5000-AUS / SE6000-AUS | -20 to +60 | Natural convection | Simple design, built in monitoring of battery status |
| Fronius | Symo | -25 to +60 | Regulated air cooling | Intelligent energy flow system allows simultaneous energy flows in all direction |
| | Symo 10.0-3-M | -40 to +60 | Regulated air cooling | Integrated data communication, dynamic peak manager |
| Redback | Smart Hybrid | -25 to +60 | Natural convection | UPS / battery backup in one unit, export control, IP65 outdoor unit |
| Huawei | Fusion Home SUN2000L | -30 to +60 | Natural convection | High efficiency inverter topology, high European weighted efficiency |
| SMA | Sunny Boy Storage SBS2.5 | -25 to +60 | Natural convection | Integrated web server, and the direct portal access |
| Enphase Energy | IQ7 | -40 to +60 | Natural convection | High system efficiency, Lightweight and simple, optimised for 60 cell, 72 cell and 96 cell |

### 2.3.4 Sizing

Sizing of the inverter with the chosen PV module is important in achieving the desired kW output the solar PV absorbs. Sizing of the inverter is affected by its ambient temperature as well as its efficiency curve.

All inverters have an efficiency curve that changes as result of the inverters power output. It is important to know when the solar panels will be operating within the curve, the flatter the better as it will ensure the efficiency is optimised. Another addition is comparing between inverters and which ones perform better, one inverter might have a higher efficiency, but another might have a slightly lower efficiency over a broader range of power output. The key characteristics that need to be taken into consideration when sizing an inverter are as follows from (EnergySavingTrust N.Y p.1):

- Maximum amount of input DC electricity (max DC power in Watts)
- Maximum input voltage (maximum voltage the inverter can manage before electronics are damaged
- Initial input voltage (sometime called start-up voltage) – the minimum number of volts the solar PV panels need to produce for the inverter to work
- Maximum power point voltage range – the voltage range at which the inverter is working most efficiently

Additional rules from the CEC are as follows, these rules are effective from 2013 and haven't changed in the current years, it allows installers to correctly install inverters that are sized correctly. The selection of the inverter for the PV system will depend on (Clean Energy Council 2018f p.11):

- Energy output
- Matching of the allowable inverter string configurations with the size of the array in kW and the size of individual modules within that array
- Whether the system will have a central inverter or multiple inverters
- Maximum DC input current

In order to facilitate the efficient design of PV systems, as per section 9.4 of the CEC guidelines, the inverter nominal AC power output cannot be less than 75% of the array peak power and it shall not be outside the inverters manufacturer's maximum allowable array size specification (Clean Energy Council 2018f p.12). This 25% difference for the inverter considers losses associated from the solar panels. All inverters being tested meet the inverter selection mentioned in the CEC guidelines, solar array peak power is as follows:

$$Array\ peak\ power = Number\ of\ modules * \ maximum\ power\ at\ STC \text{ (kW)} \qquad 8$$

For example, an array peak power is 3 kW (250W x 12). Nominal output power from an example inverter is around 2.5 kW. The inverter's nominal AC output is 83% (2.5kW / 3.0 kW), therefore this meets the first hurdle as per CEC guidelines. The second hurdle is based around the inverters DC Max input power, from the specification sheet this is 2.9 kW. Since the array peak is larger than the maximum input power this isn't allowed under the guidelines and is illegal to install in Australia with insurance.

As per section 9.5 of the CEC guidelines (Clean Energy Council 2018f p.13), crystalline PV array de-rating considerably affects the size of the inverter. Based on typical figures below, the inverter can be sized accordingly.

- 97% for manufacturer
- 95% for dirt
- 82.5% temperature rating

De-rating comes to 0.97*0.95*0.825 = 0.76

An inverter can be rated 76% of the peak power of the array in this example if the manufacturer doesn't provide DC input specifications (Clean Energy Council 2018f p.12). As previously discussed, the output power of a solar module is affected by the temperature of the solar cells. As per CEC guidelines crystalline PV modules carry around -0.5% for every 1-degree variation in temperature. This derating factor formula is (Clean Energy Council 2018f p.14) as follows:

$$F_{temp} = 1 + \left[\gamma * \left(T_{cell_{eff}} - T_{STC}\right)\right] \tag{9}$$

Where,

$F_{temp}$ = temperature de-rating factor, dimensionless

$\gamma$ = power temperature coefficient per °C

$T_{cell\_eff}$ = average daily cell temperature in °C

$T_{STC}$ = cell temperature at standard test conditions, measured in °C

It is common in Australia for the total capacity of the solar panel in array to be equal to the amount of capacity of the inverter (Brakels, R 2016). This has the advantage that energy will never be lost because of the panels producing more power than the input at the inverter. When the total capacity of the panels is greater than the inverter, this is considered oversized / overclocked. However, this comes with disadvantages, as customers with single phase power are limited to 5 kW inverters, people in rural areas can only install inverters of 5 kW or less unless they pay for export limiting equipment or an export limiting inverter, and in Queensland inverters larger than 3 kW can only be installed if they have reactive power control (Brakels, R 2016).

Additionally, the inverter can be overclocked up to 133% and still receive financial assistance in the form of Small-scale Technology Certificates (SSTC), solar rebates if applicable can cover up to half the cost of the system, so it is important to not exceed limits (Brakels, R 2016).

Typical efficiency for modern inverters usually operates high and constant, when solar panels are supplying less than around 25% of an inverter's capacity their efficiency decreases. Operating cost reduction of PV systems are an important way to increase economic viability for customers. Studies done have been performed concerning inverter sizing ratio (ISR) analysis that has been carried out in order to quantify its potential benefit in the context of residential PV systems (Paiva, GM, Pimentel, SP, Marra, EG & Alvarenga, BP 2017 p.1364). The analysis of inverter sizing has been of significant purpose in the reduction of COE, and viability of any PV system. ISR is analysed for possible tilt and azimuth angle variations, additional information regarding the financial analysis behind a solar PV system is noted in section 2.6 on page 46.

### 2.3.5 Important Inverter Specifications

**Load Shifting**

Load shifting by definition is when consumption of high wattage loads is moved to different times to ensure demand is moved from peak hours to off peak hours of the day to evenly distribute the electricity usage (BusinessDictionary 2019). Due to solar panels not functioning in the evening grid tied customers will have their demand derived from the grid.

**Total Harmonic Distortion (THD)**

Power quality of electrical systems have a severe influence on control and utilisation of power, electrical systems behave like non-linear loads, creating a deformed waveform that is made up of voltage and current harmonics (Caroline 2015). THD is the sum total of the various harmonics and allows to evaluate the extent of distortion in a system (Caroline 2015). Since PV inverters are a switching device, they can cause distortion in the system's voltage as well as abnormal conditions to sensitive loads (Caroline 2015), hence it is important to have the lowest percentage as possible.

**Voltage Operating Window**

The voltage operating window is the most important aspect of matching an inverter to solar array. If the solar array voltage is outside the limits of the inverter operating window, the inverter will not operate, or the output power of the system will be greatly reduced (Clean Energy Council 2018f p.14). Many inverter data sheets have a voltage window with an additional maximum voltage, if the inverter operates higher than this maximum operating voltage, the inverter will be damaged (Clean Energy Council 2018f p.14). As per the CEC guidelines, the best performance of the system will be when the output voltage of the solar array is matched perfectly with the operating voltages of the inverter. As mentioned earlier the output of a module is affected by cell temperature, this is provided by the temperature coefficient mentioned in the datasheets for PV arrays (Clean Energy Council 2018f p.14).

To design and implement PV array systems, the output voltage of the array shouldn’t fall outside the range of the inverter’s DC operating voltages and maximum voltage, the minimum and maximum daytime temperature for the specific site are essential. When the temperature is at a maximum then the maximum power point voltage of the array can’t fall below the minimum operating voltage of the inverter. The actual voltage at the input of the inverter isn’t just the Vmpp of the array, the voltage drop in the DC cabling must also be included when determining the actual inverter input voltage (Clean Energy Council 2018f p.15). The maximum power point voltage at specific temperature is as follows:

$$V_{mp\_cell.eff} = V_{mp\_STC} + [\gamma_v * (T_{cell_{eff}} - T_{STC})] \qquad 10$$

Where,

$V_{mp\_cell.eff}$ = maximum power point voltage at effective cell temperature, V

$V_{mp\_STC}$ = maximum power point voltage at STC, V

$\gamma_v$ = temperature coefficient, °C

$T_{cell_{eff}}$ = cell temperature at specified ambient temperature, °C

$T_{STC}$ = cell temperature at STC, °C

To maximise the performance of the array, minimum array voltage should never fall below minimum voltage operating window of the inverter. The number of modules in the string should be selected so that the maximum power voltage of the array for the highest temperature expected is above the minimum voltage operating window of the inverter. Since the daytime ambient temperature of Australia can reach 35°C it is recommended that a maximum effective cell temperature of 70°C is used (Clean Energy Council 2018f p.15). The minimum number of solar modules in the string can be determined by the following equation:

$$N_{min\ \_per\_string} = \frac{V_{inv\_min}(V)}{V_{min\ \_mpp\_inv}(V)} \qquad 11$$

Where,

$V_{inv\_min}$ = the minimum inverter input voltage, V

$V_{\min\ \_mpp\_inv}$ = minimum MPP voltage of a module at the inverter at maximum cell temperature, V

A safety margin of 10% is recommended due to variation on the quality of the solar cells installed (Clean Energy Council 2018f p.16), the maximum voltage window is similarly defined, but relates to when the open circuit voltage of the array shall never be greater than the maximum allowed voltage for the inverter (Clean Energy Council 2018f p.17).

The open circuit voltage is used due to being greater than the MPP voltage and it is the applied voltage when the system is first connected (prior to the inverter starting to operate and connecting to the grid).

**Inverter DC Input Current**

As per the CEC guidelines, total circuit current has to not exceed the maximum DC input current of the inverter (Clean Energy Council 2018f p.18).

**Length of cable and Inverter Stacking**

One of the factors that can affect inverter’s performance is the distance between the panel array and the additional battery bank (AlternativeEnergy N.Y). The longer the cable is, the lower your inverter’s voltage should be to perform optimally, because with length voltage drops and the current rises (AlternativeEnergy N.Y). Majority of the time to increase the power, this would typically be done with smaller inverters, when the choice of a bigger solar inverter is not viable. If two compatible inverters are wired together in series, the output voltage can be doubled.

## 2.4 Batteries

Due to increase in energy policies worldwide, battery storage is becoming more popular and has advantages to being installed to compliment the PV array. Due to the intermittent nature of solar PV, mismatch between customer solar PV power output and their load profiles, battery storage is a potential option to maximise savings (Sani Hassan, A, Cipcigan, L & Jenkins, N 2017 p.422). A 25% reduction to cost of batteries, has been noted for lithium-ion batteries between 2009 and 2014, as per a report written in 2015 by (Muenzel, V, Mareels, I, de Hoog, J, Vishwanath, A, Kalyanaraman, S & Gort, A 2015). Through optimising the operation of battery storage coupled to a residential PV, the effect of variable PV output is significantly minimised. The work done in multiple reports as stated in (Muenzel, V, Mareels, I, de Hoog, J, Vishwanath, A, Kalyanaraman, S & Gort, A 2015), details optimal power flow management framework with battery storage in order to maximise peak shaving or battery storage under specific tariff structures. Battery adoption in energy systems are necessity as peak electricity demands in power systems are increasing and high shares of distributed energy resources create a mismatch between generation and demand (Muenzel, V, Mareels, I, de Hoog, J, Vishwanath, A, Kalyanaraman, S & Gort, A 2015 p.424). Battery storage with PV systems can be leveraged by utility operators to maximise the usage of existing network capacity and defer network investments and thus enable electricity prices to stabilise.

### 2.4.1 Types of Batteries

Batteries used in home storage are made up of three chemical compounds: Lead Acid, Nickel Cadmium (NiCd), Nickel Metal Hydride (Ni-MH), Lithium-ion (Li-ion) and saltwater, the most common is Li-ion batteries (EnergySage 2019b).

1. Lead acid batteries are a tested technology that has been used in off-grid energy systems for decades (EnergySage 2019b), a relative short life and lower Depth of Discharge (DoD) than other battery types, least expensive option and currently on the market in the home energy sector, for owners who want to go off the grid and need to install a significant number of energy storage, lead acid is a good option.

2. Nickel-cadmium (NiCd) offers the best cost / performance value of any rechargeable battery (Texas Instrument 2011), continuing to improve, offers volumetric / gravimetric energy density that nearly doubles the best NiCd cells offered previously. Due to containing Cadmium, it is less environmentally friendly than other alternative battery types.

3. Nickel-Metal-Hydride (Ni-MH) batteries are finding widespread application in high-end portable products, notably run time is a major consideration in the purchase decision (Energizer 2018), simplified incorporation into products currently using NiCd batteries due to similarities between the two chemistries, they are an extension of the sealed NiCd battery technology with the substitution of a hydrogen absorbing negative electrode for the cadmium-based electrode (Energizer 2018).

4. Li-ion batteries are the most popular for home-based energy storage technologies, the batteries supplied by Tesla and Enphase Energy are both rechargeable Lithium-ion storage that utilise lithium iron phosphate for their chemical compositions (EnergySage 2019b), they are considerably lighter and more compact than lead acid, also have a higher Depth of Discharge (DoD) and lifespan, their advantages are outweighed by their price comparison to lead acid counterparts.

5. New in industry is a saltwater battery, doesn’t contain any heavy metals, relying solely on saltwater electrolytes (EnergySage 2019b), it can be easily balanced, however since it is a new technology, they are relatively untested and the company producing these batteries filed for bankruptcy in 2017.

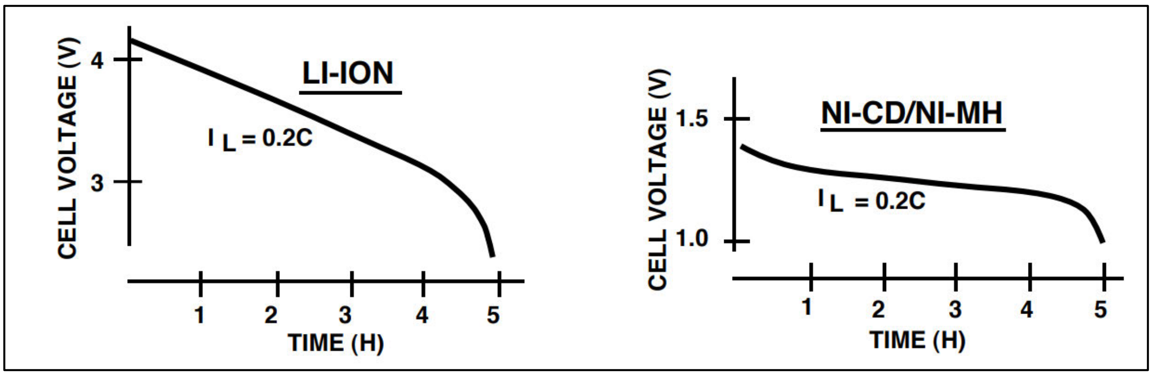


Figure 11: Cell discharge curve comparison (Texas Instrument 2011 p.4)

### AC & DC coupled

Hybrid inverter technology has advanced the development of AC coupled energy storage configurations. AC coupled energy storage is becoming the most common type of storage, whilst it isn't as efficient as storing energy as DC coupled, AC coupled solutions have significant advantages. AC coupled storage can draw power from the grid, enabling homeowners purchase power in off peak times at cheaper rates.

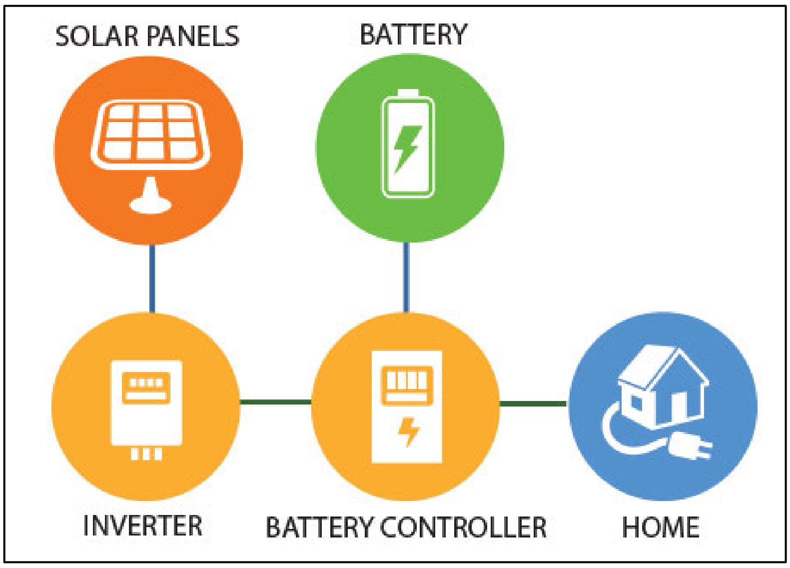


Figure 12: AC Coupled (SolarGain 2018)

AC coupled use a common inverter coupled to a battery inverter / charge to manage the battery and are installed on the grid-side, albeit simple to setup and powerful, they suffer with less efficiency charging than DC coupled systems (Svarc, J 2018c). Regardless of this they are efficient and capable of being expanded with multiple solar inverters to form microgrids. When the battery discharges, the same battery inverter converts the DC back to AC.

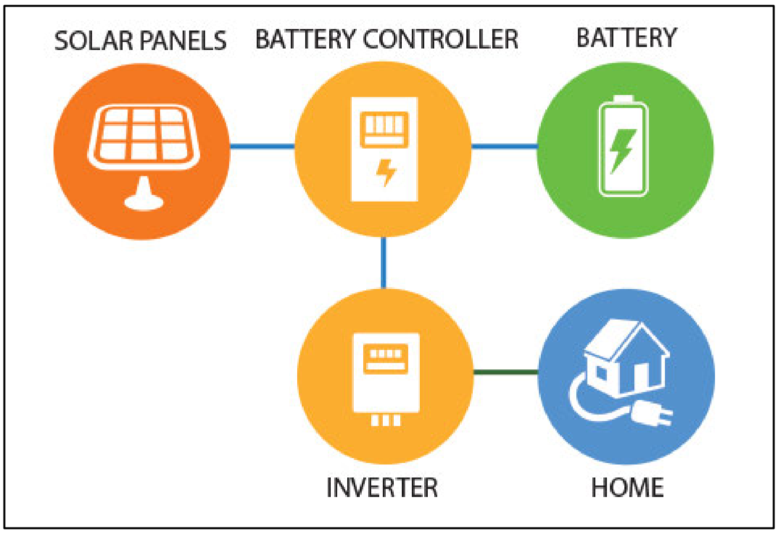


Figure 13: DC Coupled (SolarGain 2018)

As noted in the figure above, DC coupled is when the battery is stored between the panels and the inverter, this system senses when excess power is being produced and redirects it to the batteries. Later when you are consuming more power than producing, this power is then released into the inverter. One advantage of this system is that power is stored in the batteries before it is converted into AC (SolarGain 2018). The downside of DC coupled batteries is that electricity can't be taken from the grid.

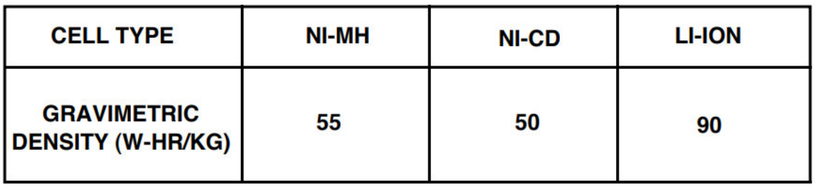
### Lead acid batteries

Until recently lead acid batteries have been the leading technology for storing solar electricity. They are capable of long cycle calendar lives and have been developed in recent years to have a much longer cycle compared to 2 decades ago (May, GJ, Davidson, A & Monahov, B 2018 p.145). Lead acid batteries are supplied by a large, well established, worldwide supplier base and have the largest market share for rechargeable batteries. Current lead acid batteries have been advanced or carbon-enhanced (LC) with devices having an integral supercapacitor function inbuilt (May, GJ, Davidson, A & Monahov, B 2018 p.146). For use with renewable energy sources, lead acid batteries are used for regular discharges with the battery not necessarily being returned routinely to a full state of charge (SoC) (May, GJ, Davidson, A & Monahov, B 2018 p.147), this partial state of charge (PSoC) can be damaging to lead acid batteries as it leads to sulphation of the negative plates and methods to overcome this problem are still in development. Lead acid batteries also come in configurations as a flooded cell type and sealed / gel type.

### Ni-MH batteries

As discussed previously, Ni-MH when compared to lead-acid batteries offer good reaction and chemical properties. The lifetime of these batteries on a smaller scale varies from 3 to 5 years (Manimekalai, P, Harikumar, R & Raghavan, S 2013) and is dependent on charging / discharging cycle, and temperature.

The Ni-MH battery is an extension on NiCd battery, however the anode used is made up of metal hydride instead of cadmium (Manimekalai, P, Harikumar, R & Raghavan, S 2013 p. 30). The gravimetric energy density for Ni-MH (measure of how much energy a battery contains in comparison to its weight), the is almost half that mentioned with a Li-ion battery as seen below. Due to having typically a 1.25 V nominal cell voltage for both NiCd and Ni-MH, they are only one third of the nominal 3.6V provided by Li-ion cell, with this information it requires three series connected NiCd or Ni-MH cells to equal the voltage of a single Li-ion cell (Texas Instrument 2011 p.4).



| CELL TYPE | NI-MH | NI-CD | LI-ION |
|---|---|---|---|
| GRAVIMETRIC DENSITY (W-HR/KG) | 55 | 50 | 90 |

Figure 14: Energy Density Comparison (Texas Instrument 2011)

**NiCd batteries**

NiCd batteries are batteries that have their positive material as nickel oxide and the negative contains cadmium. They have a higher cycle life and are temperature tolerant when compared to lead-acid batteries (Manimekalai, P, Harikumar, R & Raghavan, S 2013). Cadmium is replaced by hydrides due to environmental concerns and regulations. Typical NiCd batteries can utilise fast charging, and in order to not ruin the battery it will signal when it is completely charged. Due to damage and fire hazards, fast-charge systems must be designed to accurately monitor battery cell temperature and voltage (Texas Instrument 2011). When compared to alternative batteries, the NiCd offers the best cost / performance in large volumes regardless of manufacturers, due to containing Cadmium, expenses related to recycling the battery results in Ni-MH being the better of the two batteries.

Memory effect degrades NiCd batteries when the battery is idle for a significant amount of time. Memory effect is the process of remembering the DoD in the past, if the battery discharged to 25% repeatedly, that will be stored in memory, and if the discharge is greater than 25%, the cell voltage will drop. To recover this, the battery would be reconditioned by fully discharging and then fully charging once every few months. As seen above and mentioned previously, the NiCd/Ni-MH cells are one third of the nominal Li-ion, however the biggest advantage of the NiCd and Ni-MH batteries is that the discharge curve is extremely flat, closest to an ideal battery (Texas Instrument 2011). This means that they are well suited for use with linear regulators, as Li-ion batteries require switching converters to obtain good energy conversion efficiency in the power supply.

**Li-ion batteries**

Li-ion batteries are the highest range manufactured solar PV battery in the past decade and have a number of advantages for sustaining stationary storage. As previously discussed, the energy density is three times that of lead-acid batteries (Manimekalai, P, Harikumar, R & Raghavan, S 2013 p.30), the lithium electrode reacts with its electrolyte giving it a passive film during every discharge and charge operations.

Lithium-ion as seen with Tesla’s Powerwall and Enphase Energy’s AC battery are typically low maintenance, an advantage that is often not seen with other batteries. Additionally, they have the ability to deeply discharge, and have a reputable battery management system (BMS) and remain at mild temperatures (Texas Instrument 2011). The biggest problem seen with Li-ion is the ease that it can be damaged easily during use, internal resistance can be fairly high, if accidentally shorted, cell temperature will rise enough to cause a rupture of the battery. Another possible way of damaging a Li-ion battery is by discharging too far, doing so will result in an internal chemical reaction where the electrode will oxidize through a process that cannot be reversed by recharging (Texas Instrument 2011).

### 2.4.2 Factors Impacting Batteries

**Acid stratification and Sulphation**

In lead acid batteries there is a density difference between water and acid, due to this if the battery is left idle for a significant amount of time problems can arise. The mixture of water and acid can separate into layers, and the water will rise while the acid sinks down due to gravimetric effects (Manimekalai, P, Harikumar, R & Raghavan, S 2013 p.31). Sulphation forms during normal operation of a battery, this is done through the discharging process where a thin layer of sulfates form on the battery plates. This layer dissolves into the battery acid during charging, when a hard-crystalline layer is formed it cannot dissolve during charging, efficiency is substantially affected (Manimekalai, P, Harikumar, R & Raghavan, S 2013 p.31).

**Corrosion / Erosion**

The application of high positive potential at the positive electrode will cause the corrosion of the lead grid. Formation of layers of lead oxide and sulfates between grid and active material increases the contract resistance, resulting in an increased drop to voltage during charging and discharging process (Manimekalai, P, Harikumar, R & Raghavan, S 2013 p.31). Alleviating this issue is dependent on the battery’s electrode potential, temperature, grid alloy and quality of grid. Electrodes subjected to strong mechanical loads during cycling operation can result in the battery beginning to erode. Due to the change in volume, the active material loosens and gets separated from the electrode and forms sludge at the base of the battery (Manimekalai, P, Harikumar, R & Raghavan, S 2013 p.31). The plate connectors from the positive electrodes can also be subjected to corrosion and cause detachment of smaller layers of the connectors (Manimekalai, P, Harikumar, R & Raghavan, S 2013 p.31). To avoid these problem separators should extend upward over the electrodes.

**Low / High Temperature**

Low temperature may result in ice forming, once ice is formed on the battery, then it is difficult to operate the battery and the cell housing may rupture due to the increased volume. Increased temperature is a result of either high ambient temperature or by high current rate charging / discharging increases corrosion, sulphation, gassing and self-discharge (Manimekalai, P, Harikumar, R & Raghavan, S 2013 p.31).

### 2.4.3 Current Technology

As discussed earlier, there are multiple different batteries available on the market for PV storage, the following batteries discussed below are the currently available on the market. Total energy useable is measured at 25°C.

[1] maximum units per 20 A branch circuit is 13, 14.8 kWh with 13 modules, this is a modular unit.

N/A: information was unavailable at the time of research.

All information in the below table has been sourced from the following references: (Tesla 2018, LG Chem 2017, Enphase 2018, BYD 2018, SimpliphiPower 2018, Solataro 2018, Redflow 2017, SolaXPower 2017, Bosch 2014, Trojan 2017, Trojan 2016, Ritar 2017). Price range included is an estimate as the price varies per source and there is no universal price for the batteries at the current time of writing.

Table 20: Battery specification

| Manufacturer | Model | Battery Type | Total Energy (kWh) | DoD (%) | Roundtrip Efficiency (%) |
|---|---|---|---|---|---|
| Tesla | Powerwall 2 AC | Li-ion | 14.0 | 100.0 | 90.0 |
| LG Chem | RESU6.5 | Li-ion | 6.5 | 90.0 | 95.0 |
| | RESU10H Type-C | Li-ion | 9.8 | 95.0 | 95.0 |
| Enphase Energy[1] | AC Battery | Li-ion - phosphate | 1.2 | 100.0 | 92.0 |
| SimpliPhi | PHI 3.5 | Lithium Ferro Phosphate | 3.5 | 100.0 | 98.0 |
| Redflow | ZBM2 | Zinc Bromine Flow | 10.0 | 100.0 | 80.0 |
| SolaX | SolaX6.5 | Li-ion | 6.524 | 95.0 | >95.0 |
| Bosch | BPT-S 5 (DC) | Hybrid Li-ion | 13.2 | 50.0 | 90.0 |
| Trojan | SIND 04 2145 | Lead Acid | 8.88 | 80.0 | N/A |
| Ritar | DG6-225 | GEL battery | 1.35 | 100.0 | N/A |

Table 21: Battery Electrical Specifications

| Manufacturer | Model | Nominal Voltage (V) | Useable Energy (kWh) | Real Power, continuous (kW) | Real Power, peak (kW) |
|---|---|---|---|---|---|
| Tesla | Powerwall 2 AC | 230.0 | 13.5 | 5.0 | 7.0 |
| LG Chem | RESU6.5 | 51.8 | 5.9 | 4.2 | 4.6 |
| | RESU10H Type-C | 400.0 | 9.3 | 5.0 | 7.0 |
| Enphase Energy[1] | AC Battery | 230.0 | 1.14 | 0.26 | 0.27 |
| SimpliPhi | PHI 3.5 | 51.2 | 3.5 | 1.74 | 3.07 |
| Redflow | ZBM2 | 48 | 10.0 | 3.0 | 5.0 |
| SolaX | SolaX6.5 | 51.8 | >6.2 | N/A | N/A |
| Bosch | BPT-S 5 (DC) | 288 | 13.2 | 5.0 | 5.0 |
| Trojan | SIND 04 2145 | 4.0 | 8.88 | N/A | N/A |
| Ritar | DG6-225 | 6.0 | 1.35 | 0.27 | 0.27 |

Table 22: Battery Price & Specifications

| Manufacturer | Model | Price Range ($) | Warranty (years) | Operating Temperature (°C) |
|---|---|---|---|---|
| Tesla | Powerwall 2 AC | 9,600 to 10,100 | 10 | -20.0 to 50.0 |
| LG Chem | RESU6.5 | 6,779.1 | 10 | -10.0 to 45.0 |
| | RESU10H Type-C | 9,295.0 | 10 | -10.0 to 45.0 |
| Enphase Energy[1] | AC Battery | 2,057.0 | 10 | -20.0 to 45.0 |
| SimpliPhi | PHI 3.5 | 3,257.1 | 10 | -20.0 to 60.0 |
| Redflow | ZBM2 | 10,000.0 | 10 | 15.0 to 50.0 |
| SolaX | SolaX6.5 | 2,744.0 | 10 | -30.0 to 60.0 |
| Bosch | BPT-S 5 (DC) | 18,580.5 | 5 | -10.0 to 40.0 |
| Trojan | SIND 04 2145 | 1,780.9 | 5 | -20.0 to 50.0 |
| Ritar | DG6-225 | 327.6 | 5 | -40.0 to 60.0 |

### 2.4.4 Sizing

From using known values of wind speed and irradiance, methodologies from previous literature have been created and utilised based on the idea of sizing the batteries as well as optimising the number of batteries (Borowy, BS & Salameh, ZM 1996 p.367). Battery life is greatest when batteries are kept at near 100% of their capacity or returned to that state quickly after a partial or even deep discharge. Previous literature discusses that the use of PV modules doesn't protect batteries against deep discharges. A more dynamic energy system would be necessary for when the there is little to no irradiance, such as a wind turbine. Regardless of energy system used, storage costs still represent an economic restraint. After the power output from the renewable generator is known, they are matched to the load profile of the house that is requiring the storage. The calculation of the optimum number of PV modules and batteries is based around the Loss of Power Supply Probability (LPSP) concept. The LPSP concept is defined as the long-term average fraction of the load that isn't supplied by a stand-alone system (Borowy, BS & Salameh, ZM 1996 p.370). Typically, the battery charge efficiency is set equal to the round-trip efficiency and the discharge efficiency is set equal to 1, two cases are considered in expressing current energy stored in the batteries. When the PV array exceeds the load demand, the batteries are charged with the round-trip efficiency:

$$E_{B(t)} = E_{B(t-1)} + \left(E_{G(t)} - \frac{E_{L(t)}}{\eta_{inv}}\right) * \eta_{batt,in} \qquad 12$$

Where:

$E_{B(t)}$ = energy stored in batteries in hour (t)

$E_{B(t-1)}$ = energy stored in batteries in previous hours (t)

$E_{G(t)}$ = energy generated from PV array in hour (t)

$E_{L(t)}$ = load demand in hour (t)

$\eta_{inv}$ = efficiency of inverter

$\eta_{batt,in}$ = round-trip efficiency of batteries

When the load demand is greater than the available energy generated, the batteries will be discharged by the amount that is needed to cover the deficit (Borowy, BS & Salameh, ZM 1996 p.370) and is as follows:

$$E_{B(t)} = E_{B(t-1)} - \left(\frac{E_{L(t)}}{\eta_{inv}} - E_{G(t)}\right) \qquad 13$$

The energy stored in batteries at any hour is subject to the following constraint:

The batteries should not be over discharged or overcharged at any time.

### 2.4.5 Important Battery Specifications

**Battery Capacity**

This is the storage capacity measured in Ampere hours (Ah) or Watt-hour (Wh), typically defined by two parameters: useable capacity and nominal capacity. This is usually specified for a given discharge / charge rating and temperature rating during testing (Manimekalai, P, Harikumar, R & Raghavan, S 2013 p.29). Nominal capacity is the total amount of energy that the battery can hold at a time, depending on manufacturer the nominal capacity will be the same as useable capacity. Useable capacity is the amount of energy that a battery can hold after considering depth of discharge.

**Depth of Discharge (DoD)**

Gives a measure of energy withdrawn from a battery as a percentage of its total capacity (Manimekalai, P, Harikumar, R & Raghavan, S 2013 p.29), the state of charge (SoC) of a battery is the difference between the full charge and depth of discharge of the battery in percentage. For example, DoD is 10% then state of charge (100-10) is 90%. In off-grid settings battery banks may be deliberately sized to have a shallow DoD to extend their lifespan.

**Maximum Power**

The maximum or peak amount of power that the battery can generate a given time, typically for a short period and is measured in kW (Martin, J 2017). Typically used for when a sudden urge is required on the load. Maximum output may be limited by the capacity of the inverter attached to the system. Continuous power is the amount that the battery will generate in a normal situation, non-peak conditions (Martin, J 2017).

**Battery Life Cycle**

This is the number of complete charge and discharge cycles a battery can maintain before the nominal capacity decreases less than 80% of its initial capacity at installation (Martin, J 2017). The battery will still function after this number has been met, but capacity will be lower. The cycle life is affected by changing temperature conditions and is heavily influence by the depth of discharge. A larger depth of discharge diminishes the cycle number related to the battery life, as noted in Figure 15 on the next page, this is known as capacity fade.

**Discharge / charge (C-rate)**

This is the discharge rate of the battery relative to the capacity, the C-rate number is the discharge current over the nominal battery capacity. This result is the number of hours it takes the battery to be fully discharged (Martin, J 2017).

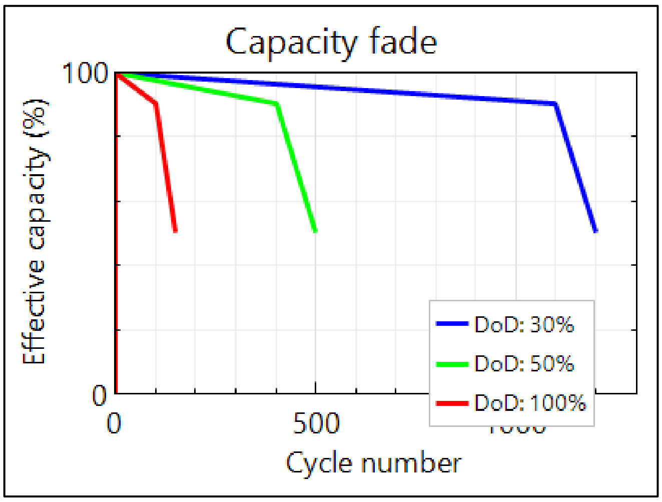


Figure 15: Capacity vs cycle numbers at different DoD rates (Martin, J 2017)

**Self-discharge and Round-Trip Efficiency**

This is the electrical capacity lost when a battery is not being used due to internal electrochemical process within the battery. This self-discharge will increase of battery temperature, when batteries can be stored at lower temperatures to reduce self-discharge. Round trip efficiency is the efficiency of charging and discharging the battery, related to the amount of kWh the battery outputs and inputs. It is measured by the ratio of total storage system input to the total storage output (Martin, J 2017), example: 10kWh is inputted and 8 kWh is retrieved while discharging, then the round-trip efficiency is 80%. Effective in fully optimising a system, depending on the battery type, round trip efficiency can range from 75% to 97% (Martin, J 2017).

## 2.5 Localised Energy Grid

For a full system (solar + inverter + battery storage) it can increase self-consumption for residential homes, and therefore contribute to a decentralised renewable system. Previous studies in forecast-based operations strategies in localised energy grids with battery storage in mind have shown that increasing the battery life is essential to prolonging the life of the system (Angenendt, G, Zurmühlen, S, Axelsen, H & Sauer, DU 2018). Using forecast based strategies in combination with variable power feed in limits of the system have also shown to relieve the grid. LCOE is the main point of optimising a system, the better economic evaluation of the system, the better the ROI. Strategies discussed below can easily be implemented on existing PV Battery Energy Storage Systems (BESS), since no additional communication interface is required (Angenendt, G, Zurmühlen, S, Axelsen, H & Sauer, DU 2018). Results from this report show that in a long-term investment, the combination of PV systems with batteries will be the most economical solution, however this is only when combined with feed-in tariffs, not standalone off grid systems. In order to optimise a system, strategies have to be developed and utilised in order to test which works best for the system that is being analysed. As seen in

Figure 16, a grid connected DC coupled system is analysed in the report by Angenendt, G, Zurmühlen, S, Axelsen, H & Sauer, DU 2018.

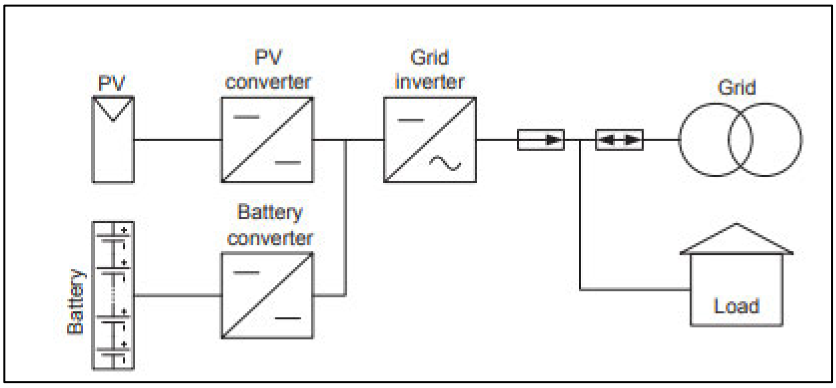


Figure 16: Grid connected PV BESS DC coupled system ((Angenendt, G, Zurmühlen, S, Axelsen, H & Sauer, DU 2018).

There are many different strategies that can be deployed when attempting to optimise a system, the following are the most popular have been sourced from the report by Angenendt, G, Zurmühlen, S, Axelsen, H & Sauer, DU 2018.

Table 23: Deployment strategies

| Strategy | Details |
|---|---|
| PV power plant without BESS | PV alone can't support the load profile during the evening, will require grid connections to meet demand. |
| Maximising PV self-consumption | Use all PV and battery will be stored only when excess power is available, most economical option for residential users and will be used in this project. |
| fixed SoC | Prolong Li-ion life but requires extreme care, this scenario can cause the battery to not be fully optimised as well and not be able to support the demand overnight and would require grid connection (Angenendt, G, Zurmühlen, S, Axelsen, H & Sauer, DU 2018) to fulfil a full day load profile. |
| Forecast based operation | Increase the average SoC as the battery will typically not fully discharge under this strategy, this will lead to the battery being damaged. Various studies have been conducted to store only the amount of energy which is predicted to be needed due to forecasting. Load demand can't be met even with forecasting, as circumstances change in regard to daily demand (Angenendt, G, Zurmühlen, S, Axelsen, H & Sauer, DU 2018). |

**Fixed cut-off limit + forecast based operation strategies**

This enhances battery life and doesn't see a reduction in energy needs, only amount of energy predicted to be needed during the night is stored to reduce the average SoC. Stores energy as soon as cut off limit is met, leads to excess energy which assists in the following day's load profile (Angenendt, G, Zurmühlen, S, Axelsen, H & Sauer, DU 2018). Regardless of strategy used, system designers must consider the system output including the efficiency of the panels and inverters (Clean Energy Council 2018f p.4). The energy yield formula is used:

$$E_{sys} = P_{array\_STC} * f_{man} * f_{dirt} * f_{temp} * H_{tilt} * \eta_{pv_{inv}} * \eta_{inv} * \eta_{inv\_sb} \qquad 14$$

Where,

$E_{sys}$ = average yearly energy output of the PV array (kWh)

$P_{array\_STC}$ = rated output power of the array under STC (W)

$f_{man}$ = de-rating factor for manufacturing tolerance

$f_{dirt}$ = de-rating factor for dirt

$f_{temp}$ = temperature de-rating factor

$H_{tilt}$ = Yearly (daily) irradiation value (kWh / $m^2$) for the selected site

$\eta_{pv_{inv}}$ = efficiency of the subsystem (cables) between the PV array and the inverter

$\eta_{inv}$ = efficiency of the inverter (%)

$\eta_{inv\_sb}$ = efficiency of the subsystem (cables) between the inverter and switchboard (%)

The most losses and de-rating factors are due to the following, in which are typical values seen on an average selection of components:

1. Manufacturer's power tolerance (1%)
2. Temperature loss (10%)
3. Dirt (5%)
4. Wiring Losses (2%)
5. Inverter efficiency (4%)

A typical 10 kW system will have a peak of 7.8 kW once installed due to losses seen as de-rating factors are taken into consideration. Commercial Solar PV price index as of February 2019 for Australia include incentives through the federal Renewable Energy Target as well as GST, but don't incorporate meter installation fees or additional costs related to labour (SolarChoice 2019). Additionally, the Solar price index for all cities and all sizes can be seen on the following page in Figure 17.

Table 24: Solar choice average system prices - February 2019 (SolarChoice 2019)

| **Solar Choice: Solar PV system price, $ / Watt – February 2019** | | | |
|---|---|---|---|
| | **Average ($)** | 10 kW | 30 kW |
| **Adelaide, SA** | 1.13 | 1.18 | 1.10 |
| **Brisbane, QLD** | 1.19 | 1.21 | 1.20 |
| **Canberra, ACT** | 1.05 | 1.19 | 1.01 |
| **Hobart, TAS** | 1.26 | 1.40 | 1.25 |
| **Melbourne, VIC** | 1.17 | 1.25 | 1.12 |
| **Sydney, NSW** | 1.12 | 1.19 | 1.12 |
| **Perth, WA** | 1.25 | 1.43 | 1.22 |
| **Average** | 1.17 | 1.26 | 1.15 |

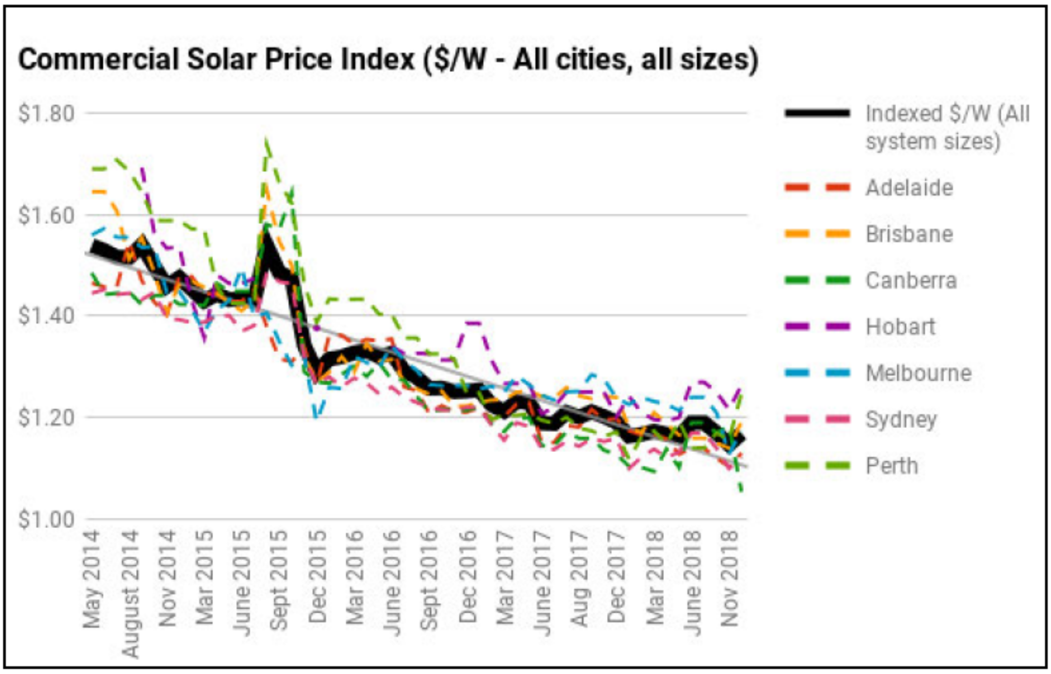


Figure 17: Average Solar PV system Prices (SolarChoice 2019)

### Capacity factor

This is the ratio of the system's predicted output in the first year of operation to the nameplate output (NREL 2015) and is measured using the following formula as per the NREL SAM® software:

$$Capacity\ factor\ (\%) = \frac{Net\ Annual\ Energy\ (\mathrm{kWh}/\mathrm{year})}{(System\ Capacity\ (\mathrm{kWh}) * 8760}$$ 15

The System capacity is dependent on technology being modelled, the software converts the capacity value to the appropriate units (MW, kW, or W) before calculating (NREL 2015).

**Emissions**

Emissions related to electrical energy storage is important in optimising off grid systems, so therefore life-cycle analysis (LCA) is important to discussing the pressing need to recycle, in order to improve sustainable battery technologies says a 2015 report by Larcher, D & Tarascon, JM. Early LCA estimations, revealed in the report that 400 kWh of energy is taken to produce, obtain materials and recycle to make a 1 kWh Li-ion battery (Larcher, D & Tarascon, JM 2015 p.20).

Comparing to 1 kWh of production from grid connections which produce around 1 kg of Carbon dioxide ($CO_2$), to the 75 kg of $CO_2$ for the 1kWh battery tested. Another study testing a Li-ion battery (Ellingsen, L, Majeau-Bettez, G, Singh, B, Srivastava, A, Valøen, L & Strømman, A 2013 p.22) resulted in the tested battery showing a production impact of 172 kg of $CO_2$ / kWh capacity.

## 2.6 Financials

The financial side of this project will be one of the main parts of this optimisation, if the economics isn't right, users possibly can see diminished returns quickly, if a system is oversized or undersized incorrectly.

**Return on Investment (ROI)**

Performance measure used to evaluate the efficiency of an investment, it directly measures the amount of return on a particular investment (Chen, J 2019), and is as follows:

$$ROI(\%) = \frac{Gain\ from\ Investment(\$)\ -\ Cost\ of\ Investment(\$)}{Cost\ of\ Investment} * 100 \tag{16}$$

The gain from investment takes into consideration any feed in tariffs, Renewable Energy Certificates (RECs), solar credits, small scale technology certificates (STCs) and selling excess energy back to the grid. Cost of investment include the capital cost for the PV system, replacement cost, maintenance costs, and cost of buying from grid if the system is connected.

**Renewable Energy Certificates (RECs)**

RECs are an electronic form of currency part of the Solar Credits program to meet Australia's Renewable Energy Target, where one REC is equivalent to 1 MWh of electricity generated by the solar PV system (Clean Energy Council 2018c p.7). The prices for RECs change based on market conditions, and can be registered, sold and traded for systems up to 100kW. Small-scale technology certificates (STCs) apply to residential solar installations. They are issued when systems that qualify for the rebate are used and can be redeemed for a dollar value that is deducted from the cost of the solar system. Depending on the zoning, the rating number used in this formula below will be changed accordingly:

$$STC_{num}\ (rounded\ down) = Sys_{size}\ (\text{kW}) * Rating * D_{period}(\text{years}) \quad 17$$

Where,

$STC_{num}$ = number of STCs available

$Sys_{size}\ (kW)$ = System size (kW)

$Rating$ = Zone rating number (1.382, 1.536 for areas being studied in this project)

$D_{period}(years)$ = Deeming period (12 years for 2019, phased out in 2030)

**Cost of Investment**

Includes the cost of the PV array as well as the battery system, includes total number of arrays, inverters and batteries required. Also includes the number of replacements the batteries, inverters and panels need throughout the expected lifetime of the system. Additionally, it involves a cost component known as Operation and Maintenance (O&M), this is entered as an annual amount and may include emission penalties and miscellaneous annual costs.

**Inflation and Interest Rate**

It is important to consider inflation when replacing components of the system over their expected life, additionally as (HomerEnergy 2019a) real discount rate ($i$) can be calculated to convert between one-time costs and annualized costs. The Real discount rate is calculated as follows:

$$i = \frac{(i' - f)}{1 + f} \quad 18$$

Where,

$i$ = real discount rate

$i'$ = nominal discount rate (interest rate at which money can be borrowed)

$f$ = expected inflation rate

**Net Present Cost**

Net Present Cost (NPC) or life-cycle cost is the present value of all the costs the system incurs over its lifetime, minus the present value of all the revenue it earns (HomerEnergy 2019b). Costs include initial capital costs, replacement costs, O&M costs, fuel costs (if applicable), emissions penalties (if applicable), and cost of buying power from grid when the system isn't capable of supplying the demand.

### Net Present Value

Net Present Value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time (Kenton, W 2019). NPV is used typically in budgeting and investment planning to analyse the profitability of a projected investment. It is calculated as follows:

$$NPV(\$) = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t} \tag{19}$$

Where:

NPV = Net Present Value ($)

$R_t$ = net cash flow – outflows during a single period (t) (after tax)

$i$ = real discount rate or return that could be earned in alternative investments

$t$ = number of time periods

A positive NPV will ensure that the investment will be profitable and negative will result in a net loss, will be a main component in fully optimising an off-grid system.

### Levelized Cost of Electricity (LCOE)

LCOE is the average cost per kWh of useful electrical energy produced by the system being analysed. It is calculated as follows:

$$LCOE\,(\frac{\$}{\text{kWh}}) = \frac{Total\ cost\ of\ ownership\ (\$)}{System\ production\ over\ its\ life\ time\ (\text{kWh})} \tag{20}$$

This takes into consideration all electrical power technologies available and provides a common base for comparison. Anything that increases production or reduces costs lowers the LCOE, anything that decreases production or raises the cost increases the LCOE, hence a lower LCOE will be at an advantage for any system.

### Operating Cost

These are the expenses associated with the maintenance and administration of an investment. The operating cost is deducted from revenue to arrive at operating income. Operating cost is calculated as follows:

$$O_c\left(\frac{\$}{\text{year}}\right) = Revenue(\$) - Operating\ Expense(\$) \tag{21}$$

Revenue will be from feed-in tariffs if the site is still connected the grid.

**Payback Period**

The payback period is the length of time required to recover the cost of investment (Kagan, J 2019), the payback period is an important factor on whether or not to continue with the project, as a longer payback period isn't desirable from an investment standpoint. The payback period is calculated in both NREL SAM® and HOMER Pro® and is the project savings in years 2 and later of the cash flow to equal the initial investment in year zero. Manual calculation will occur in the multiyear analysis of each location and will utilise the following formula per year, and will be calculated for a worse-case scenario:

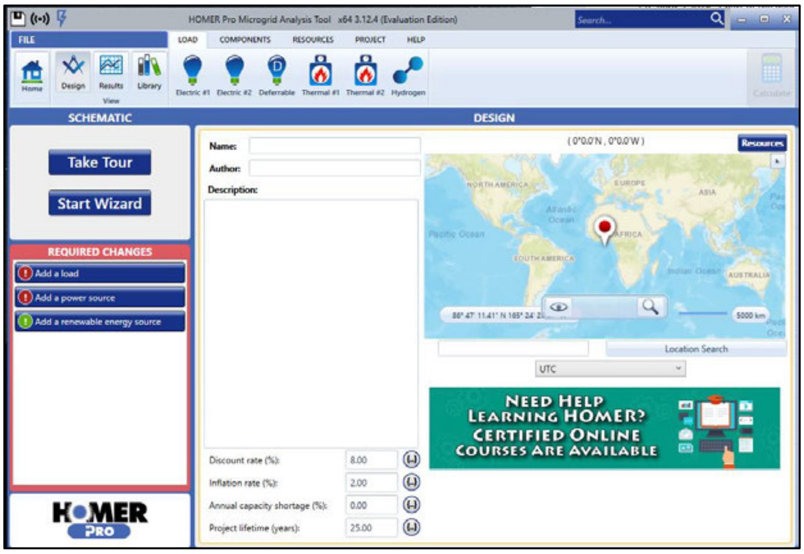
$$\textit{Current Cost}\,(\$) = \textit{Initial Capital} * (1+\textit{interest rate}) - \textit{Energy not bought} * \textit{tariff} - \textit{Energy sold} * \textit{feed-in tariff} + \textit{Operation \& Maintenance cost} \tag{22}$$

Fixed interest rate = 5.0%

Operation & Maintenance costs will include every 10 / 20 years capital costs of replacing key components at the end of their warranty lifetime, grid supply charges, and any additional costs to be as accurate as possible.

## 2.7 Software

The software that will be used for this project is respectively HOMER Pro®, NREL SAM® and MATLAB®. The commercial software HOMER Pro®, is used to evaluate from a techno-economic point of view and is specifically concerned with NPC as suggested in the journal by Singh, A, Baredar, P & Gupta, B 2015 p.743. It is a popular tool developed by the National Renewable Energy Laboratory (NREL) and is used by many companies and researchers as it analyses the sizing, costing optimisation and control strategy of any applicable system. The main user interface (UI) is noted in Figure 18, the UI details the location, the load, components available, and additional resource and project options that further enhances the software (HomerEnergy 2019c).

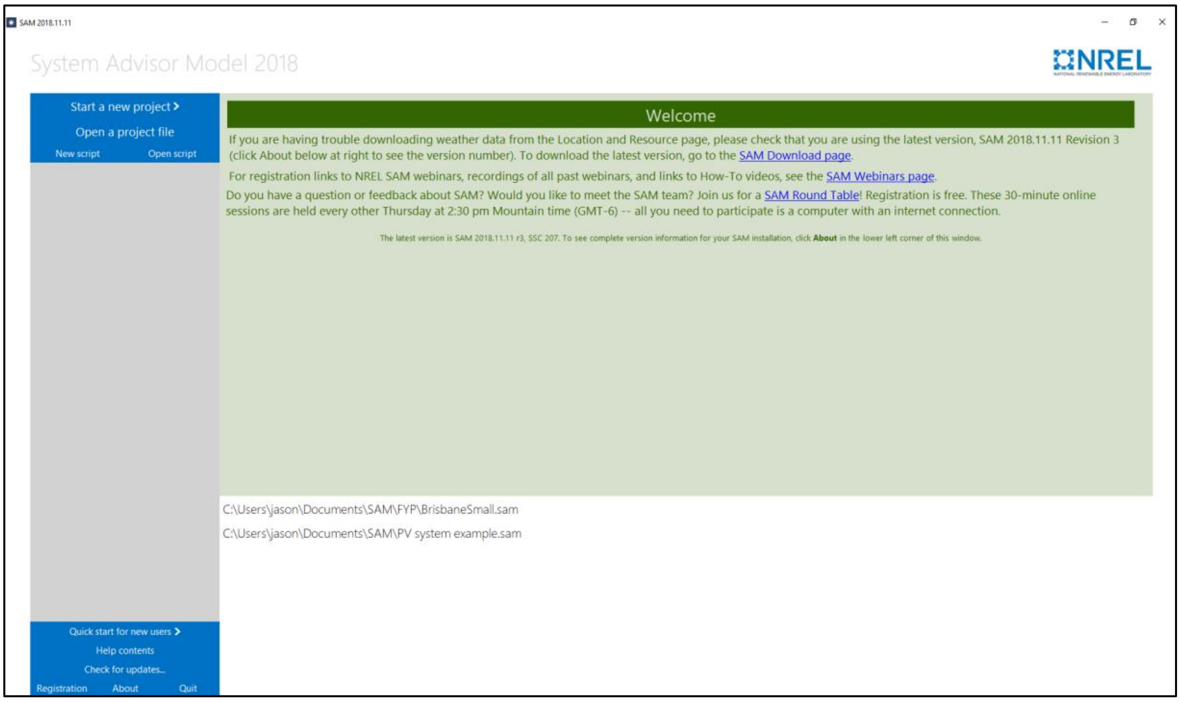


Discount rate (%): 8.00
Inflation rate (%): 2.00
Annual capacity shortage (%): 0.00
Project lifetime (years): 25.00

Figure 18: HOMER Pro® main screen v3.12.4 (HomerEnergy 2019c)

Location information, load demand profiles, irradiance profiles, wind speed, and additional weather data can all obtained through the linked databases to ensure the software is capable of optimising an accurate location. Depending on the extent of the sensitivity or parameters, HOMER Pro$^{®}$ can simulate up to thousands of simulations for varying systems (HomerEnergy 2019c). HOMER Pro$^{®}$ is an abbreviation of Hybrid Optimization Model for Multiple Energy Resources and allows for variety of combinations beyond solar PV modules, such as wind turbines, biomass-based power generators, micro-turbines, fuel cells, batteries, hydrogen storage and auxiliary generators with various fuel options and different types of loads (HomerEnergy 2019c). HOMER Pro$^{®}$ is a widely used tool for a multitude of studies, papers such as the 2018 paper written by Oulis Rousis, A, Tzelepis, D, Konstantelos, I, Booth, C & Strbac, G 2018, shows that HOMER Pro$^{®}$ was used to evaluate Islanded Residential applications successfully, as a result of being able to provide solar resources through the NASA data available. As a result of HOMER Pro$^{®}$'s objective function to minimise the total NPC, and its ability to perform thousands of simulations (Oulis Rousis, A, Tzelepis, D, Konstantelos, I, Booth, C & Strbac, G 2018), the paper resulted with 1943 solutions that assessed various system designs.

This optimisation from HOMER Pro$^{®}$, is the key point to choosing this software compared to alternatives in the market, research suggests that HOMER Pro$^{®}$ has been downloaded by over 150,000 people in 193 countries (HomerEnergy 2019c) in which includes a community of pioneering in renewable and distributed power. The NREL's SAM$^{®}$ software is a powerful tool similar to HOMER Pro$^{®}$ and has been used by many researchers to characterise performance of systems and aid analysis and evaluation. A report in 2018 by Ezeanya, EK, Massiha, GH, Simon, WE, Raush, JR & Chambers, TL, developed a predictive model that characterised a 50 kW Concentrated solar power (CSP) plant.



If you are having trouble downloading weather data from the Location and Resource page, please check that you are using the latest version, SAM 2018.11.11 Revision 3 (click About below at right to see the version number). To download the latest version, go to the SAM Download page.

For registration links to NREL SAM webinars, recordings of all past webinars, and links to How-To videos, see the SAM Webinars page.

Do you have a question or feedback about SAM? Would you like to meet the SAM team? Join us for a SAM Round Table! Registration is free. These 30-minute online sessions are held every other Thursday at 2:30 pm Mountain time (GMT-6) -- all you need to participate is a computer with an internet connection.

The latest version is SAM 2018.11.11 r3, SSC 207. To see complete version information for your SAM installation, click **About** in the lower left corner of this window.

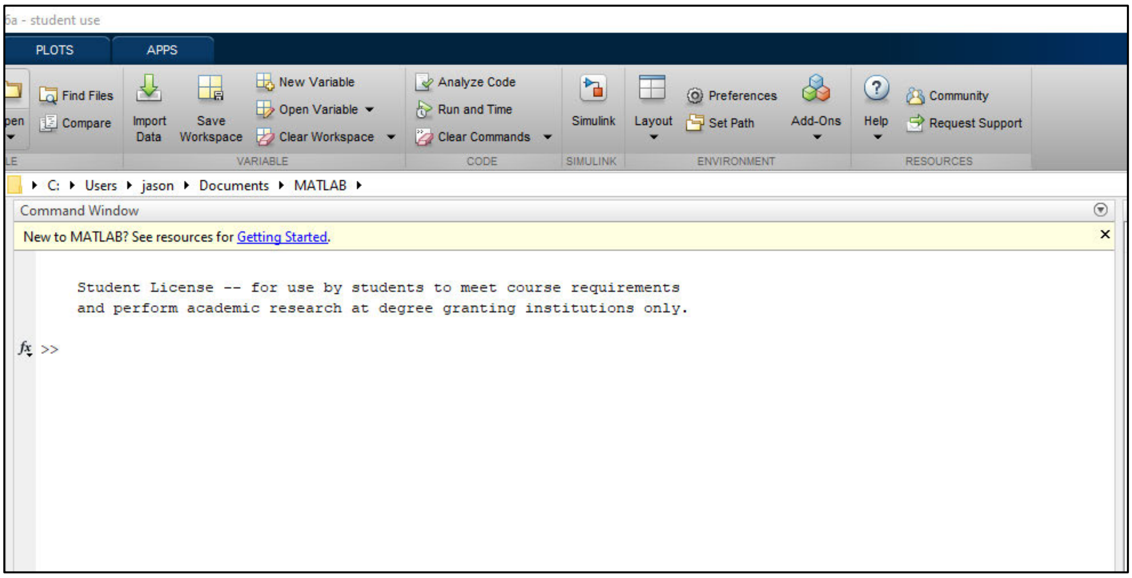
C:\Users\jason\Documents\SAM\FYP\BrisbaneSmall.sam

C:\Users\jason\Documents\SAM\PV system example.sam

Figure 19: SAM$^{®}$ UI v2018.11.11 (NREL 2019)

In the report the researchers validate their model through SAM®, with the actual power plant output (Ezeanya, EK, Massiha, GH, Simon, WE, Raush, JR & Chambers, TL 2018 p.15). This was done to ensure the model is making the correct predictions, this same methodology approach will be implemented in this project, where the results from HOMER Pro is validated with those in SAM®, and then subsequently verified if necessary, via manual calculations in MATLAB® to ensure accuracy is upheld. An additional paper by Guzman, L, Henao, A & Vasquez, R 2014, analysed a parabolic trough solar power plant of 50 MW, the model included thermal energy storage (TES) with natural gas backup. Just as seen with the report prior, a sensitivity analysis was performed to find the optimum size which minimises the LCOE (Guzman, L, Henao, A & Vasquez, R 2014 p.497). After optimisation, LCOE was at 9.76 cents / kWh, and by using SAM® was able to conclude that the plant was able to supply 50% of this demand (Guzman, L, Henao, A & Vasquez, R 2014 p.505). These journal articles are one of many that detail how useful SAM® is at optimising systems for varying locations and hence why it has been chosen to be used for this project.

MATLAB® is a programming environment for algorithm development, data analysis, visualisation, and numeric computation. It is made by MathWorks, who is a leader in developing mathematical computing software (MathWorks 2019). This software will be used to standardise load profiles and provide error checking to ensure calculations are accurate from the HOMER Pro® software and NREL SAM® software when applicable.



New to MATLAB? See resources for Getting Started.

```
Student License -- for use by students to meet course requirements
and perform academic research at degree granting institutions only.

>>
```

Figure 20: MATLAB® R2016a UI

# Chapter 3. Methodology

The components that will be used in order to successfully complete this project are as follows, this includes all steps required for the investigation and research into Home Based Solar Power Generation and Optimisation using the mentioned HOMER Pro® and NREL’s SAM® programs. Various assumptions will be made to streamline the testing process and will be relevant to each program, models will be constructed from the available literature to ensure all components, load profiles and tariffs are accurate for the sites to be tested. Even though there is plenty of literature worldwide detailing off-grid analysis, as noted in the literature review, there is no models for Australian sites available for review and an analysis detailing a full optimisation of multiple sites, the following sections will detail and outline how to construct the models for both HOMER Pro® software and NREL’s SAM®.

## 3.1 Required Resources

As described earlier MATLAB® is a highly efficient programming environment that allows for numerical processing, designed by MathWorks, the software in this project will be used to provide error checking to ensure calculations are accurate in comparison to the HOMER Pro® software and NREL’s SAM®. HOMER Pro® was designed by Dr. Peter Lilenthal and is a global standard in decision making for microgrid and distributed energy resource space (HomerEnergy 2019d). The HOMER Pro® principle engineers have been working with economic and engineering optimisation of microgrids for over 25 years and will be a valuable tool to use for this project due to costs associated with owning this software during the length of the project. In order to perform a complete optimisation NREL’s SAM® will be used in addition, this model by the NREL is a performance and financial model designed to facilitate decision making for people involved in the renewable energy industry (NREL 2010).

## 3.2 Identification and investigation of relevant literature and sources

The first stage of the project was reviewing the relevant literature and resources available for Home Based Solar Power Generation and Battery Storage. It was important that the most updated information was used from a variety of cross-referenced sources to ensure that the data was relevant. Literature studied involved current technologies related to solar panels, inverters (micro-inverter and standard) and battery banks, tariffs and renewable energy certificates were also studied to ensure all monies related to incentives or fees are included in the optimisation models. Microgrid systems were also analysed as per the objective in the project specification, this was done to ensure that systems that function off grid or partially off grid are understood. All sources in relation to the literature review have been researched thoroughly to ensure potential sources of bias are removed.

## 3.3 Locations Used

Table 25: Brisbane location

| **Brisbane** | | |
|---|---|---|
| Postcode | 4200 | |
| Daily electricity usage (kWh) | Small House | 12.62 |
| | Medium House | 14.84 |
| | Large House | 29.54 |

Table 26: Toowoomba location

| **Toowoomba** | | |
|---|---|---|
| Postcode | 4350 | |
| Daily electricity usage (kWh) | Small House | 12.63 |
| | Medium House | 13.32 |
| | Large House | 28.14 |

Table 27: Hervey Bay location

| **Hervey Bay** | | |
|---|---|---|
| Postcode | 4655 | |
| Daily electricity usage (kWh) | Small House | 12.63 |
| | Medium House | 14.84 |
| | Large House | 29.54 |

Table 28: Barcaldine location

| **Barcaldine** | | |
|---|---|---|
| Postcode | 4725 | |
| Daily electricity usage (kWh) | Small House | 19.41 |
| | Medium House | 22.78 |
| | Large House | 24.32 |

Table 29: Cairns location

| **Cairns** | | |
|---|---|---|
| Postcode | 4870 | |
| Daily electricity usage (kWh) | Small House | 17.54 |
| | Medium House | 20.05 |
| | Large House | 21.59 |

## 3.4 Weather Data

Weather data will be observed from available data sources: BOM, EnergyPlus, Climate.OneBuilding. Solar irradiance will be taken from EnergyPlus data source, this data source has global typical-year hourly data from various sources, over 2,100 locations, and can be easily imported into SAM®. BOM will be used to obtain daily weather observations, solar irradiance, temperature and all data will be used to scale the data seen from the EnergyPlus so that accurate data for each location is being used. BOM data will be sourced from the closest available weather station and the data taken from the EnergyPlus database will be modified to ensure that it matches with the BOM data and the full year of 2018 data will be used. More accurate data was costly, this was the best in regard to the scope of this project. HOMER Pro® downloads the weather data straight from the NASA Surface meteorology and Solar Energy database over a 22-year period.

## 3.5 Load Profiles

The load profile for the relevant residential homes, will be simulated for this project. The load profiles for multiple houses isn't readily accessible and using simulations (synthetic profiles) allows for confidentiality to be maintained when analysing results. The load profiles for daily electricity usage can be simulated in both NREL's SAM® and HOMER Pro® programs and scaled accordingly to match the actual locations in this project (using a scaling factor in both programs). Load growth of 1% per year will be applied, to get realistic values that reflect a real load profile.

## 3.6 Modelling Home Based Solar Power Generation and Battery Storage

The modelling of the Home Based Solar Power Generation and Battery storage will be concerned with the renewable fraction, net annual energy usage, LCOE, ROI, NPC, system energy output, total land area required, system performance factor (measure of PV system's annual electric generation output compared to its nameplate rated capacity in kW), optimal storage capacity and cash flow variables to ensure customers get the most optimised system. Sensitivity and parametric analysis and searches will be conducted on both with sizes varying on panels, inverters and batteries to get the most optimised system for each location. Once testing has been conducted, the results will be sorted with the lowest LCOE and highest renewable fraction, testing will be done via modifying each inverter being used and selecting the system that matches accordingly. Following on, NREL's SAM® will be used to further optimise the best system from HOMER Pro® with emphasis on shading and battery dispatch modes respectively. Testing will cycle through the tariffs discussed in the literature review (standing rate) to determine the best tariffs for each location.

## Assumptions

Assumptions and technical variables that will be tested in both programs, is as follows in Table 31 on page 56, these sensitivity tests are one of the strengths of both software to simulate operating conditions and compare changes to obtain optimal feasibility through the alteration of a single variable. To ensure a baseline, the inverter will be set to its maximum capacity that it can legally accept as per the CEC rules and guidelines. Accordingly, the PV panel capacity will be set to its maximum allowable to meet the constraints of the inverter being tested. HOMER Pro© tool will be used on the number of batteries to maximise the renewable fraction of the systems being analysed. Additionally, system configurations will be configured so that they are within the physical constraints, and tariff rates used for grid connected systems will be applicable to the areas they service.

## Components

The components used have been extracted from the available technology mentioned in the literature review, these will reflect the current technology available and can be seen below in the below table. Due to the sheer number of simulations, the following inverters, solar panels and batteries, will be used for the results section to streamline the project and achieve completion in line with the requirements of this project.

Table 30: Components used for simulation

| Components | Sensitivity | |
|---|---|---|
| Solar Panels | # | 8 |
| | Model | Sun360W, REC275W, REC330W, Han295W, Tri295W, LG340W, LG330W, JKM260W |
| Inverters | # | 3 |
| | Model | Fronius 2.5 kW, SolaX 5.0 kW, Fronius 10.0 kW |
| Batteries | # | 10 |
| | Model | Enphase, LGChem6.4, LGChem10, TeslaPW2, PHI3.5, REDZBM2, SIND, BPT-5, SolaX6.5, Ritar |

The number of calculations that will occur will be at minimum 17,280 due to the variations in the tariffs, combination of components and locations. Some locations will have fewer calculations than others due to their location and tariff availability.

### 3.6.1 HOMER Pro®

HOMER Pro® which will include the additional packages of advanced grid and multi-year can evaluate a range of equipment options through variation of electricity, kW size, number of inverters / batteries, in order to fully optimise small scale power systems (Oulis Rousis, A, Tzelepis, D, Konstantelos, I, Booth, C & Strbac, G 2018) and has the capability to simulate thousands of different system designs. HOMER will list the optimal system configuration, in which is defined as the one with the least net present cost (Oulis Rousis, A, Tzelepis, D, Konstantelos, I, Booth, C & Strbac, G 2018).

Table 31: Technical assumptions and variables being tested in both HOMER Pro® and NREL's SAM®

| Sensitivity Variable | | Brisbane | Toowoomba | Hervey Bay | Barcaldine | Cairns |
|---|---|---|---|---|---|---|
| Discount Rate (%) | | 5 - 15 | | | | |
| Inflation Rate (%) | | 1.8 - 2.5 | | | | |
| Project lifetime (years) | | 25.0 | | | | |
| Daily consumption (kWh / day) | Small | 12.62 | 12.63 | 12.63 | 19.41 | 17.54 |
| | Medium | 14.84 | 13.32 | 14.84 | 22.78 | 20.05 |
| | Large | 29.54 | 28.14 | 29.54 | 24.32 | 21.59 |
| PV System (kW)* | | 2.2, 3.0, 4.4, 6.6, 8.8, 10.2, 12, 13 | | | | |
| PV lifetime (years) | | 20 – 25 (varies between manufacturer) | | | | |
| Inverter (kW) | | 2.5, 5.0, 10.0 | | | | |
| Battery Storage (#) | | HOMER® Optimised | | | | |
| Load growth (%/year) | | 1 | | | | |
| Grid price (%/year) | | 1 | | | | |
| PV deg (%/year) | | 0 | | | | |

*Dependent on inverter size

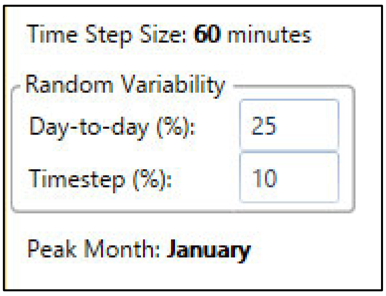
The sensitivity analysis mentioned earlier will repeat this optimisation as user defined factors, such as fuel prices, load size, reliability required, and resource quality are varied. This can be achieved via the search space, which can be added for each component to determine the optimum component size or inventory required. The following steps will detail the model for Brisbane for a small residential household, the same process is used throughout all locations and load profiles.

## Load Profile

A simulated load will be used for HOMER Pro®, this is a quick way to generate a load that is relatively realistic; for this project the peak month will be chosen as January (HomerEnergy 2016 p.28) and BOM data will be used to scale to realistic values. To make the load more realistic of a typical household both options seen below will be combined, the random variability option will be utilised with the values currently input being used across all tests.

**Day-to-Day:** Size of the load profile varies randomly daily, but the shape remains (HomerEnergy 2016 p.255)

**Timestep:** Disturbs the shape of the load without affecting its size (HomerEnergy 2016 p.255)



Time Step Size: **60** minutes

Random Variability

Day-to-day (%): 25

Timestep (%): 10

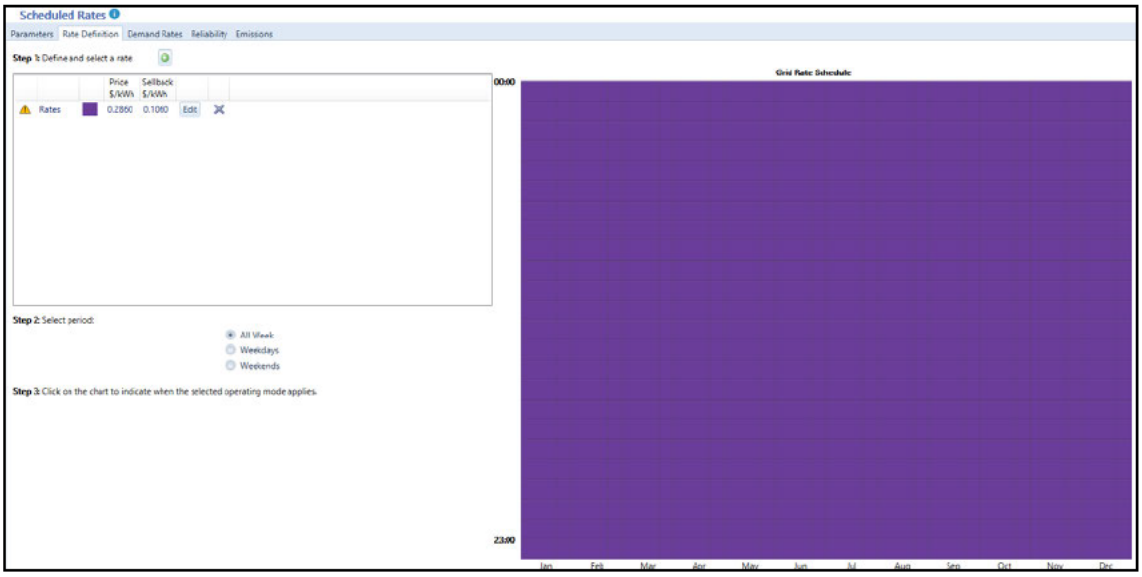
Peak Month: **January**

Figure 21: Load profile - variability input (HomerEnergy 2016)

Efficiency will be analysed for the cost-effectiveness that would reduce the electrical demand, for example replacing incandescent bulbs with LEDs. This will be implemented after all testing has been conducted to determine if households can become more efficient, a cheaper PV storage system may be available.

## Grid

*Scheduled rates* will be used to create a base system to compare against, additionally the grid will be removed to simulate an off-grid system. The *scheduled rates* permit different prices according to the time of day, month of year, and weekdays or weekends, as seen below AGL rates have been inputted. Additional control options will be used, in order to charge the battery only through the PV installed, the grid will be prohibited from charging the battery, selling to the grid during charging, and discharging and selling only when excess electricity is available. Daily supply charges will also be included under the economic option *System fixed O&M cost* ($ / year).



**Step 1:** Define and select a rate

| | | | Price $/kWh | Sellback $/kWh |
|---|---|---|---|---|
| ⚠ | Rates | ■ | 0.2860 | 0.1060 |

**Step 2:** Select period:

● All Week
○ Weekdays
○ Weekends

**Step 3:** Click on the chart to indicate when the selected operating mode applies.

Figure 22: AGL Scheduled rates (HomerEnergy 2016)

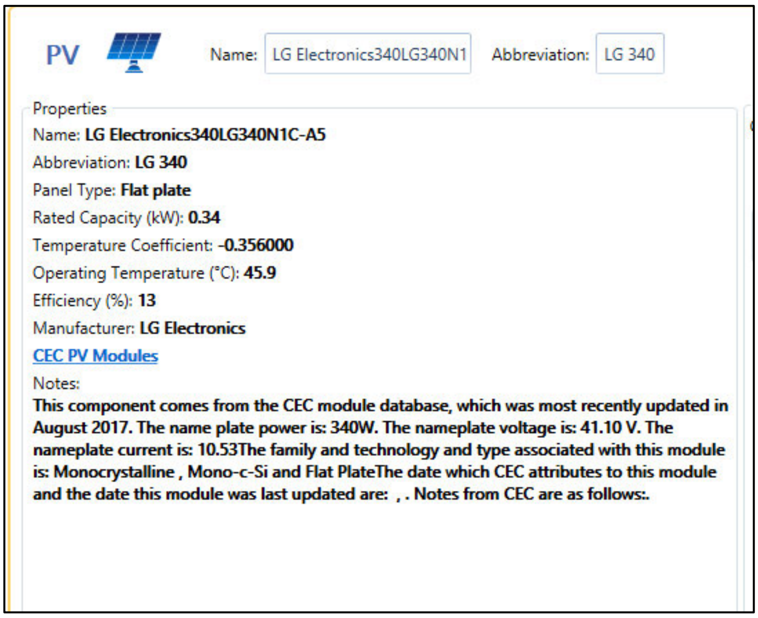
## PV system

The LG Neon 2 340 W panel is used to simulate the following outline of the methodology, assumptions used for the panel varies slightly between panels, but the following steps are constant throughout each system, regardless of size or manufacturer, the details for each module can be seen in Appendix D.2 on page 154.

Table 32: PV Assumptions

| PV assumptions | Value |
|---|---|
| Lifetime (years) | 25 |
| Ground reflectance (%) | 20 |
| Tracking system | No |
| Temperature effects considered? | Yes |
| Panel slope (degrees) | Optimised per location |
| Panel Azimuth (degrees West of South) | Optimised per location |

Search space used will reflect the capacity mentioned in Table 31, a zero value will be included to allow HOMER Pro® to consider systems without the PV installed. A solar GHI resource is then sourced by placing the coordinates of the system into HOMER Pro®, which then subsequently obtains it from the attached NASA database with HOMER Pro®. As noted in Figure 26 and is then scaled accordingly to the 2018 past year data from the BOM database.



Name: LG Electronics340LG340N1 Abbreviation: LG 340

Properties

Name: **LG Electronics340LG340N1C-A5**

Abbreviation: **LG 340**

Panel Type: **Flat plate**

Rated Capacity (kW): **0.34**

Temperature Coefficient: **-0.356000**

Operating Temperature (°C): **45.9**

Efficiency (%): **13**

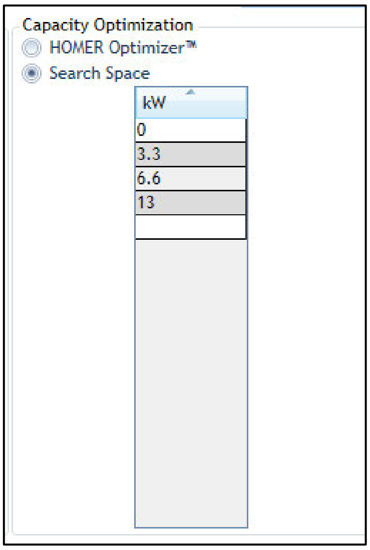
Manufacturer: **LG Electronics**

CEC PV Modules

Notes:

**This component comes from the CEC module database, which was most recently updated in August 2017. The name plate power is: 340W. The nameplate voltage is: 41.10 V. The nameplate current is: 10.53The family and technology and type associated with this module is: Monocrystalline , Mono-c-Si and Flat PlateThe date which CEC attributes to this module and the date this module was last updated are: , . Notes from CEC are as follows:.**

Figure 23: Solar PV system selection for LG Neon 2 340 W (LG340W)

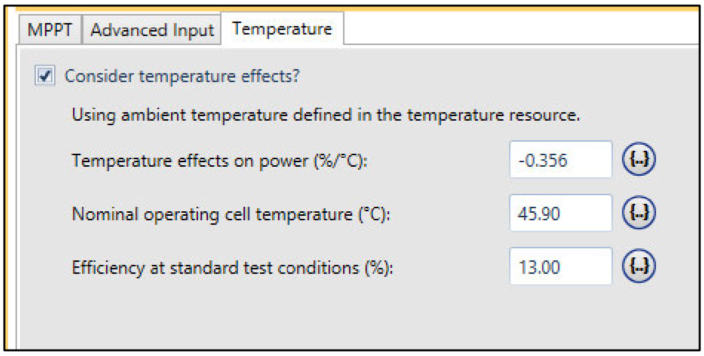

Capacity Optimization

○ HOMER Optimizer™

● Search Space

| kW |
|---|
| 0 |
| 3.3 |
| 6.6 |
| 13 |

Figure 24: Search space for project



☑ Consider temperature effects?

Using ambient temperature defined in the temperature resource.

Temperature effects on power (%/°C): -0.356

Nominal operating cell temperature (°C): 45.90

Efficiency at standard test conditions (%): 13.00

Figure 25: Solar PV temperature effects used

Choose Data Source: ● Enter monthly averages ○ Import from a time series data file or the library

Monthly Average Solar Global Horizontal Irradiance (GHI) Data

| Month | Clearness Index | Daily Radiation (kWh/m²/day) |
|---|---|---|
| Jan | 0.623 | 7.400 |
| Feb | 0.506 | 5.600 |
| Mar | 0.477 | 4.600 |
| Apr | 0.547 | 4.300 |
| May | 0.632 | 4.000 |
| Jun | 0.608 | 3.400 |
| Jul | 0.643 | 3.800 |
| Aug | 0.655 | 4.700 |
| Sep | 0.561 | 5.000 |
| Oct | 0.493 | 5.200 |
| Nov | 0.611 | 7.100 |
| Dec | 0.563 | 6.800 |

Annual Average (kWh/m²/day): 5.16

Scaled Annual Average (kWh/m²/da 5.20

Figure 26: Solar GHI resource for Brisbane

### Inverter (Converter)

The inverter has similar inputs as the PV system had, costs associated will be inputted accordingly, as well as technical details associated with the chosen inverter. If the inverter isn't in the database, the generic system inverter will be used and modified to match the inverter being analysed from the available datasheet. The inverter used in this example is a SolaX 5.0 kW.

Table 33: Inverter Assumptions

| Inverter Assumptions | Value |
|---|---|
| Capital Cost ($) | Varies between Inverters |
| Replacement ($) | Capital Cost |
| O&M ($/year) | 5.0 |
| Lifetime (years) | 10 |
| Efficiency (%) | >90 |
| Capacity (kW) | 2.5, 5.0, 10.0 |

### Battery Storage

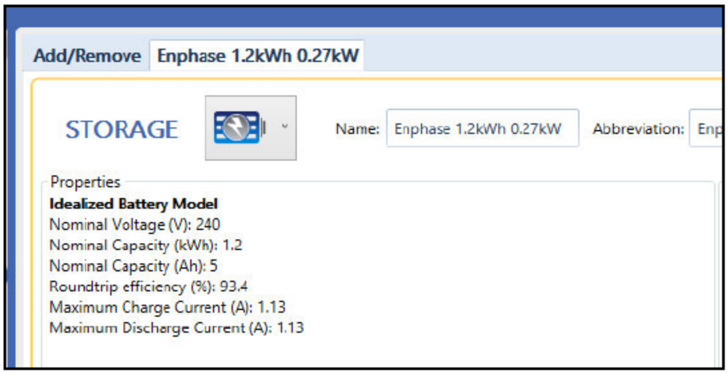
As noted in the literature it is important to set out the minimum state of charge for the battery, due to degradation effects seen when incorrect cycling procedures are followed. Majority of rechargeable batteries aren't meant to be fully discharged, resulting in increased costs to O&M of the system. As per the HOMER Pro® manual, section 7.16 shows that minimum SoC is typically set to 30 – 50% in order to avoid damaging the storage bank by excessive discharge (HomerEnergy 2016). Battery costs can be noted in section 2.4.3 on page 38; these will be used for the costs associated with buying the battery system. HOMER Pro® model batteries through either a Load Following (LF) strategy or cycle charging (CC) strategy. Load following is when a generator produces only enough power to meet the primary load (HomerEnergy 2016 p.364). Cycle charging is whenever a generator needs to operate to serve the primary load, it operates at full output power (HomerEnergy 2016 p.364) and surplus power charges the battery bank. For this example, the AC Enphase 1.2 kWh battery will be used, all batteries mentioned in the battery section of the literature review will be used throughout testing.

**Costs associated with components**

As noted below, the constant battery assumptions that will be analysed are as follows. The battery assumptions can be seen in Table 34, where the capital costs and replacement costs have been assumed to be the same, O&M of $10.0 per year for cleaning and checking the battery for damage and Lifetime assumed to be 10 years as per specification sheets for the batteries being used. Initial State of Charge will be set at 70.0% for all batteries being tested.

Table 34: Battery Assumptions

| Battery Assumptions | Value |
|---|---|
| Capital Cost ($) | Varies between Batteries |
| Replacement Cost ($) | Capital Cost |
| O&M ($/year) | 10.0 |
| Lifetime (years) | 10.0 |
| Initial State of Charge (%) | 70.0 |
| Minimum SoC (%) | Varies between batteries |
| Throughput (kWh): | Varies between batteries |



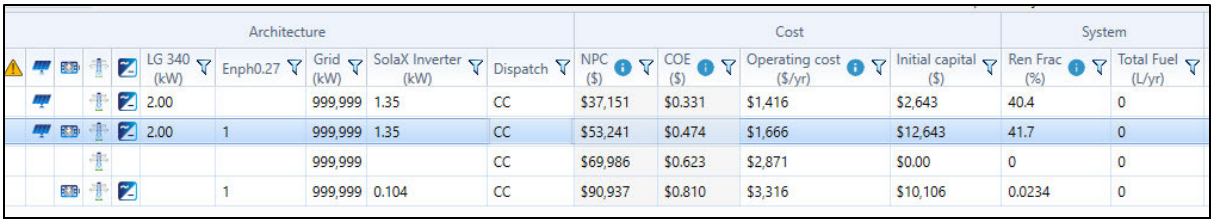
Name: Enphase 1.2kWh 0.27kW
Abbreviation: Enp

Properties
**Idealized Battery Model**
Nominal Voltage (V): 240
Nominal Capacity (kWh): 1.2
Nominal Capacity (Ah): 5
Roundtrip efficiency (%): 93.4
Maximum Charge Current (A): 1.13
Maximum Discharge Current (A): 1.13

Figure 27: Enphase 1.2kWh 0.27kW

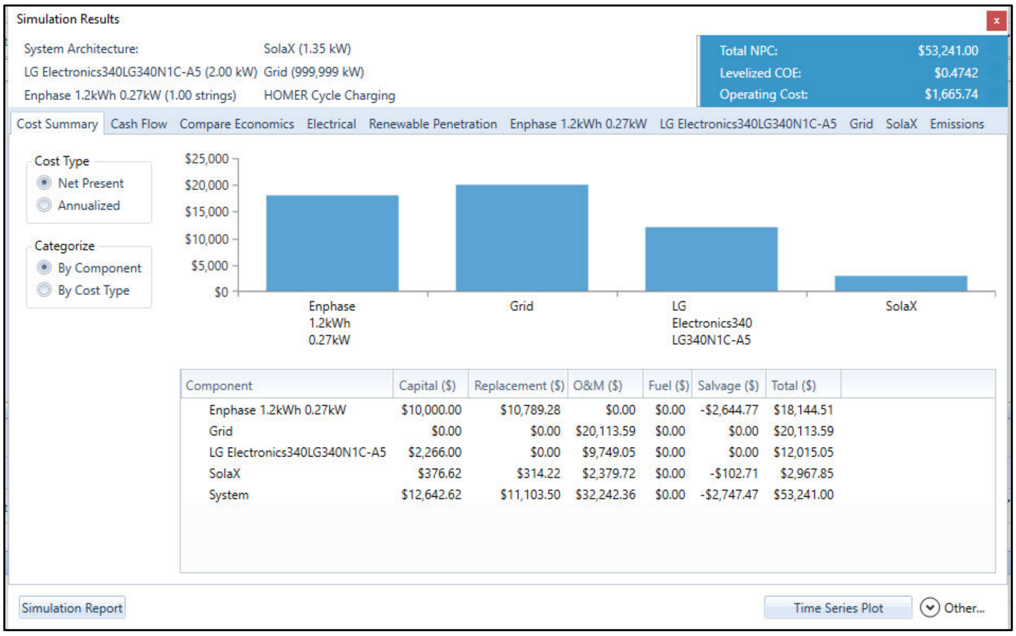
## Result Analysis

The results are as follows after optimisation occurs. Modelling of the energy output will be detailed using HOMER Pro®, as well as the state of charge, the renewable fraction of the renewable energy sources, return on investment, internal rate of return, payback period, net present cost, annualised, AC and DC primary load served, grid sales (if applicable), total load served, excess electricity, rated capacity and levelized cost.



| Architecture | | | | | Cost | | | | System | |
|---|---|---|---|---|---|---|---|---|---|---|
| LG 340 (kW) | Enph0.27 | Grid (kW) | SolaX Inverter (kW) | Dispatch | NPC ($) | COE ($) | Operating cost ($/yr) | Initial capital ($) | Ren Frac (%) | Total Fuel (L/yr) |
| 2.00 | | 999,999 | 1.35 | CC | $37,151 | $0.331 | $1,416 | $2,643 | 40.4 | 0 |
| 2.00 | 1 | 999,999 | 1.35 | CC | $53,241 | $0.474 | $1,666 | $12,643 | 41.7 | 0 |
| | | 999,999 | | CC | $69,986 | $0.623 | $2,871 | $0.00 | 0 | 0 |
| | 1 | 999,999 | 0.104 | CC | $90,937 | $0.810 | $3,316 | $10,106 | 0.0234 | 0 |

Figure 28: Optimisation results for Brisbane Small



Simulation Results

System Architecture: SolaX (1.35 kW)
LG Electronics340LG340N1C-A5 (2.00 kW) Grid (999,999 kW)
Enphase 1.2kWh 0.27kW (1.00 strings) HOMER Cycle Charging

Total NPC: $53,241.00
Levelized COE: $0.4742
Operating Cost: $1,665.74

Cost Type
● Net Present
○ Annualized

Categorize
● By Component
○ By Cost Type

| Component | Capital ($) | Replacement ($) | O&M ($) | Fuel ($) | Salvage ($) | Total ($) |
|---|---|---|---|---|---|---|
| Enphase 1.2kWh 0.27kW | $10,000.00 | $10,789.28 | $0.00 | $0.00 | -$2,644.77 | $18,144.51 |
| Grid | $0.00 | $0.00 | $20,113.59 | $0.00 | $0.00 | $20,113.59 |
| LG Electronics340LG340N1C-A5 | $2,266.00 | $0.00 | $9,749.05 | $0.00 | $0.00 | $12,015.05 |
| SolaX | $376.62 | $314.22 | $2,379.72 | $0.00 | -$102.71 | $2,967.85 |
| System | $12,642.62 | $11,103.50 | $32,242.36 | $0.00 | -$2,747.47 | $53,241.00 |

Figure 29: Simulation Results of HOMER Pro®

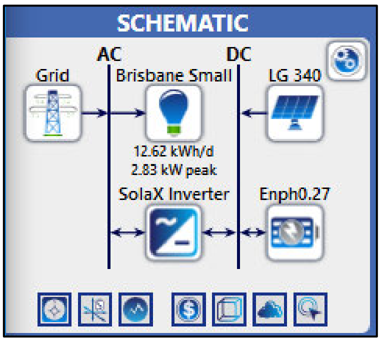


Figure 30: Schematic for microgrid (Brisbane-Small), Enphase 1.2 kWh battery

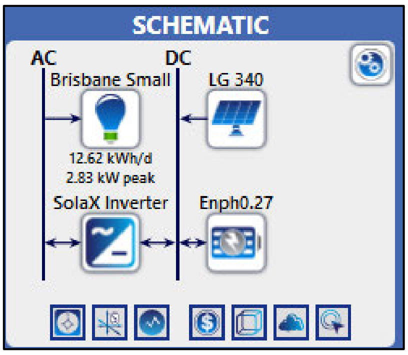


Figure 31: Schematic for microgrid (Brisbane-Small) without grid connection on AC bus

### 3.6.2 NREL's SAM®

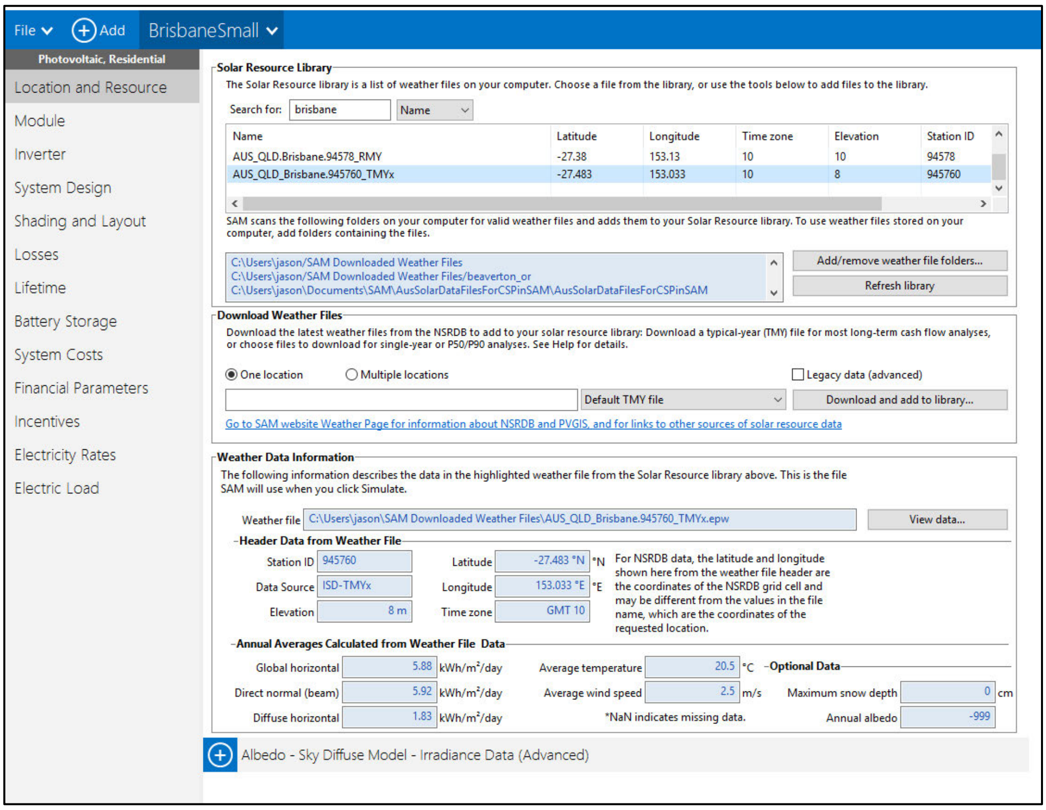
The System Advisor Model (SAM®) is a performance and financial model for renewable energy power systems and projects. It is similar to HOMER Pro® as it makes performance predictions and cost of energy estimates for grid-connected power projects based on costs associated with installation and operation. After the best system is chosen in HOMER Pro®, that same system will be simulated in SAM® to ensure that it is the best system for off-grid or partially off-grid utilising feed-in tariffs in place in addition to realistic shading affects and battery dispatch modelling. Limitations for SAM® include having to be coupled with solar PV generation, it only allows grid tied systems to be modelled, however capacity can be increased to ensure that grid usage is at a minimum or non-existent. Solar PV will be adequately sized and designed according to the electricity load and site conditions and batteries scaled accordingly. A worse-case scenario will be analysed to ensure the system in HOMER Pro® is actually the best optimised system.

**Location and Resources**

As noted in the SAM® help document (NREL 2015), the input into SAM® is as follows, the type of PV panel is chosen, if it isn't available, data from the relevant datasheets can be inputted to ensure that specific PV panel is included as accurate as possible. A financing option is chosen next, this is related to how the cash flow and economics of the project is related (NREL 2015 p.11). The input UI can be seen in Figure 32, the location and weather are selected from this page, using the data sourced from EnergyPlus and Climate.OneBuilding the location for Brisbane will be demonstrated below. In SAM® the weather that will be used is for a typical meteorological year (TMY) this represents one year of hourly data that represents historical weather data over a multi-year period.

**Modules**

After the location has been chosen, the PV module is selected next, the LG Neon 2 panel (LG340NIC-A5) is selected as shown in Figure 33, all module characteristics are inputted based on the information in the module database.



**Solar Resource Library**

The Solar Resource library is a list of weather files on your computer. Choose a file from the library, or use the tools below to add files to the library.

Search for: brisbane Name

| Name | Latitude | Longitude | Time zone | Elevation | Station ID |
|---|---|---|---|---|---|
| AUS_QLD.Brisbane.94578_RMY | -27.38 | 153.13 | 10 | 10 | 94578 |
| AUS_QLD_Brisbane.945760_TMYx | -27.483 | 153.033 | 10 | 8 | 945760 |

SAM scans the following folders on your computer for valid weather files and adds them to your Solar Resource library. To use weather files stored on your computer, add folders containing the files.

C:\Users\jason/SAM Downloaded Weather Files
C:\Users\jason/SAM Downloaded Weather Files/beaverton_or
C:\Users\jason\Documents\SAM\AusSolarDataFilesForCSPinSAM\AusSolarDataFilesForCSPinSAM

**Download Weather Files**

Download the latest weather files from the NSRDB to add to your solar resource library: Download a typical-year (TMY) file for most long-term cash flow analyses, or choose files to download for single-year or P50/P90 analyses. See Help for details.

● One location ○ Multiple locations ☐ Legacy data (advanced)

Default TMY file

Go to SAM website Weather Page for information about NSRDB and PVGIS, and for links to other sources of solar resource data

**Weather Data Information**

The following information describes the data in the highlighted weather file from the Solar Resource library above. This is the file SAM will use when you click Simulate.

Weather file C:\Users\jason\SAM Downloaded Weather Files\AUS_QLD_Brisbane.945760_TMYx.epw

**Header Data from Weather File**

Station ID 945760
Data Source ISD-TMYx
Elevation 8 m
Latitude -27.483 °N °N
Longitude 153.033 °E °E
Time zone GMT 10

For NSRDB data, the latitude and longitude shown here from the weather file header are the coordinates of the NSRDB grid cell and may be different from the values in the file name, which are the coordinates of the requested location.

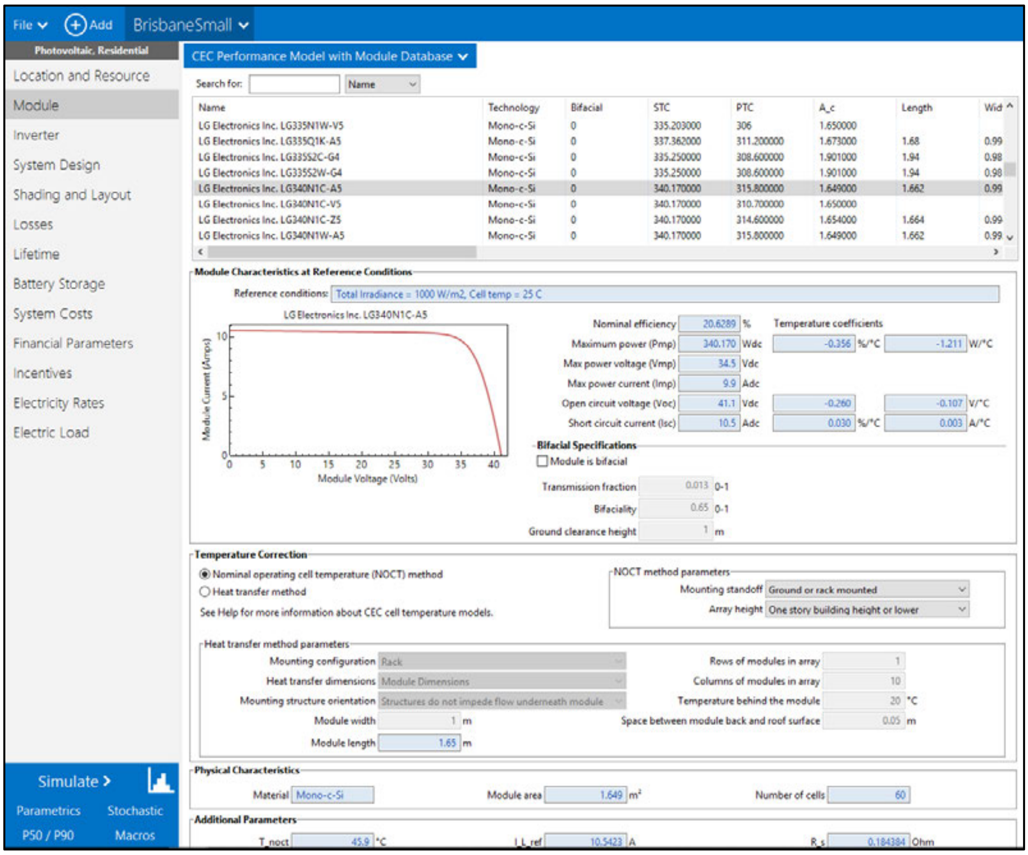
**Annual Averages Calculated from Weather File Data**

Global horizontal 5.88 kWh/m²/day
Direct normal (beam) 5.92 kWh/m²/day
Diffuse horizontal 1.83 kWh/m²/day
Average temperature 20.5 °C
Average wind speed 2.5 m/s
*NaN indicates missing data.

**Optional Data**

Maximum snow depth 0 cm
Annual albedo -999

Figure 32: SAM® UI for Location and Resource



Search for: Name

| Name | Technology | Bifacial | STC | PTC | A_c | Length | Wid |
|---|---|---|---|---|---|---|---|
| LG Electronics Inc. LG335N1W-V5 | Mono-c-Si | 0 | 335.203000 | 306 | 1.650000 | | |
| LG Electronics Inc. LG335Q1K-A5 | Mono-c-Si | 0 | 337.362000 | 311.200000 | 1.673000 | 1.68 | 0.99 |
| LG Electronics Inc. LG335S2C-G4 | Mono-c-Si | 0 | 335.250000 | 308.600000 | 1.901000 | 1.94 | 0.98 |
| LG Electronics Inc. LG335S2W-G4 | Mono-c-Si | 0 | 335.250000 | 308.600000 | 1.901000 | 1.94 | 0.98 |
| LG Electronics Inc. LG340N1C-A5 | Mono-c-Si | 0 | 340.170000 | 315.800000 | 1.649000 | 1.662 | 0.99 |
| LG Electronics Inc. LG340N1C-V5 | Mono-c-Si | 0 | 340.170000 | 310.700000 | 1.650000 | | |
| LG Electronics Inc. LG340N1C-Z5 | Mono-c-Si | 0 | 340.170000 | 314.600000 | 1.654000 | 1.664 | 0.99 |
| LG Electronics Inc. LG340N1W-A5 | Mono-c-Si | 0 | 340.170000 | 315.800000 | 1.649000 | 1.662 | 0.99 |

**Module Characteristics at Reference Conditions**

Reference conditions: Total Irradiance = 1000 W/m2, Cell temp = 25 C

| | | | Temperature coefficients | | | |
|---|---|---|---|---|---|---|
| Nominal efficiency | 20.6289 | % | | | | |
| Maximum power (Pmp) | 340.170 | Wdc | -0.356 | %/°C | -1.211 | W/°C |
| Max power voltage (Vmp) | 34.5 | Vdc | | | | |
| Max power current (Imp) | 9.9 | Adc | | | | |
| Open circuit voltage (Voc) | 41.1 | Vdc | -0.260 | | -0.107 | V/°C |
| Short circuit current (Isc) | 10.5 | Adc | 0.030 | %/°C | 0.003 | A/°C |

**Bifacial Specifications**

☐ Module is bifacial

Transmission fraction 0.013 0-1
Bifaciality 0.65 0-1
Ground clearance height 1 m

**Temperature Correction**

● Nominal operating cell temperature (NOCT) method
○ Heat transfer method

See Help for more information about CEC cell temperature models.

NOCT method parameters

Mounting standoff Ground or rack mounted
Array height One story building height or lower

Heat transfer method parameters

Mounting configuration Rack
Heat transfer dimensions Module Dimensions
Mounting structure orientation Structures do not impede flow underneath module
Module width 1 m
Module length 1.65 m
Rows of modules in array 1
Columns of modules in array 10
Temperature behind the module 20 °C
Space between module back and roof surface 0.05 m

**Physical Characteristics**

Material Mono-c-Si
Module area 1.649 m²
Number of cells 60

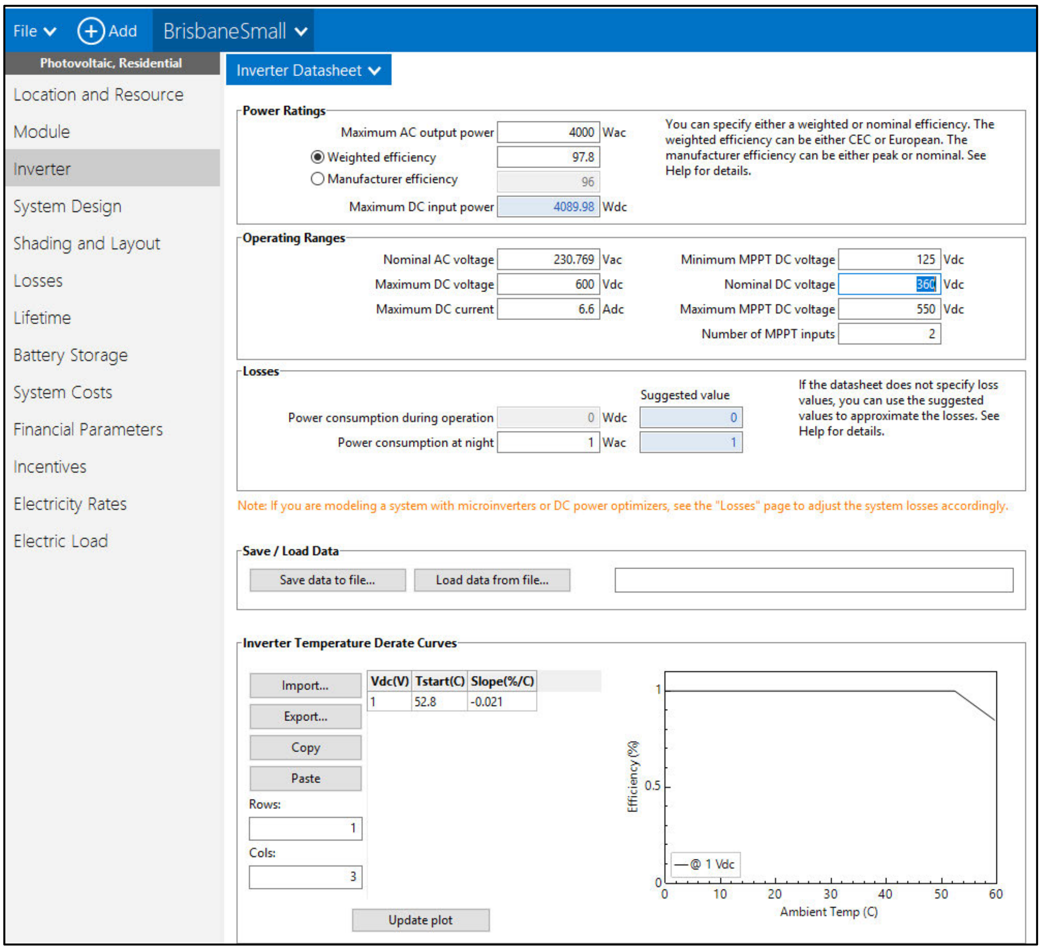
**Additional Parameters**

T_noct 45.9 °C
I_L_ref 10.5423 A
R_s 0.184384 Ohm

Figure 33: SAM® UI for Module selection

## Inverter

The PV panel is chosen from the selection as per the module database, if the module isn't in the database, the relevant information related to the panel can be inputted via a user interface. The SolaX 5.0kW inverter for the example is chosen next, this is seen below in Figure 34.



**Power Ratings**

Maximum AC output power: 4000 Wac
● Weighted efficiency: 97.8
○ Manufacturer efficiency: 96
Maximum DC input power: 4089.98 Wdc

You can specify either a weighted or nominal efficiency. The weighted efficiency can be either CEC or European. The manufacturer efficiency can be either peak or nominal. See Help for details.

**Operating Ranges**

Nominal AC voltage: 230.769 Vac
Maximum DC voltage: 600 Vdc
Maximum DC current: 6.6 Adc
Minimum MPPT DC voltage: 125 Vdc
Nominal DC voltage: 360 Vdc
Maximum MPPT DC voltage: 550 Vdc
Number of MPPT inputs: 2

**Losses**

Power consumption during operation: 0 Wdc; Suggested value: 0
Power consumption at night: 1 Wac; Suggested value: 1

If the datasheet does not specify loss values, you can use the suggested values to approximate the losses. See Help for details.

Note: If you are modeling a system with microinverters or DC power optimizers, see the "Losses" page to adjust the system losses accordingly.

**Save / Load Data**

**Inverter Temperature Derate Curves**

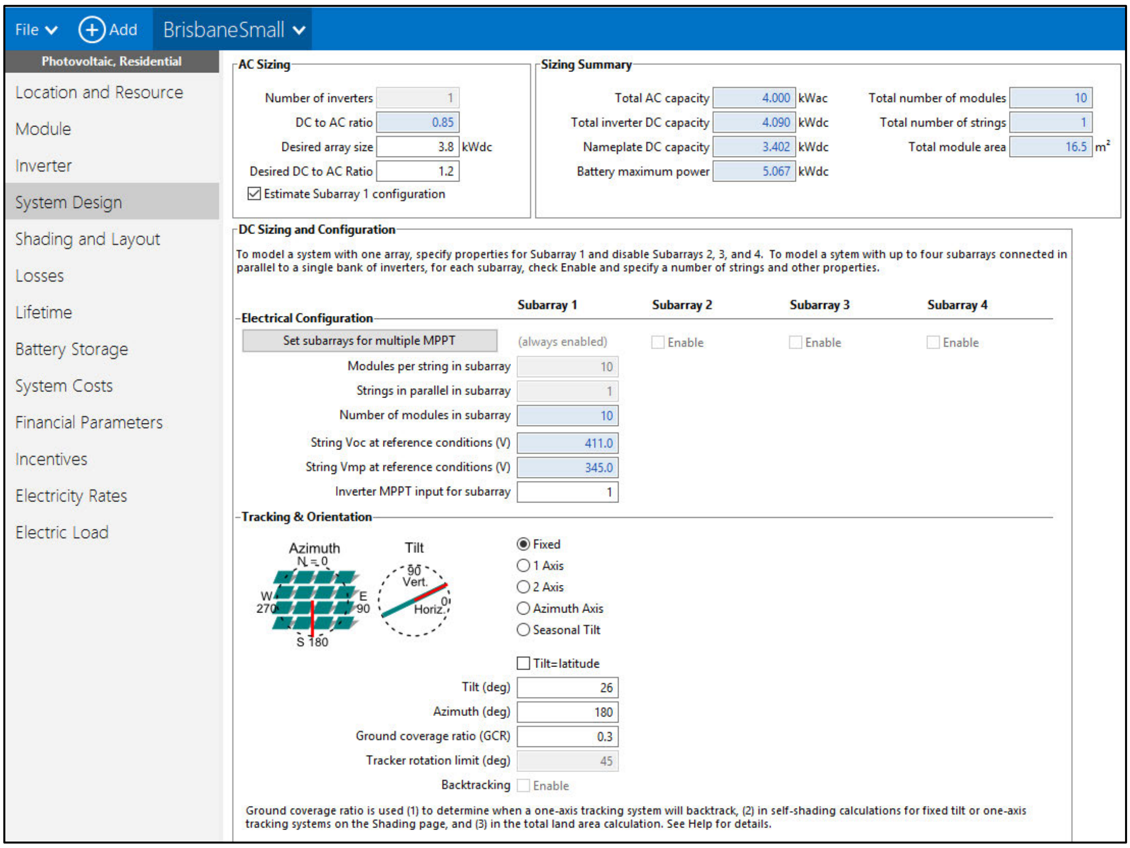
| Vdc(V) | Tstart(C) | Slope(%/C) |
|---|---|---|
| 1 | 52.8 | -0.021 |

Rows: 1
Cols: 3

Figure 34: SAM® UI for Inverter selection

## System Design

The system design is next, this is where the desired array size and desired DC to AC ratio is inputted. The program automatically configures the total number of modules required and strings required to meet the desired array size as seen in Figure 35, in addition the Azimuth and tilt angles values are the same values used in HOMER Pro®.



**AC Sizing**

Number of inverters: 1
DC to AC ratio: 0.85
Desired array size: 3.8 kWdc
Desired DC to AC Ratio: 1.2
☑ Estimate Subarray 1 configuration

**Sizing Summary**

Total AC capacity: 4.000 kWac
Total inverter DC capacity: 4.090 kWdc
Nameplate DC capacity: 3.402 kWdc
Battery maximum power: 5.067 kWdc
Total number of modules: 10
Total number of strings: 1
Total module area: 16.5 $m^2$

**DC Sizing and Configuration**

To model a system with one array, specify properties for Subarray 1 and disable Subarrays 2, 3, and 4. To model a sytem with up to four subarrays connected in parallel to a single bank of inverters, for each subarray, check Enable and specify a number of strings and other properties.

**Electrical Configuration**

| | Subarray 1 | Subarray 2 | Subarray 3 | Subarray 4 |
|---|---|---|---|---|
| Set subarrays for multiple MPPT | (always enabled) | ☐ Enable | ☐ Enable | ☐ Enable |
| Modules per string in subarray | 10 | | | |
| Strings in parallel in subarray | 1 | | | |
| Number of modules in subarray | 10 | | | |
| String Voc at reference conditions (V) | 411.0 | | | |
| String Vmp at reference conditions (V) | 345.0 | | | |
| Inverter MPPT input for subarray | 1 | | | |

**Tracking & Orientation**

● Fixed
○ 1 Axis
○ 2 Axis
○ Azimuth Axis
○ Seasonal Tilt

☐ Tilt=latitude
Tilt (deg): 26
Azimuth (deg): 180
Ground coverage ratio (GCR): 0.3
Tracker rotation limit (deg): 45
Backtracking: ☐ Enable

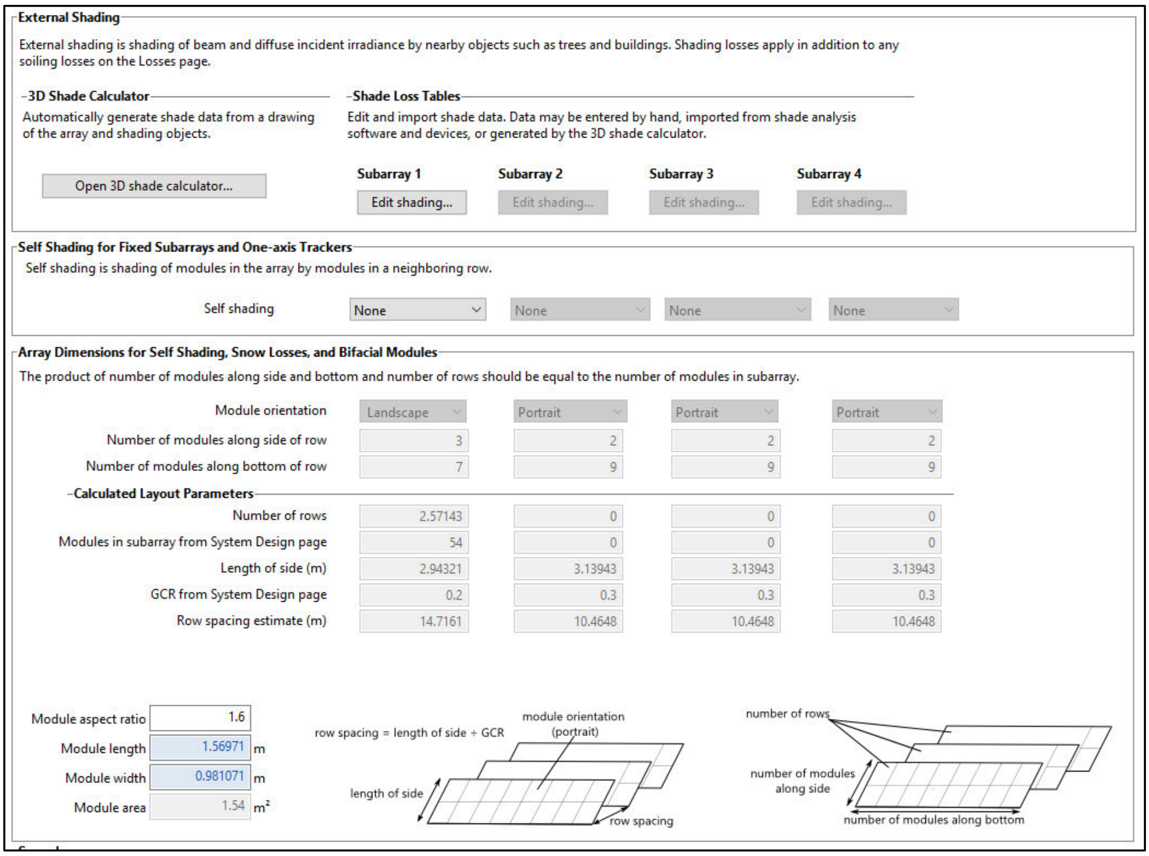
Ground coverage ratio is used (1) to determine when a one-axis tracking system will backtrack, (2) in self-shading calculations for fixed tilt or one-axis tracking systems on the Shading page, and (3) in the total land area calculation. See Help for details.

Figure 35: SAM® UI for System Design

## Shading and Layout

Shading and layout are next, this details the amount of shade the panels undergo due to external shading elements and the sizing and configuration. Losses can be stipulated, these range from soil, module mismatch, Diodes and connections, DC wiring, tracking error, Nameplate, DC power optimizer loss, AC losses, transformer losses and transmission losses. Shading is also utilised, in order to not complicate the process and as it outside the scope of the project, default values are used. Layout is modified to match the appropriate number of modules that are required from the selected panel to obtain the desired output.

The 3D shade calculator is utilised as well to fully simulate a residential home with shading from trees. The following, as seen in Figure 36 and Figure 37, has been created to automatically generate the effect of shade on a property with solar panels, a diurnal analysis is subsequently performed for the 3D model, this updates the annual energy that is produced and provides a more realistic analysis to determine if the optimised system in HOMER Pro® is the best choice.



**External Shading**

External shading is shading of beam and diffuse incident irradiance by nearby objects such as trees and buildings. Shading losses apply in addition to any soiling losses on the Losses page.

**3D Shade Calculator**

Automatically generate shade data from a drawing of the array and shading objects.

**Shade Loss Tables**

Edit and import shade data. Data may be entered by hand, imported from shade analysis software and devices, or generated by the 3D shade calculator.

**Self Shading for Fixed Subarrays and One-axis Trackers**

Self shading is shading of modules in the array by modules in a neighboring row.

| | | | | |
|---|---|---|---|---|
| Self shading | None | None | None | None |

**Array Dimensions for Self Shading, Snow Losses, and Bifacial Modules**

The product of number of modules along side and bottom and number of rows should be equal to the number of modules in subarray.

| | | | | |
|---|---|---|---|---|
| Module orientation | Landscape | Portrait | Portrait | Portrait |
| Number of modules along side of row | 3 | 2 | 2 | 2 |
| Number of modules along bottom of row | 7 | 9 | 9 | 9 |
| **Calculated Layout Parameters** | | | | |
| Number of rows | 2.57143 | 0 | 0 | 0 |
| Modules in subarray from System Design page | 54 | 0 | 0 | 0 |
| Length of side (m) | 2.94321 | 3.13943 | 3.13943 | 3.13943 |
| GCR from System Design page | 0.2 | 0.3 | 0.3 | 0.3 |
| Row spacing estimate (m) | 14.7161 | 10.4648 | 10.4648 | 10.4648 |

Module aspect ratio 1.6
Module length 1.56971 m
Module width 0.981071 m
Module area 1.54 $m^2$

Figure 36: UI for Shading and Layout

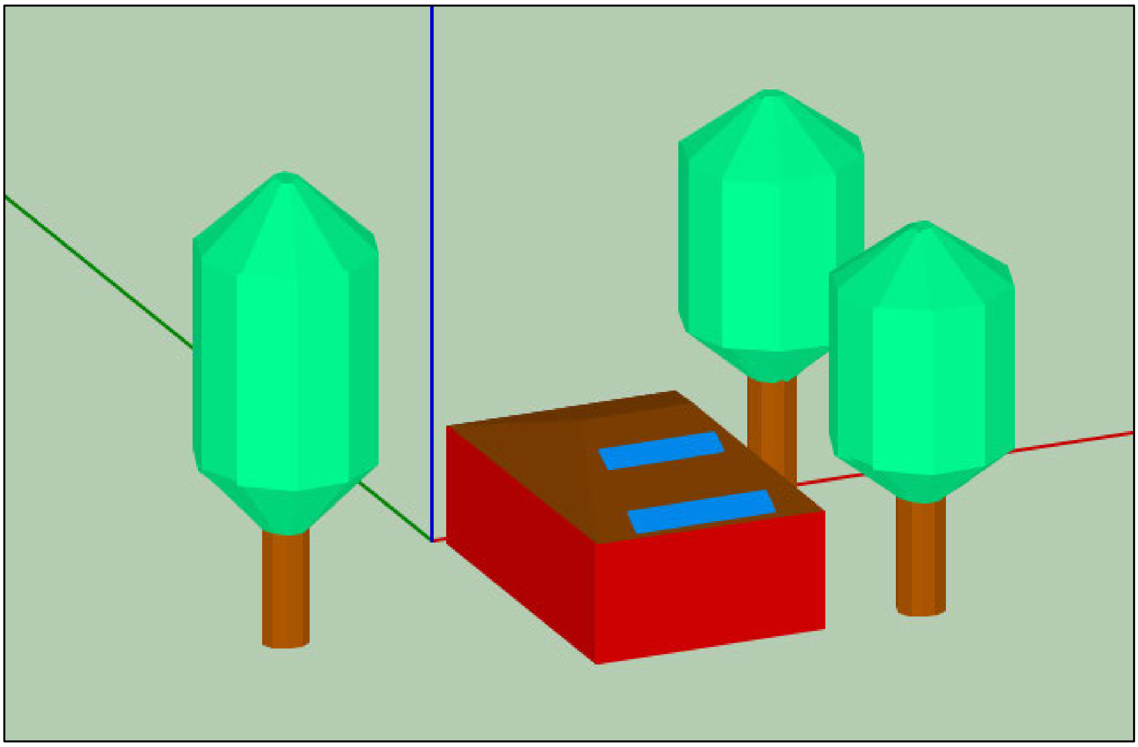
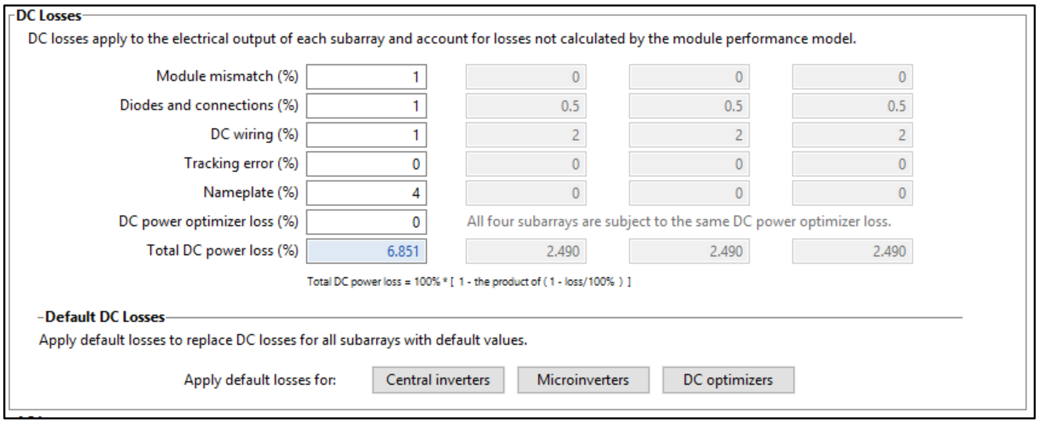


Figure 37: 3D shade calculator for Brisbane location with 2 strings in blue (source: NREL 2018)

## Lifetime and Losses

Next stage is adding the lifetime, there will be by default a 0.5% per year degradation to simulate degradation rate over the years to represent real effect on the PV, inverter and battery as dirt, aging and degradation take effect.



**DC Losses**

DC losses apply to the electrical output of each subarray and account for losses not calculated by the module performance model.

| | | | | |
|---|---|---|---|---|
| Module mismatch (%) | 1 | 0 | 0 | 0 |
| Diodes and connections (%) | 1 | 0.5 | 0.5 | 0.5 |
| DC wiring (%) | 1 | 2 | 2 | 2 |
| Tracking error (%) | 0 | 0 | 0 | 0 |
| Nameplate (%) | 4 | 0 | 0 | 0 |
| DC power optimizer loss (%) | 0 | All four subarrays are subject to the same DC power optimizer loss. | | |
| Total DC power loss (%) | 6.851 | 2.490 | 2.490 | 2.490 |

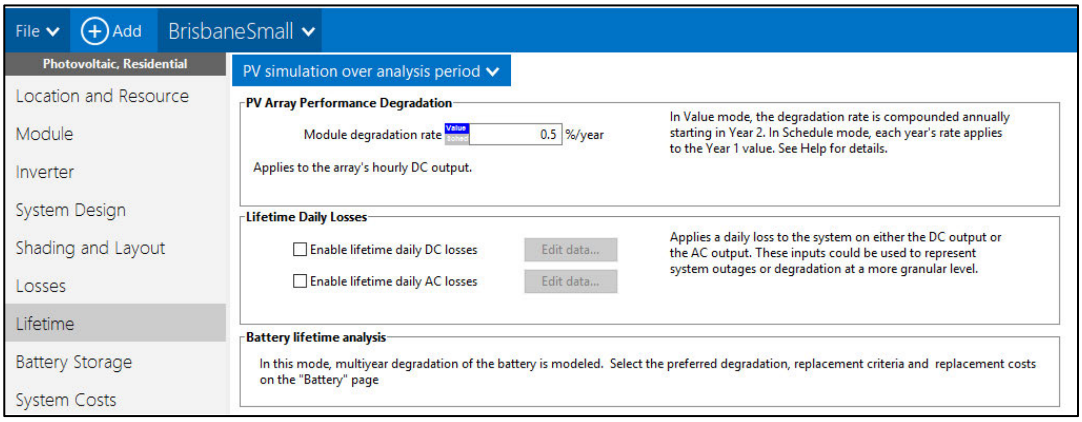
Total DC power loss = 100% * [ 1 - the product of ( 1 - loss/100% ) ]

**Default DC Losses**

Apply default losses to replace DC losses for all subarrays with default values.

Figure 38: UI for inputting in Losses

Appropriate degradation rate is applied to the system these are default values that are typically seen, this 0.5% per year is to resemble degradation that would happen as per weather and temperature effect, as well as age of devices.



**PV Array Performance Degradation**

Module degradation rate 0.5 %/year

Applies to the array's hourly DC output.

In Value mode, the degradation rate is compounded annually starting in Year 2. In Schedule mode, each year's rate applies to the Year 1 value. See Help for details.

**Lifetime Daily Losses**

☐ Enable lifetime daily DC losses

☐ Enable lifetime daily AC losses

Applies a daily loss to the system on either the DC output or the AC output. These inputs could be used to represent system outages or degradation at a more granular level.

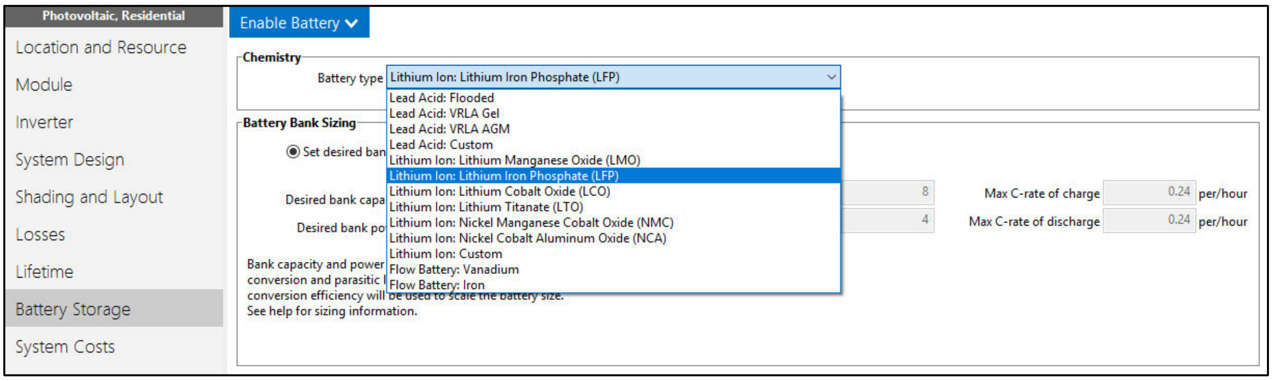
**Battery lifetime analysis**

In this mode, multiyear degradation of the battery is modeled. Select the preferred degradation, replacement criteria and replacement costs on the "Battery" page

Figure 39: UI for inputting Lifetime

## Battery Storage

This is the next phase; this section details the chemistry of the battery and relevant dispatch as seen in Figure 40 on page 69. The sizing of the battery bank values are as follows, the desired bank size function or cells can be specified, for this project the desired bank size will be used, therefore the cells will be automatically calculated. If there are any unknown details for the batteries that is missing from the datasheets being used the default values for that battery technology will be used.



Battery type: Lithium Ion: Lithium Iron Phosphate (LFP)

Desired bank capa: 8

Desired bank po: 4

Max C-rate of charge: 0.24 per/hour

Max C-rate of discharge: 0.24 per/hour

Bank capacity and power conversion and parasitic l conversion efficiency will be used to scale the battery size. See help for sizing information.

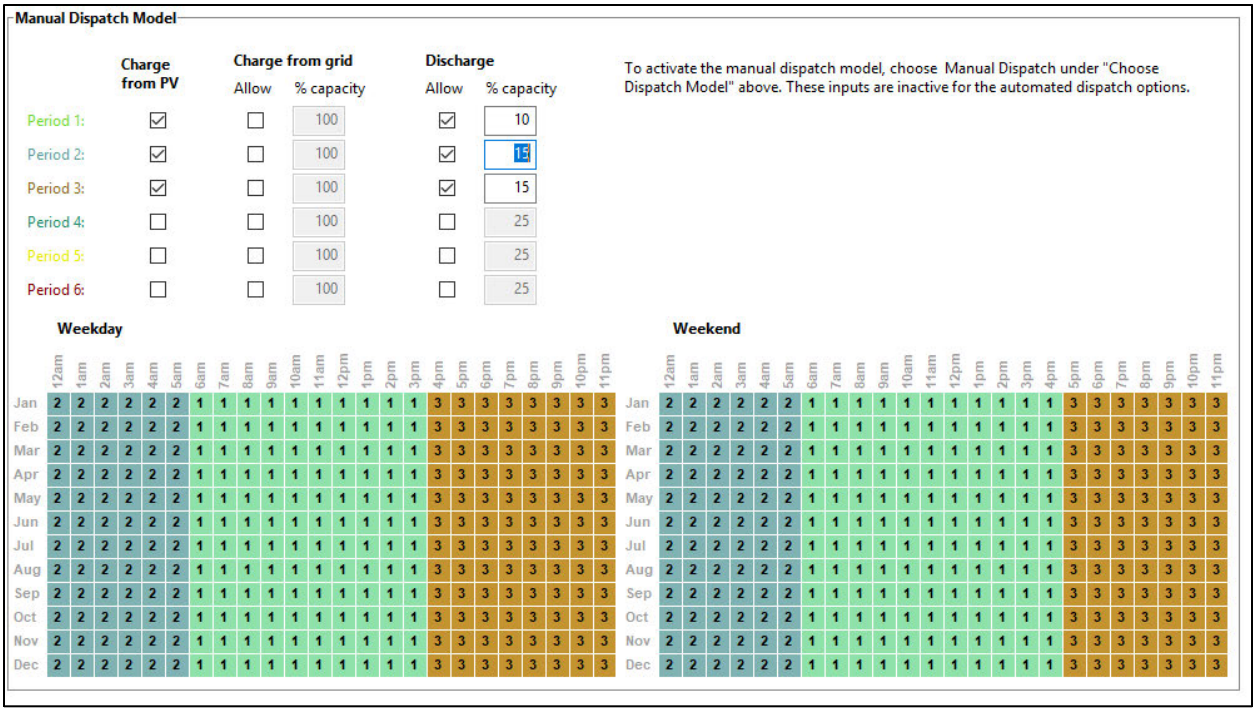
Figure 40: UI for inputting in Battery Storage

The battery dispatch can be used for peak shaving, automated grid power target or manual dispatch, this will be adjusted accordingly to achieve the most energy output for the chosen system being tested for each load profile within testing of each location. *Manual dispatch mode* will be used for all cases to ensure that the battery is properly charged and dispatched accordingly to ensure grid electricity isn’t used. Values are entered into the Charge Limits & Priority section which varies accordingly to the battery being used, in which the sizes are noted in Appendix C, and in Table 31.

In order to best optimise the batteries, the details related to the SoC will be adjusted according to the datasheets. If the values are missing, adjustments will be made to optimise the annual energy for the system, and within realistic values for the battery technology being analysed.

**System Costs, Financial Parameters and Incentives**

Direct capital costs for all components will be inputted on a case by case basis, costs associated to land area, land purchase, land prep and transmission will be set to $0.0, as that isn’t in the scope of the project. Financial parameters will remain as default, where federal income tax will be set to 30%, and state income tax and sales isn’t relevant to Australian conditions and will be set to 0%. Insurance is set to zero as it will be assumed an indirect cost associated with the final project cost. Additional taxes / rates / charges that could be modelled as property tax are not considered in this project. After running the simulation, the results page is shown. In the Metering and Billing section, net billing option will be used to sell back any excess electricity once the load has been served and that the battery is charged. Running the simulations, the results page is shown below in Figure 42 on page 71.



**Manual Dispatch Model**

To activate the manual dispatch model, choose Manual Dispatch under "Choose Dispatch Model" above. These inputs are inactive for the automated dispatch options.

| | Charge from PV | Charge from grid | | Discharge | |
|---|---|---|---|---|---|
| | | Allow | % capacity | Allow | % capacity |
| Period 1: | ☑ | ☐ | 100 | ☑ | 10 |
| Period 2: | ☑ | ☐ | 100 | ☑ | 15 |
| Period 3: | ☑ | ☐ | 100 | ☑ | 15 |
| Period 4: | ☐ | ☐ | 100 | ☐ | 25 |
| Period 5: | ☐ | ☐ | 100 | ☐ | 25 |
| Period 6: | ☐ | ☐ | 100 | ☐ | 25 |

**Weekday**

| | 12am | 1am | 2am | 3am | 4am | 5am | 6am | 7am | 8am | 9am | 10am | 11am | 12pm | 1pm | 2pm | 3pm | 4pm | 5pm | 6pm | 7pm | 8pm | 9pm | 10pm | 11pm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Feb | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Mar | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Apr | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| May | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Jun | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Jul | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Aug | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Sep | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Oct | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Nov | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Dec | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |

**Weekend**

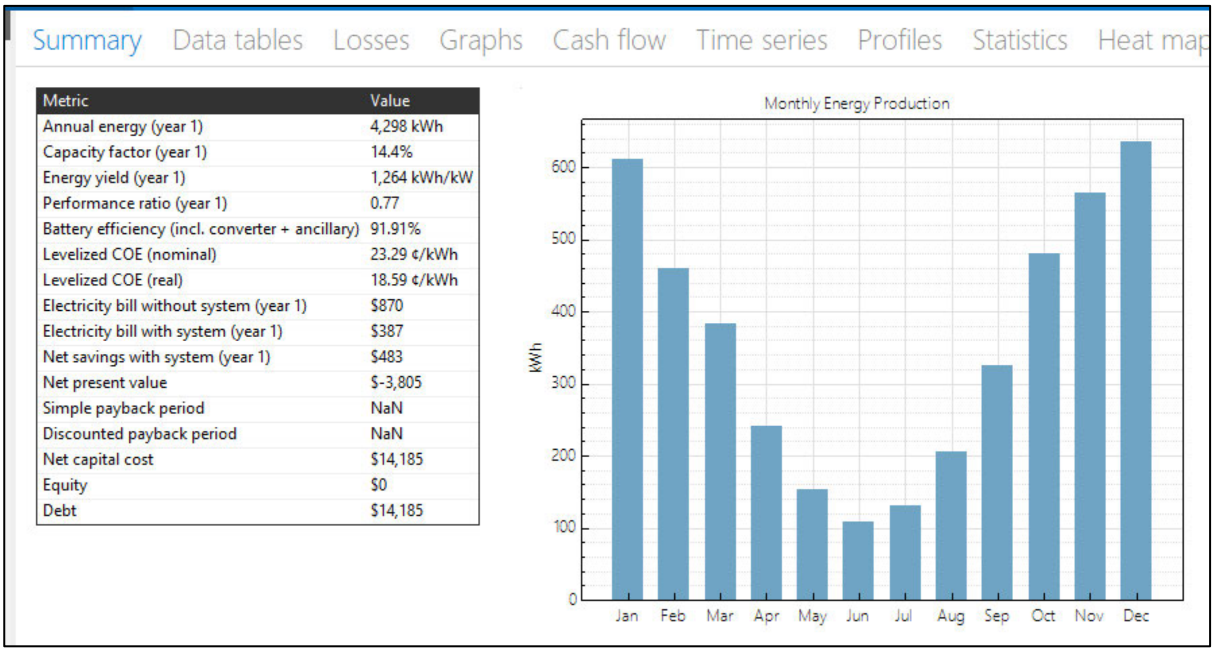
| | 12am | 1am | 2am | 3am | 4am | 5am | 6am | 7am | 8am | 9am | 10am | 11am | 12pm | 1pm | 2pm | 3pm | 4pm | 5pm | 6pm | 7pm | 8pm | 9pm | 10pm | 11pm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Feb | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Mar | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Apr | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| May | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Jun | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Jul | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Aug | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Sep | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Oct | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Nov | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Dec | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |

Figure 41: SAM® UI for Battery Dispatch model

## Results

From here a summary table is seen, a variety of data tables can be seen, the important graphs will be related to charge of battery, energy demand, cost of electricity (with & without system), to ensure the correct system is chosen and optimised fully from the selected components available. The example above is just for the small household located in Brisbane, the other locations will follow the same procedure, as well as changing the components for each location or load profile, to determine the best solution for each location. Annual energy usage with and without system will be determined by using SAM® software, the results from the testing will generate a substantial amount of output data. The parameters that will ensure off grid optimisation is obtained will be:

- Configuration of solar panel + Inverter + Battery bank that obtains the best ROI and annual energy usage
- Net Present Value (NPV)
- Net savings with system
- Best cycling period (depth of discharge + state of charge)
- System lifetime analysis



| Metric | Value |
|---|---|
| Annual energy (year 1) | 4,298 kWh |
| Capacity factor (year 1) | 14.4% |
| Energy yield (year 1) | 1,264 kWh/kW |
| Performance ratio (year 1) | 0.77 |
| Battery efficiency (incl. converter + ancillary) | 91.91% |
| Levelized COE (nominal) | 23.29 ¢/kWh |
| Levelized COE (real) | 18.59 ¢/kWh |
| Electricity bill without system (year 1) | $870 |
| Electricity bill with system (year 1) | $387 |
| Net savings with system (year 1) | $483 |
| Net present value | $-3,805 |
| Simple payback period | NaN |
| Discounted payback period | NaN |
| Net capital cost | $14,185 |
| Equity | $0 |
| Debt | $14,185 |

Figure 42: System Results from simulation

### 3.6.3 MATLAB®

MATLAB® will be used to verify the results of the two software programs discussed above i.e. calculating system output and comparing against output calculated with HOMER Pro®, it will ensure full optimisation has occurred. Simple algorithm will be developed to calculate a variety of financials related to this project and as well to check results are accurate from the two simulation programs.

# Chapter 4. Results

Before simulations were conducted, preliminary testing was performed in order to develop an understanding of the technology and form the methodology detailed prior, this was done for both software's being used in the project. The overall result tables can be seen below, the detailed results can be seen on the following pages.

Table 35: Overall analysis results across 5 locations with HOMER Pro®

| Location | Household Size | System Size (kW) | Panel | | Battery | | Renewable Fraction (%) | NPC ($) | LCOE ($/ kWh) |
|---|---|---|---|---|---|---|---|---|---|
| | | | Model | # | Model | Capacity (kWh) | | | |
| Brisbane | Small | 6.60 | JKM260PP-60 | 25 | Trojan SIND | 17.8 | 98.8 | 13,103 | 0.0724 |
| | Medium | 13.0 | JKM260PP-60 | 50 | Tesla PW2 | 13.5 | 99.9 | 3,044 | 0.0080 |
| | Large | 13.0 | JKM260PP-60 | 50 | Tesla PW2 | 13.5 | 92.3 | 18,763 | 0.0463 |
| Toowoomba | Small | 6.60 | JKM260PP-60 | 25 | Trojan SIND | 17.8 | 99.3 | 16,955 | 0.0875 |
| | Medium | 6.60 | JKM260PP-60 | 25 | Trojan SIND | 17.8 | 98.9 | 17,783 | 0.0917 |
| | Large | 13.0 | LG330W | 39 | Tesla PW2 | 13.5 | 94.4 | 29,295 | 0.0703 |
| Hervey Bay | Small | 13.0 | JKM260PP-60 | 50 | Tesla PW2 | 13.5 | 100.0 | 16,128 | 0.0410 |
| | Medium | 6.60 | JKM260PP-60 | 25 | Trojan SIND | 17.8 | 97.3 | 19,514 | 0.0999 |
| | Large | 13.0 | JKM260PP-60 | 50 | Trojan SIND | 88.8 | 100.0 | 55,344 | 0.2767 |
| Barcaldine | Small | 6.60 | JKM260PP-60 | 25 | Trojan SIND | 53.3 | 100.0 | 34,489 | 0.2624 |
| | Medium | 6.60 | JKM260PP-60 | 25 | Trojan SIND | 71.0 | 100.0 | 38,309 | 0.2484 |
| | Large | 13.0 | JKM260PP-60 | 50 | Trojan SIND | 53.3 | 100.0 | 43,075 | 0.2615 |
| Cairns | Small | 6.60 | JKM260PP-60 | 25 | Trojan SIND | 88.8 | 100.0 | 36,346 | 0.3061 |
| | Medium | 6.60 | JKM260PP-60 | 25 | Tesla PW2 | 13.5 | 92.7 | 34,946 | 0.1859 |
| | Large | 13.0 | JKM260PP-60 | 50 | Trojan SIND | 53.3 | 100.0 | 27,032 | 0.0775 |

Table 36: Overall NREL's SAM® system analysis

| Location | System Size (kW) | Panel | Battery | | | Annual Energy (kWh / day) | NPV ($) | LCOE ($/ kWh) | Capacity factor (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | Model | Model | Capacity (kWh) | # | | | | |
| Brisbane | 13.0 | JKM260PP-60 | Tesla PW2 | 13.5 | 1 | 48.0931 | 28,387 | 0.0581 | 14.3 |
| Toowoomba | 6.60 | JKM260PP-60 | Trojan SIND 042145 | 17.8 | 2 | 28.2330 | 15,050 | 0.1725 | 18.8 |
| Hervey Bay | 13.0 | JKM260PP-60 | Tesla PW2 | 13.5 | 1 | 50.1643 | 21,662 | 0.0710 | 14.9 |
| Barcaldine | 6.60 | JKM260PP-60 | Trojan SIND 042145 | 71.0 | 8 | 33.8680 | 12,596 | 0.1755 | 22.6 |
| Cairns | 13.0 | JKM260PP-60 | Trojan SIND 042145 | 53.3 | 6 | 55.4328 | 26,174 | 0.0679 | 16.4 |

Table 37: Return on Investment for optimised systems based on largest load

| Location | System Size (kW) | Panel | Battery | | | ROI (%) Optimised system | ROI (%) Grid only | ROI (%) Grid + PV only |
|---|---|---|---|---|---|---|---|---|
| | | Model | Model | Capacity (kWh) | # | | | |
| Brisbane | 13.0 | JKM260PP-60 | Tesla PW2 | 13.5 | 1 | 14.7 | 0.0 | 39.8 |
| Toowoomba | 6.60 | JKM260PP-60 | Trojan SIND 042145 | 17.8 | 2 | 15.6 | 0.0 | 28.8 |
| Hervey Bay | 13.0 | JKM260PP-60 | Tesla PW2 | 13.5 | 1 | 11.7 | 0.0 | 33.8 |
| Barcaldine | 6.60 | JKM260PP-60 | Trojan SIND 042145 | 71.0 | 8 | 7.5 | 0.0 | 28.1 |
| Cairns | 13.0 | JKM260PP-60 | Trojan SIND 042145 | 53.3 | 6 | 10.3 | 0.0 | 23.9 |

Please note: JKM260PP-60 = JKM260W = JKM260PP

## 4.1 Brisbane

Brisbane will be conducted using the AGL tariffs as they are the best tariff to use out of all available tariffs tested for this location, and by following the Methodology, Renewable Fraction (%) is the percentage that the renewable system serves the load. Weather data observed below is a result of the resources mentioned in the literature review.

- Scaled Annual Average Temperature (°C) = 21.75
- Scaled Annual Average Solar Irradiance (kWh/m$^2$/day) = 5.20
- Project Lifetime (years) = 25.0
- Derating factor (%) = 85.0

### 4.1.1 Small Brisbane Analysis

From the above tables, the best tariff for the Brisbane location has been chosen as the **AGL tariff**, this was based on analysing for the best renewable fraction, NPC and COE, in addition to comparing the tariff rates available at the Brisbane location.

Nominal discount (%) = 5.0
Expected Inflation Rate (%) = 2.5
Daily Load (kWh / day) = 12.60

Table 38: Small Brisbane Analysis

| Architecture | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inverter | | | Battery | | | Panel | | | System | | Financial | | |
| Model | Size (kW) | # | Model | Capacity (kWh) | # | Model | Size (kW) | # | Grid (Y/N) | Ren Frac. (%) | NPC ($) | LCOE ($) | Initial Capital ($) |
| Fronius | 2.5 | 1 | Trojan SIND | 17.8 | 2 | LG330W | 3.30 | 10 | Y | 89.2 | 25,215 | 0.2666 | 8,873 |
| SolaX | 5.0 | 1 | Trojan SIND | 17.8 | 2 | JKM260PP | 6.60 | 25 | Y | 98.8 | 13,103 | 0.0724 | 11,541 |
| Fronius | 10.0 | 1 | Tesla PW2 | 13.5 | 1 | Han295W | 13.0 | 44 | N | 100.0 | 9,466 | 0.0261 | 24,361 |

- The SolaX 5.0 kW configuration: this is the best configuration for a system still connected to the grid. Return on investment of 10.5%, with an annual worth of $1,044.00 and Total production at 10,527 kWh / year (28.84 kWh / day) + grid purchases of 113 kWh / year.

- The Fronius 10.0 kW configuration: this is the best configuration for 100% off grid system. Return on investment of 6.6%, with an annual worth of $1,240.00 and Total production at 20,281 kWh / year (55.56 kWh / day).

### 4.1.2 Medium Brisbane Analysis

Nominal discount (%) = 5.0

Expected Inflation Rate (%) = 2.5

Daily Load (kWh / day) = 14.84

Table 39: Medium Brisbane Analysis

| Architecture | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inverter | | | Battery | | | Panel | | | System | | Financial | | |
| Model | Size (kW) | # | Model | Capacity (kWh) | # | Model | Size (kW) | # | Grid (Y/N) | Ren Frac. (%) | NPC ($) | LCOE ($) | Initial Capital ($) |
| Fronius | 2.5 | 1 | Enphase | 1.2 | 1 | JKM260PP | 3.3 | 13 | Y | 62.3 | 22,007 | 0.1487 | 5,556 |
| SolaX | 5.0 | 1 | Trojan SIND 042145 | 17.8 | 2 | JKM260PP | 6.60 | 25 | Y | 97.1 | 15,888 | 0.0847 | 11,541 |
| Fronius | 10.0 | 1 | Tesla PW2 | 13.5 | 1 | JKM260PP | 13.0 | 50 | Y | 99.9 | 3,044 | 0.0080 | 19,031 |

- The SolaX 5.0 kW configuration: this is the best configuration for a system still connected to the grid. Return on investment of 11.2%, with an annual worth of $1,126.00 and Total production at 10,779 kWh / year (29.53 kWh / day) + grid purchases of 297 kWh / year.

- The Fronius 10.0kW configuration: this is the best configuration for off-grid sustainability whilst still being connected to the grid. Return on investment is 11.0%, with an annual worth of $1,818.00 and Total production at 21,231 kWh / year (58.167 kWh / day).

### 4.1.3 Large Brisbane Analysis

Nominal discount (%) = 5.0

Expected Inflation Rate (%) = 2.5

Daily Load (kWh/day) = 29.54

Table 40: Large Brisbane Analysis

| Architecture | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inverter | | | Battery | | | Panel | | | System | | Financial | | |
| Model | Size (kW) | # | Model | Capacity (kWh) | # | Model | Size (kW) | # | Grid (Y/N) | Ren Frac. (%) | NPC ($) | LCOE ($) | Initial Capital ($) |
| Fronius | 2.5 | 1 | ZBM2 | 10.3 | 1 | JKM260PP | 3.30 | 13 | Y | 42.7 | 54,799 | 0.2604 | 13,556 |
| SolaX | 5.0 | 1 | Trojan SIND 042145 | 17.8 | 2 | JKM260PP | 6.60 | 25 | Y | 73.4 | 34,801 | 0.1407 | 11,541 |
| Fronius | 10.0 | 1 | Tesla PW2 | 13.5 | 1 | JKM260PP | 13.0 | 50 | Y | 92.3 | 18,763 | 0.0463 | 19,031 |

- The SolaX 5.0kW configuration: this is the best configuration for a system still connected to the grid. Return on investment of 15.7%, with an annual worth of $1,641.00 and Total production at 10,779 kWh / year (29.53 kWh/day) + grid purchases of 3,551 kWh / year.

- The Fronius 10.0kW configuration: this is the best configuration with the lowest COE. Return on investment is 14.7%, with an annual worth of $2,506 / year and Total production at 21,231 kWh / year (58.167 kWh / day) + grid purchases of 1,691 kWh / year.

### 4.1.4 LCOE vs Renewable Fraction: Brisbane

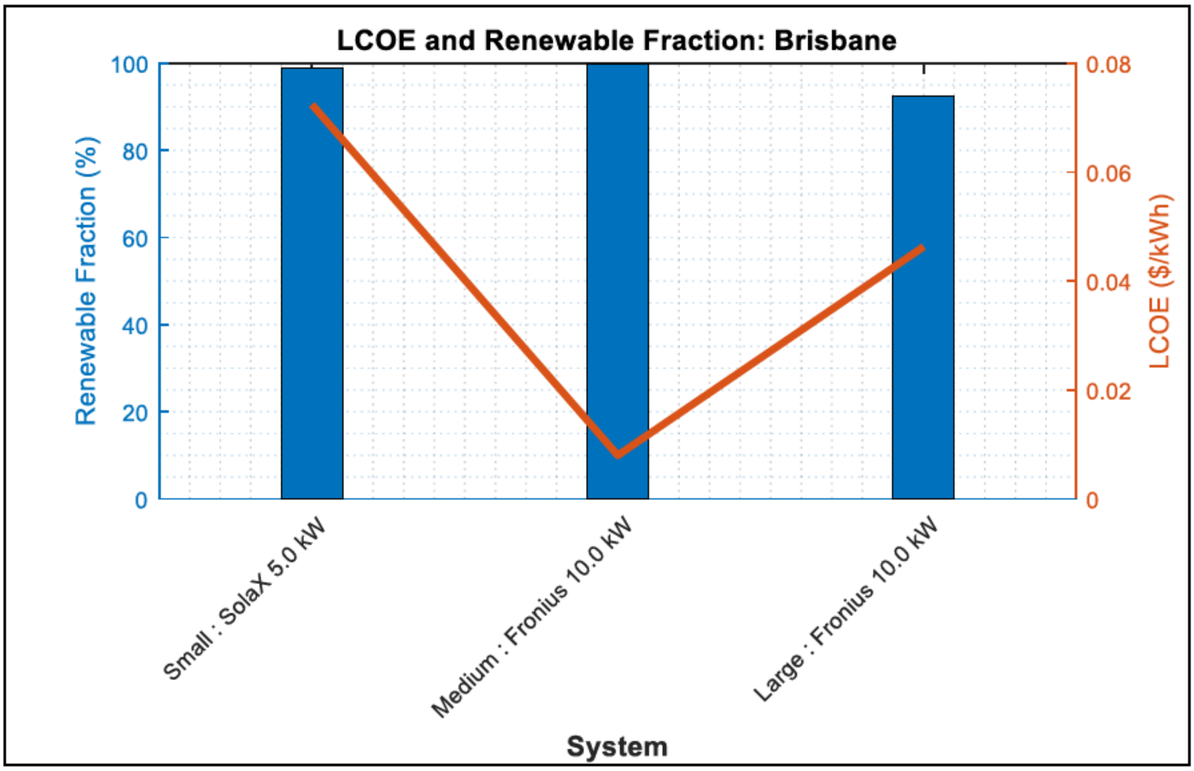


Figure 43: LCOE vs Renewable Fraction: Brisbane

As noted in Figure 43, the best system configuration will be the Fronius 10.0 kW, which aligns with a 13.0 kW solar system + a single Tesla Powerwall 2 AC 13.5 kWh battery, further analysis is conducted below using NREL System Advisor Model.

### 4.1.5 NREL SAM® Analysis: Brisbane

Comparing all systems and load profiles, the best system that can cover all load profiles is the Fronius 10.0 kW inverter to make up a 13.0 kW system with the Jinko Solar Eagle 60P (JMK260PP-60) panels with the 13.5 kWh Tesla Powerwall 2 AC. In keeping in line with the objectives of the project a comparison will be made with the newly introduced Enphase AC battery system. Adding the components to NREL SAM®, the 3D shade calculator is detailed below for the Brisbane location, this includes the panels in blue, inverter in dark blue, and Powerwall 2 in white as depicted. Simulating realistic shading, losses and including costs associated with overhead and installation is the prime use of the SAM® software.

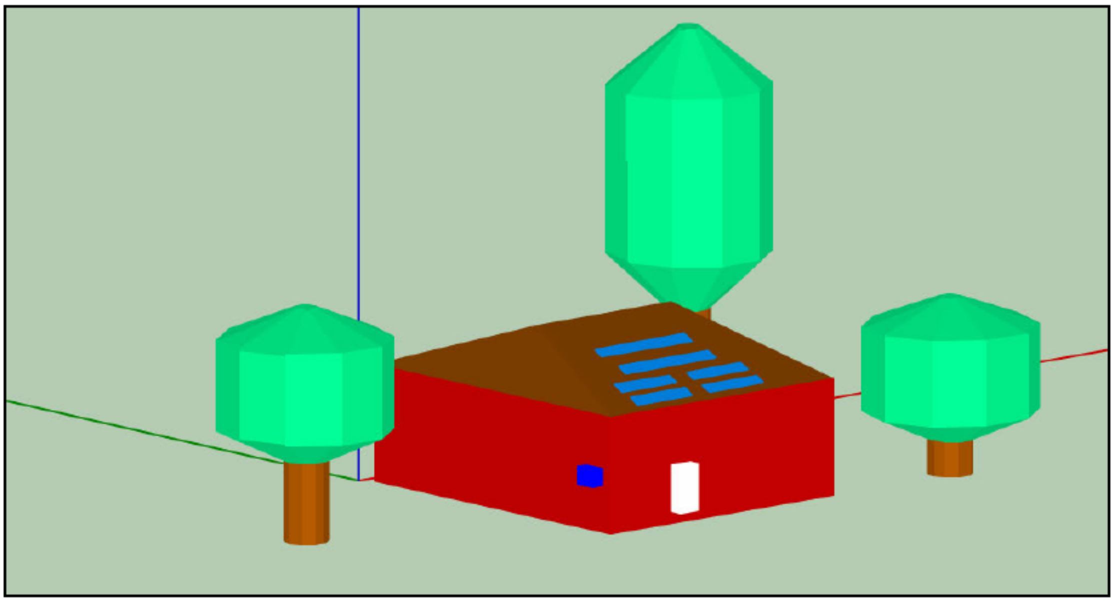


Figure 44: 3D model for Brisbane

Table 41: NREL SAM® Data Analysis: Brisbane

| Software | Battery | Battery capacity (kWh) | PV Annual Energy (kWh) | Capacity factor (%) | LCOE ($/kWh) | Bill with system ($) | Initial Capital ($) |
|---|---|---|---|---|---|---|---|
| HOMER Pro® | Tesla PW2 | 13.5 | 21,231 | 18.6 | 0.0463 | -2,281.9 | 19,031.3 |
| | Enphase | 1.2 | | | -0.0322 | -2,317.7 | 11,431.3 |
| NREL SAM® | Tesla PW2 | 13.5 | 17,554 | 14.3 | 0.0581 | -1,488.0 | 20,536.0 |
| | Enphase | 1.2 | 17,621 | | 0.0367 | -1,264.0 | 13,006.0 |
| NPV (Tesla PW2) ($) | | 28,387 | | | | | |

## 4.1.6 Battery Dispatch Model: Brisbane

To match the largest load profile (29.54 kWh / day) the battery dispatch was manually adjusted, comparing it against the default value, this is a better dispatch for the Li-ion battery as seen in Figure 45.

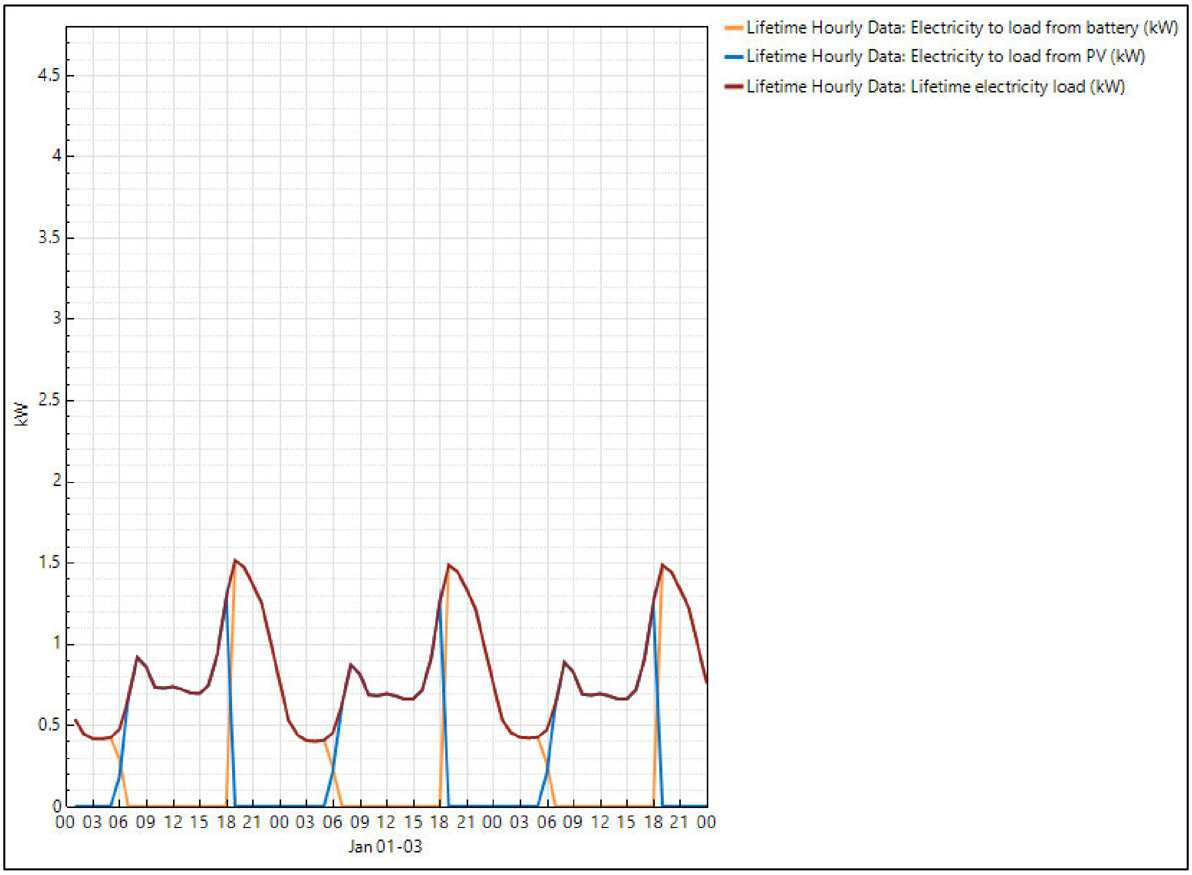
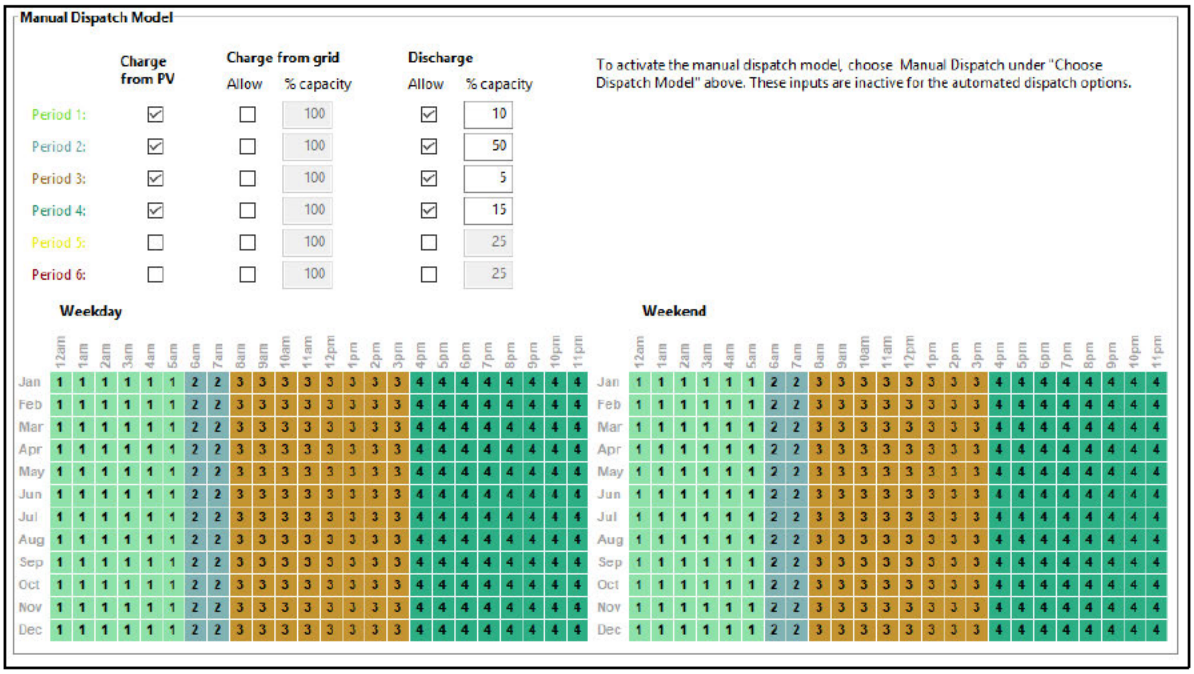


Figure 45: After adjusting battery dispatch (1st day)

As discussed previously, SAM® allows for manual dispatch strategy to be employed, the dispatch strategy seen in Figure 46, allows the load to be served by the PV during the day and any excess electricity charges the battery. Period 1 goes between the hours of 12am to 5am at a 10% discharge rate, and for period 2 ( 6am to 7am) the battery discharges at 50% per hour to meet the load as well as discharge it for the following day in order to get a charge routine in place and ensure the lithium-ion battery is operating correctly. Between 8 am and 3 pm the battery is only discharging at 5%, and between 4 pm to 11 pm the battery is discharged at a 15% rate. This is the best discharge rate used for the Brisbane location.



**Manual Dispatch Model**

| | Charge from PV | Charge from grid Allow | Charge from grid % capacity | Discharge Allow | Discharge % capacity |
|---|---|---|---|---|---|
| Period 1: | ☑ | ☐ | 100 | ☑ | 10 |
| Period 2: | ☑ | ☐ | 100 | ☑ | 50 |
| Period 3: | ☑ | ☐ | 100 | ☑ | 5 |
| Period 4: | ☑ | ☐ | 100 | ☑ | 15 |
| Period 5: | ☐ | ☐ | 100 | ☐ | 25 |
| Period 6: | ☐ | ☐ | 100 | ☐ | 25 |

To activate the manual dispatch model, choose Manual Dispatch under "Choose Dispatch Model" above. These inputs are inactive for the automated dispatch options.

**Weekday**

| | 12am | 1am | 2am | 3am | 4am | 5am | 6am | 7am | 8am | 9am | 10am | 11am | 12pm | 1pm | 2pm | 3pm | 4pm | 5pm | 6pm | 7pm | 8pm | 9pm | 10pm | 11pm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Feb | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Mar | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Apr | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| May | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jun | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jul | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Aug | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Sep | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Oct | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Nov | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Dec | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

**Weekend**

| | 12am | 1am | 2am | 3am | 4am | 5am | 6am | 7am | 8am | 9am | 10am | 11am | 12pm | 1pm | 2pm | 3pm | 4pm | 5pm | 6pm | 7pm | 8pm | 9pm | 10pm | 11pm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Feb | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Mar | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Apr | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| May | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jun | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jul | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Aug | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Sep | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Oct | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Nov | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Dec | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

Figure 46: Battery Dispatch: Brisbane

### 4.1.7 Multiyear Analysis: Brisbane

Multiyear analysis was done using the specified conditions in section 3.6.1 on page 56, the below figure details when the system will be paid off, detailed annual description of load profile, and financial profit / sales is detailed in Table 42, key components are replaced at year 10 and year 20 respectively in line with manufacturer warranty.

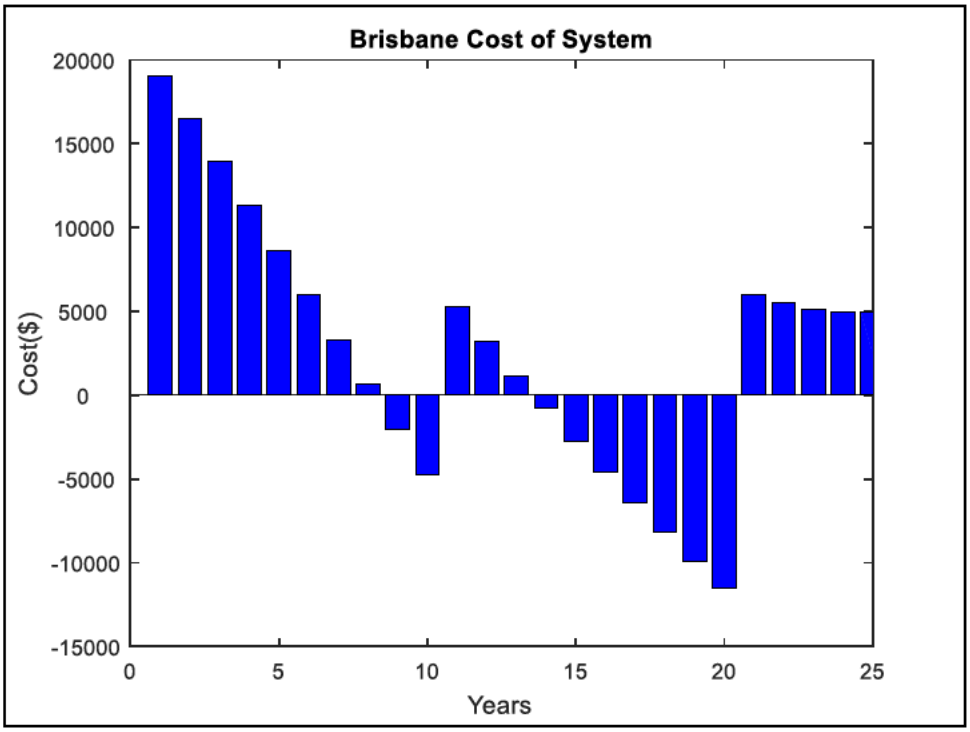


Figure 47: Payback period: Brisbane

Table 42: Multiyear Analysis: Brisbane

| Year | System Cost ($) | O&M ($) | Grid Sales ($) | Grid Purchases ($) | Money saved with PV ($) | AC Primary Load (kWh) | Ren Fraction (%) |
|---|---|---|---|---|---|---|---|
| 1 | 19,031.3 | 578.2 | 1,693.4 | 483.6 | 2,926.6 | 10,998 | 92.3 |
| 2 | 16,487.6 | 578.2 | 1,677.5 | 518.8 | 2,863.7 | 11,218 | 91.7 |
| 3 | 13,931.9 | 578.2 | 1,662.5 | 553.6 | 2,799.6 | 11,442 | 91.2 |
| 4 | 11,298.3 | 578.2 | 1,649.0 | 592.8 | 2,799.6 | 11,442 | 90.7 |
| 5 | 8,651.1 | 578.2 | 1,634.2 | 630.6 | 2,734.1 | 11,671 | 90.1 |
| 6 | 5,990.9 | 578.2 | 1,620.5 | 671.8 | 2,667.5 | 11,904 | 89.6 |
| 7 | 3,320.5 | 578.2 | 1,606.9 | 714.7 | 2,599.4 | 12,142 | 89.0 |
| 8 | 642.5 | 578.2 | 1,589.9 | 753.0 | 2,529.9 | 12,385 | 88.4 |
| 9 | -2,042.9 | 578.2 | 1,577.2 | 799.6 | 2,459.0 | 12,633 | 87.8 |
| 10 | -4,731.1 | 13,239.5 | 1,562.2 | 844.2 | 2,386.6 | 12,886 | 87.2 |
| 11 | 5,240.6 | 578.2 | 1,547.1 | 889.7 | 2,313.1 | 13,143 | 86.6 |
| 12 | 3,185.6 | 578.2 | 1,533.5 | 939.2 | 2,237.9 | 13,406 | 86.0 |
| 13 | 1,167.5 | 578.2 | 1,517.3 | 985.5 | 2,161.3 | 13,674 | 85.4 |
| 14 | -810.4 | 578.2 | 1,502.6 | 1,036.4 | 2,082.9 | 13,948 | 84.8 |
| 15 | -2,742.0 | 578.2 | 1,487.1 | 1086.8 | 2,003.1 | 14,227 | 84.1 |
| 16 | -4,623.1 | 578.2 | 1,470.9 | 1,137.9 | 1,921.9 | 14,511 | 83.5 |
| 17 | -6,447.7 | 578.2 | 1,454.8 | 1,191.4 | 1,838.6 | 14,802 | 82.9 |
| 18 | -8,209.2 | 578.2 | 1,437.4 | 1,243.2 | 1,754.0 | 15,098 | 82.3 |
| 19 | -9,903.6 | 578.2 | 1,422.9 | 1,302.4 | 1,667.9 | 15,399 | 81.6 |
| 20 | -11,520.8 | 19,609.5 | 1,407.1 | 1,360.5 | 1,579.8 | 15,707 | 80.9 |
| 21 | 5,976.2 | 578.2 | 1,390.9 | 1,420.2 | 1,489.7 | 16,022 | 80.2 |
| 22 | 5,484.4 | 578.2 | 1,371.9 | 1,476.3 | 1,398.2 | 16,342 | 79.6 |
| 23 | 5,136.5 | 578.2 | 1,355.5 | 1,538.9 | 1,304.7 | 16,669 | 78.9 |
| 24 | 4,945.5 | 578.2 | 1,338.1 | 1,601.8 | 1,209.4 | 17,002 | 78.2 |
| 25 | 4,922.5 | 578.2 | 1,320.2 | 1,665.3 | 1,112.2 | 17,342 | 77.6 |

### 4.1.8 Solar Credits: Brisbane

Zone = 3

Rating = 1.382

Years = 12

Size (kW) = 13.0

Using the formulas from the literature, the solar credits are as follows:

$$STC\ number = 13.0 * 12 * 1.382 = 215$$

$$Value\ (\$) \ = STC\ number * 35.0 = 215 * 35 = \$7{,}525.0$$

This is applied in year 0.

Original Capital ($) = 19,031.30
New Capital ($) = 11,506.30

## 4.2 Toowoomba

Results for Toowoomba will be conducted using Ergon Energy tariffs due to the assumption that majority of residential homes would be connected to Ergon Energy as a retailer, and by following the Methodology described in Chapter 3.

- Scaled Annual Average (°C) = 18.50
- Scaled Annual Average Solar Irradiance (kWh/m$^2$/day) = 5.40
- Project Lifetime (years) = 25.0
- Derating factor (%) = 85.0

### 4.2.1 Small Toowoomba Analysis

From the calculations and analysis of results for all three inverters, the best tariff used for the Toowoomba location is the **Ergon Energy tariff**, this was based on analysis for the best renewable fraction, NPC and LCOE, in addition to comparing tariffs available for the Toowoomba location.

Nominal discount (%) = 5.0

Expected Inflation Rate (%) = 2.5

Daily Load (kWh / day) = 12.63

Table 43: Small Toowoomba Analysis

| Architecture | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inverter | | | Battery | | | Panel | | | System | | Financial | | |
| Model | Size (kW) | # | Model | Capacity (kWh) | # | Model | Size (kW) | # | Grid (Y/N) | Ren Frac. (%) | NPC ($) | LCOE ($) | Initial Capital ($) |
| Fronius | 2.5 | 1 | PHI 3.5 | 3.53 | 1 | JKM260PP | 3.30 | 12 | Y | 75.5 | 20,488 | 0.1581 | 6,813 |
| SolaX | 5.0 | 1 | Trojan SIND | 17.8 | 2 | JKM260PP | 6.60 | 25 | Y | 99.3 | 16,955 | 0.0875 | 11,541 |
| Fronius | 10.0 | 1 | Tesla PW2 | 13.5 | 1 | LG330W | 13.00 | 39 | Y | 100.0 | 19,781 | 0.0507 | 25,947 |

- The SolaX 5.0 kW configuration: this is the best configuration for a system still connected to the grid. Return on investment of 8.2%, with an annual worth of $778.0 and Total production at 11,293 kWh / year (30.94 kWh / day) + grid purchases of 71.8 kWh / year.

- The Fronius 10.0 kW configuration: this is the best configuration for off-grid sustainability. Return on investment of 3.8%, with an annual worth of $664.0 and Total production at 21,875 kWh / year (59.932 kWh / day).

### 4.2.2 Medium Toowoomba Analysis

Nominal discount (%) = 5.0

Expected Inflation Rate (%) = 2.5

Load (kWh / day) = 13.32

Table 44: Medium Toowoomba Analysis

| Architecture | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inverter | | | Battery | | | Panel | | | System | | Financial | | |
| Model | Size (kW) | # | Model | Capacity (kWh) | # | Model | Size (kW) | # | Grid (Y/N) | Ren Frac. (%) | NPC ($) | LCOE ($) | Initial Capital ($) |
| Fronius | 2.5 | 1 | Trojan SIND | 17.8 | 2 | JKM260PP | 3.30 | 12 | Y | 90.5 | 24,016 | 0.2402 | 7,117 |
| SolaX | 5.0 | 1 | Trojan SIND | 17.8 | 2 | JKM260PP | 6.60 | 25 | Y | 98.9 | 17,783 | 0.09170 | 11,541 |
| Fronius | 10.0 | 1 | Trojan SIND | 17.8 | 2 | JKM260PP | 13.00 | 50 | Y | 99.7 | 5,132 | 0.01308 | 19,909 |

- The SolaX 5.0 kW configuration: this is the best configuration for a system still connected to the grid. Return on investment of 8.4%, with an annual worth of $803.0 and Total production at 11,293 kWh / year (30.94 kWh / day) + grid purchases of 111.0 kWh / year.

- The Fronius 10.0 kW configuration: this is the best configuration for off-grid sustainability. Return on investment of 12.9%, with an annual worth of $1,485.00 and Total production at 22,306 kWh / year (62.4 kWh / day).

### 4.2.3 Large Toowoomba Analysis

Nominal discount (%) = 5.0

Expected Inflation Rate (%) = 2.5

Load (kWh / day) = 28.14

Table 45: Large Toowoomba Analysis

| Architecture | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inverter | | | Battery | | | Panel | | | System | | Financial | | |
| Model | Size (kW) | # | Model | Capacity (kWh) | # | Model | Size (kW) | # | Grid (Y/N) | Ren Frac. (%) | NPC ($) | LCOE ($) | Initial Capital ($) |
| Fronius | 2.5 | 1 | PHI 3.5 | 3.53 | 1 | JKM260PP | 3.30 | 12 | Y | 47.6 | 47,061 | 0.2268 | 6,813 |
| SolaX | 5.0 | 1 | Trojan SIND | 17.8 | 2 | REC330W | 6.60 | 20 | Y | 77.4 | 33,386 | 0.1365 | 13,891 |
| Fronius | 10.0 | 1 | Tesla PW2 | 13.5 | 1 | LG330W | 13.0 | 39 | Y | 94.4 | 29,295 | 0.0703 | 25,947 |

- The SolaX 5.0 kW configuration: this is the second-best configuration for a system still connected to the grid. Return on investment of 12.0%, with an annual worth of $1,467.00 and Total production at 11,250 kWh / year (30.94 kWh / day) + grid purchases of 2,981 kWh / year.

- The Fronius 10.0 kW configuration: this is the best configuration system that is connected to the grid. Return on investment of 7.9%, with an annual worth of $1,688.00 and Total production at 22,357 kWh / year (61.252 kWh / day) + grid purchases of 1,258 kWh / year.

### 4.2.4 LCOE vs Renewable Fraction: Toowoomba

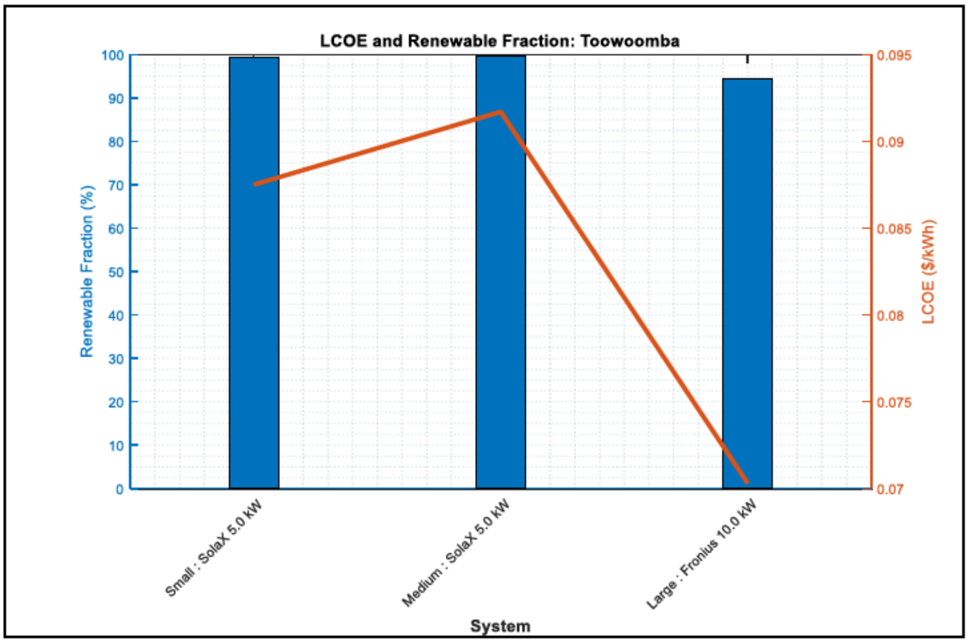


Figure 48: LCOE vs Renewable fraction: Toowoomba

As noted in Figure 48 the best system configuration will be the SolaX 5.0 kW, which aligns with a 6.60 kW solar system + two Trojan SIND batteries 17.8 kWh battery, further analysis is conducted below using NREL System Advisor Model.

### 4.2.5 NREL SAM® Analysis: Toowoomba

Comparing all systems and load profiles, the best system that can cover all load profiles comfortably is the SolaX 5.0kW inverter to make up a 6.6 kW system with the Jinko Solar Eagle 60P (JMK260PP-60) panels with two Trojan SIND 17.8 kWh.

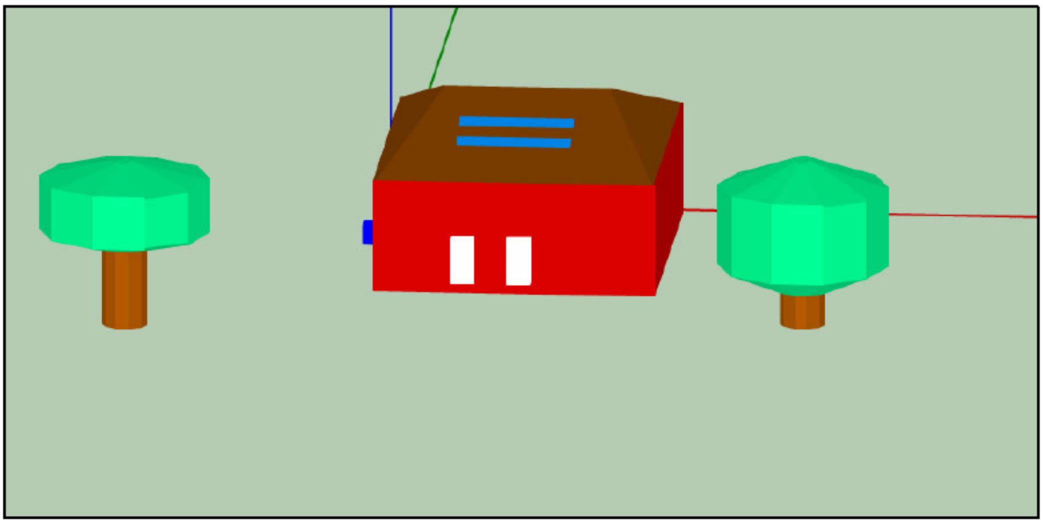


Figure 49: 3D model for Toowoomba

Table 46: NREL SAM® Data Analysis: Toowoomba

| Software | Battery | Battery capacity (kWh) | PV Annual Energy (kWh) | Capacity factor (%) | LCOE ($/kWh) | Bill with system ($) | Initial Capital ($) |
|---|---|---|---|---|---|---|---|
| HOMER Pro® | SIND 042145 | 17.8 | 11,293 | 19.5 | 0.1239 | 82.3 | 11,541.4 |
| | Enphase | 1.2 | | | 0.07726 | 63.9 | 9,979.4 |
| NREL SAM® | SIND 042145 | 17.8 | 10,305 | 18.8 | 0.1725 | 701.0 | 11,866.0 |
| | Enphase | 1.2 | 10,541 | | 0.0704 | 531.0 | 8,867.0 |
| NPV (Trojan SIND) ($) | | 15,050 | | | | | |

## 4.2.6 Battery Dispatch Model: Toowoomba

To match the largest load profile (28.14 kWh / day) the battery dispatch was manually adjusted, comparing it against the default value, this is a better dispatch for the lead acid batteries as seen in Figure 50. Manual dispatch for the battery is at 10% discharge between 12 am to 5 am, charging the battery with excess electricity between 6 am and 2 pm, use 10% battery discharge whilst still charging it from 3 pm to 11 pm. This is the best discharge rate used for the Toowoomba location.

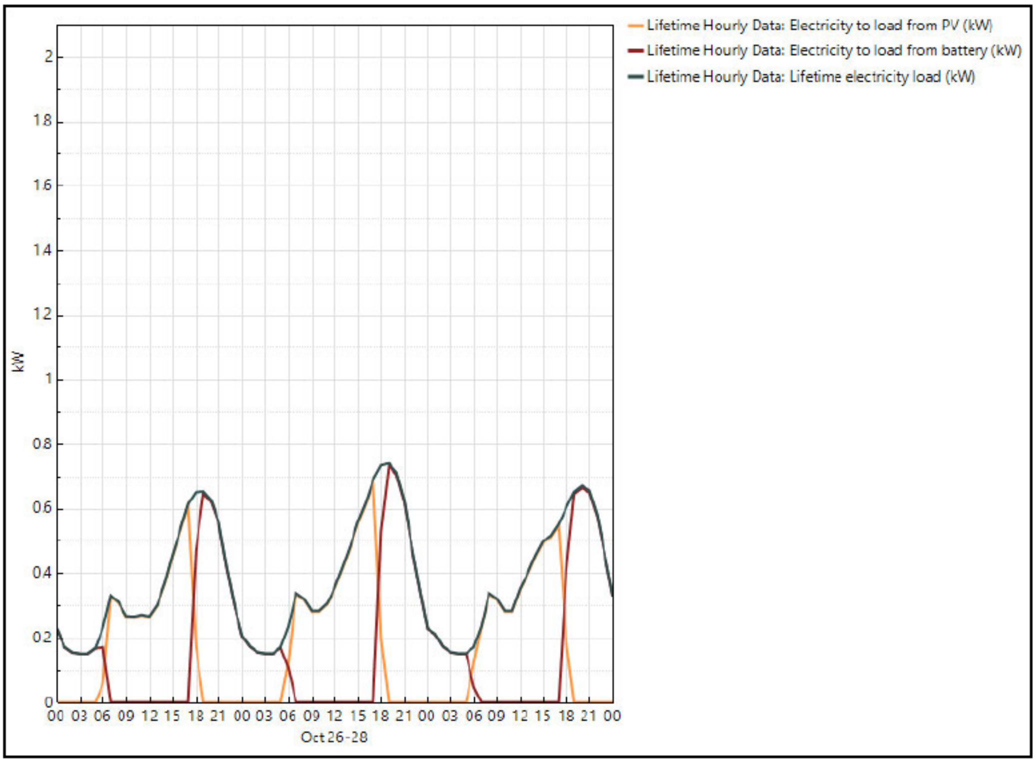
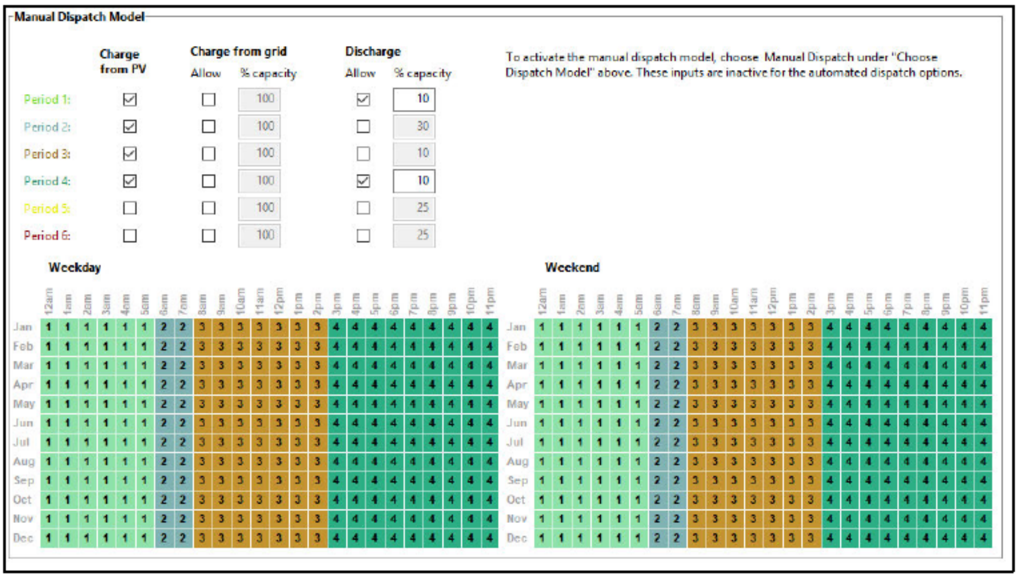


Figure 50: Battery dispatch adjusted to match load



**Manual Dispatch Model**

| | Charge from PV | Charge from grid Allow | Charge from grid % capacity | Discharge Allow | Discharge % capacity |
|---|---|---|---|---|---|
| Period 1: | ☑ | ☐ | 100 | ☑ | 10 |
| Period 2: | ☑ | ☐ | 100 | ☐ | 30 |
| Period 3: | ☑ | ☐ | 100 | ☐ | 10 |
| Period 4: | ☑ | ☐ | 100 | ☑ | 10 |
| Period 5: | ☐ | ☐ | 100 | ☐ | 25 |
| Period 6: | ☐ | ☐ | 100 | ☐ | 25 |

To activate the manual dispatch model, choose Manual Dispatch under "Choose Dispatch Model" above. These inputs are inactive for the automated dispatch options.

**Weekday**

| | 12am | 1am | 2am | 3am | 4am | 5am | 6am | 7am | 8am | 9am | 10am | 11am | 12pm | 1pm | 2pm | 3pm | 4pm | 5pm | 6pm | 7pm | 8pm | 9pm | 10pm | 11pm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Feb | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Mar | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Apr | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| May | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jun | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jul | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Aug | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Sep | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Oct | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Nov | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Dec | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

**Weekend**

| | 12am | 1am | 2am | 3am | 4am | 5am | 6am | 7am | 8am | 9am | 10am | 11am | 12pm | 1pm | 2pm | 3pm | 4pm | 5pm | 6pm | 7pm | 8pm | 9pm | 10pm | 11pm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Feb | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Mar | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Apr | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| May | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jun | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jul | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Aug | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Sep | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Oct | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Nov | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Dec | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

Figure 51: Battery Dispatch: Toowoomba

### 4.2.7 Multiyear Analysis: Toowoomba

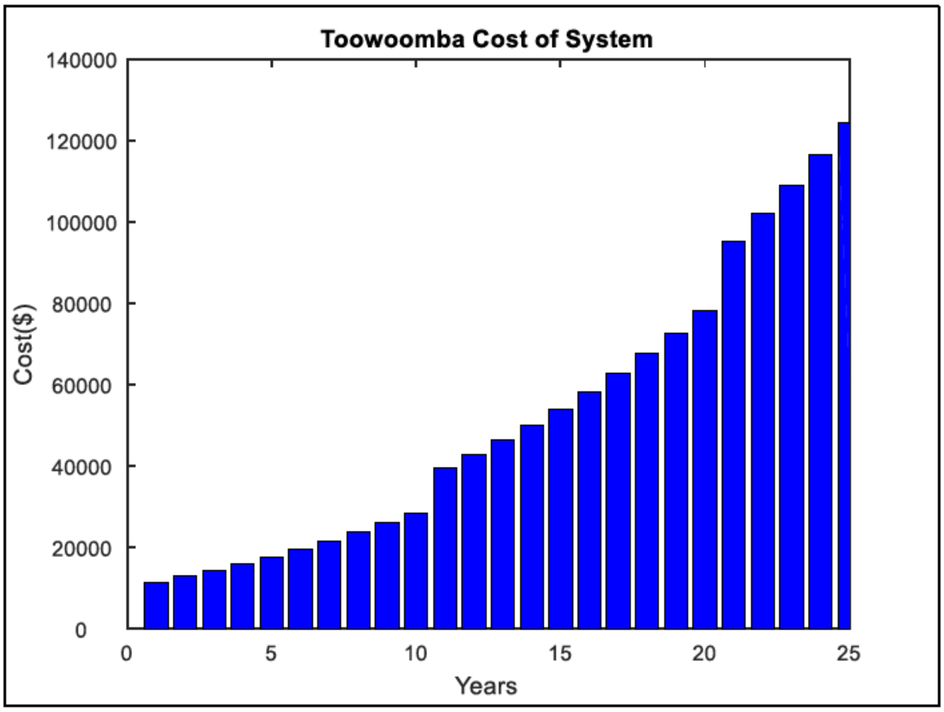


Figure 52: Payback period: Toowoomba

Table 47: Multiyear Analysis: Toowoomba

| Year | System Cost ($) | O&M ($) | Grid Sales ($) | Grid Purchases ($) | Money saved with PV ($) | AC Primary Load (kWh) | Ren Fraction (%) |
|---|---|---|---|---|---|---|---|
| 1 | 11,541.4 | 484.4 | 276.7 | 815.9 | 279.8 | 10,271 | 77.5 |
| 2 | 12,890.4 | 484.4 | 273.6 | 835.9 | 251.6 | 10,374 | 77.0 |
| 3 | 14,358.5 | 484.4 | 270.4 | 855.0 | 223.1 | 10,478 | 76.6 |
| 4 | 15,950.9 | 484.4 | 267.8 | 875.8 | 194.6 | 10,582 | 76.2 |
| 5 | 17,675.2 | 484.4 | 264.6 | 895.3 | 165.6 | 10,688 | 75.8 |
| 6 | 19,537.8 | 484.4 | 262.0 | 916.4 | 136.3 | 10,795 | 75.4 |
| 7 | 21,546.7 | 484.4 | 258.9 | 937.2 | 106.7 | 10,903 | 75.0 |
| 8 | 23,709.8 | 484.4 | 255.6 | 957.2 | 76.9 | 11,012 | 74.6 |
| 9 | 26,081.4 | 484.4 | 252.5 | 978.2 | 0 | 11,293 | 74.1 |
| 10 | 28,579.3 | 8,791.8 | 249.0 | 998.0 | 16.4 | 11,233 | 73.8 |
| 11 | 39,563.6 | 484.4 | 246.0 | 1,020.4 | -14.5 | 11,346 | 73.3 |
| 12 | 42,846.1 | 484.4 | 241.7 | 1,039.0 | -45.4 | 11,459 | 73.0 |
| 13 | 46,347.1 | 484.4 | 239.1 | 1,062.0 | -76.9 | 11,574 | 72.5 |
| 14 | 50,080.3 | 484.4 | 236.8 | 1,086.7 | -108.4 | 11,689 | 72.1 |
| 15 | 54,059.1 | 484.4 | 233.8 | 1,110.5 | -140.4 | 11,806 | 71.6 |
| 16 | 58,295.9 | 484.4 | 230.2 | 1,132.1 | -172.7 | 11,924 | 71.2 |
| 17 | 62,802.8 | 484.4 | 227.0 | 1,155.4 | -205.6 | 12,044 | 70.8 |
| 18 | 67,594.3 | 484.4 | 224.1 | 1,179.2 | -238.4 | 12,164 | 70.4 |
| 19 | 72,685.5 | 484.4 | 220.8 | 1,203.0 | -271.8 | 12,286 | 70.0 |
| 20 | 78,092.0 | 12,025.8 | 217.8 | 1,227.9 | -305.5 | 12,409 | 69.6 |
| 21 | 95,372.1 | 484.4 | 214.7 | 1,252.3 | -339.5 | 12,533 | 69.1 |
| 22 | 102,036.6 | 484.4 | 211.1 | 1,276.4 | -373.7 | 12,658 | 68.7 |
| 23 | 109,096.7 | 484.4 | 208.5 | 1,303.2 | -408.5 | 12,785 | 68.3 |
| 24 | 116,574.0 | 484.4 | 206.1 | 1,330.9 | -443.2 | 12,912 | 67.8 |
| 25 | 124,490.9 | 484.4 | 201.9 | 1,353.1 | -478.8 | 13,042 | 67.5 |

### 4.2.8 Solar Credits: Toowoomba

Zone = 3

Rating = 1.382

Years = 12

Size (kW) = 6.6

Using the formulas from the literature, the solar credits are as follows:

$$STC\ number = 6.6 * 12 * 1.382 = 109$$

$$Value\ (\$)\ = STC\ number * 35.0 = 109 * 35 = \$3{,}815.0$$

This is applied in year 0.

Original Capital ($) = 11,541.40
New Capital ($) = 7,726.40

## 4.3 Hervey Bay

Results for Hervey Bay will be conducted using Ergon Energy tariffs due to the assumption that majority of residential homes would be connected to Ergon Energy as a retailer, and by following the Methodology described in Chapter 3.

- Scaled Annual Average (°C) = 21.30
- Scaled Annual Average Solar Irradiance (kWh/m$^2$/day) = 5.50
- Project Lifetime (years) = 25.0
- Derating factor (%) = 85.0

### 4.3.1 Small Hervey Bay Analysis

From the calculations and analysis of results for all three inverters, the best tariff used for the Hervey Bay location is the **Ergon Energy tariff**, this was based on analysis for the best renewable fraction, NPC and LCOE, in addition to comparing the tariffs available for the Hervey Bay location.

Nominal discount (%) = 5.0

Expected Inflation Rate (%) = 2.5

Daily Load (kWh / day) = 12.63

Table 48: Small Hervey Bay Analysis

| Architecture | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inverter | | | Battery | | | Panel | | | System | | Financial | | |
| Model | Size (kW) | # | Model | Capacity (kWh) | # | Model | Size (kW) | # | Grid (Y/N) | Ren Frac. (%) | NPC ($) | LCOE ($) | Initial Capital ($) |
| Fronius | 2.5 | 1 | Trojan SIND | 17.8 | 2 | JKM260PP | 3.30 | 12 | Y | 91.2 | 23,220 | 0.2365 | 7,117 |
| SolaX | 5.0 | 1 | LGChem 6.4 | 6.44 | 1 | JKM260PP | 6.60 | 25 | Y | 95.2 | 21,943 | 0.1051 | 14,758 |
| Fronius | 10.0 | 1 | Tesla PW2 | 13.5 | 1 | JKM260PP | 13.0 | 50 | Y | 100.0 | 16,128 | 0.0410 | 19,031 |

- The SolaX 5.0 kW configuration: this is the best configuration for a system still connected to the grid. Return on investment of 4.9%, with an annual worth of $509.0 and Total production at 11,255 kWh / year (30.84 kWh / day) + grid purchases of 545.0 kWh / year.

- The Fronius 10.0 kW configuration: this is the best configuration for off-grid sustainability whilst still being connected to the grid. Return on investment of 5.8%, with an annual worth of $822.0 and Total production at 22,169 kWh / year (60.7369 kWh / day).

### 4.3.2 Medium Hervey Bay Analysis

Nominal discount (%) = 5.0

Expected Inflation Rate (%) = 2.5

Daily Load (kWh / day) = 14.84

Table 49: Medium Hervey Bay Analysis

| Architecture | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inverter | | | Battery | | | Panel | | | System | | Financial | | |
| Model | Size (kW) | # | Model | Capacity (kWh) | # | Model | Size (kW) | # | Grid (Y/N) | Ren Frac. (%) | NPC ($) | LCOE ($) | Initial Capital ($) |
| Fronius | 2.5 | 1 | RED ZBM2 | 10.3 | 1 | JKM260PP | 3.30 | 12 | Y | 64.3 | 22,057 | 0.1469 | 13,556 |
| SolaX | 5.0 | 1 | Trojan SIND | 17.8 | 2 | JKM260PP | 6.60 | 25 | Y | 97.3 | 19,514 | 0.0999 | 11,541 |
| Fronius | 10.0 | 1 | Trojan SIND | 17.8 | 2 | JKM260PP | 13.0 | 50 | Y | 99.2 | 7,133 | 0.0182 | 12,993 |

- The SolaX 5.0 kW configuration: this is the best configuration for a system still connected to the grid. Return on investment of 8.9%, with an annual worth of $864.0 and Total production at 11,255 kWh / year (30.84 kWh / day) + grid purchases of 280.0 kWh / year.

- The Fronius 10.0 kW configuration: this is the best configuration for off-grid sustainability whilst still being connected to the grid. Return on investment of 13.30%, with an annual worth of $1,531.0 and Total production at 22,169 kWh / year (60.7369 kWh / day) + grid purchases of 169.0 kWh / day.

### 4.3.3 Large Hervey Bay Analysis

Nominal discount (%) = 5.0

Expected Inflation Rate (%) = 2.5

Daily Load (kWh / day) = 29.54

Table 50: Large Hervey Bay Analysis

| Architecture | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inverter | | | Battery | | | Panel | | | System | | Financial | | |
| Model | Size (kW) | # | Model | Capacity (kWh) | # | Model | Size (kW) | # | Grid (Y/N) | Ren Frac. (%) | NPC ($) | LCOE ($) | Initial Capital ($) |
| Fronius | 2.5 | 1 | SolaX 6.5 | 6.53 | 1 | JKM260W | 3.30 | 12 | Y | 39.7 | 49,279 | 0.2167 | 6,300 |
| SolaX | 5.0 | 1 | Tesla PW2 | 13.5 | 1 | JKM260W | 6.60 | 25 | Y | 79.8 | 41,758 | 0.1721 | 17,579 |
| Fronius | 10.0 | 1 | Trojan SIND | 88.8 | 10 | JKM260W | 13.0 | 50 | N | 100.0 | 55,344 | 0.2767 | 31,583 |

- The SolaX 5.0 kW configuration: this is the best configuration for a system still connected to the grid. Return on investment of 8.0%, with an annual worth of $1,158.0 and Total production at 11,255 kWh / year (30.84 kWh / day) + grid purchases of 2,648 kWh / year.

- The Fronius 10.0 kW configuration: this is the best configuration for off-grid capability. Return on investment of 4.1%, with an annual worth of $709.0 and Total production at 22,169 kWh / year (60.7369 kWh / day).

### 4.3.4 LCOE vs Renewable Fraction: Hervey Bay

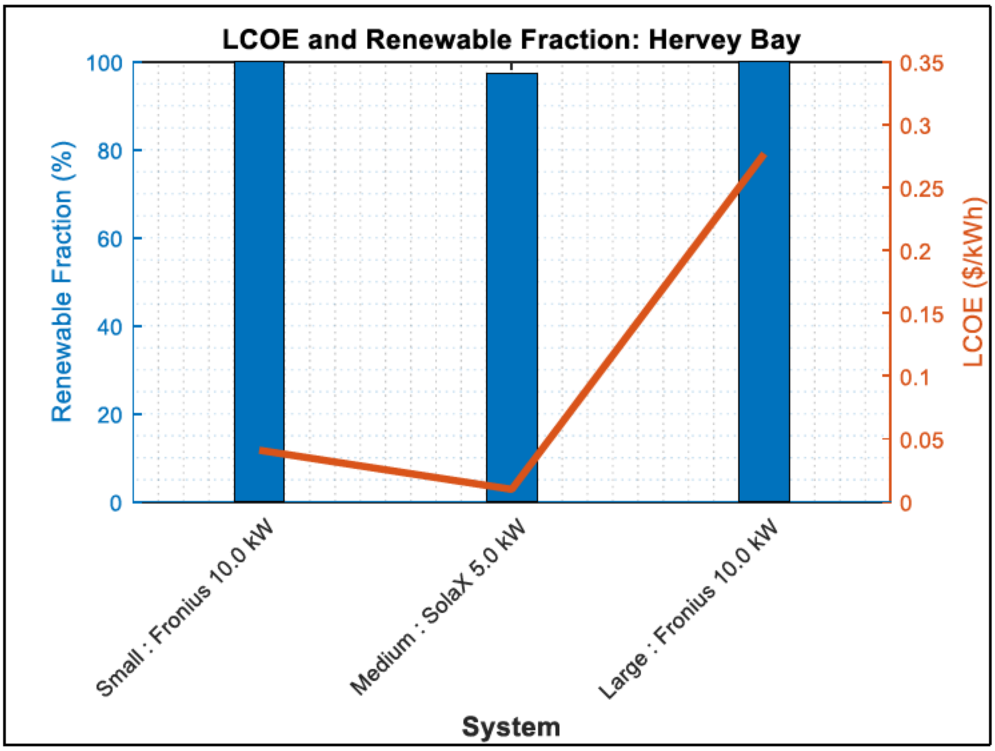


Figure 53: LCOE vs Renewable fraction: Hervey Bay

As noted in Figure 53, the best system configuration will be the Fronius 10.0 kW, which aligns with a 13.0 kW solar system + one Tesla Powerwall 2 AC, further analysis is conducted below using NREL System Advisor Model.

### 4.3.5 NREL SAM® Analysis: Hervey Bay

Comparing all systems and load profiles, the best system that can cover all load profiles is the Fronius 10.0 kW inverter to make up a 13.0 kW system with the Jinko Solar Eagle 60P (JMK260PP-60) panels with one Powerwall 2 battery resulting in 13.5 kWh capacity. This system is connected to the grid but based on the annual energy produced is more than capable of meeting all load profiles for Hervey Bay.

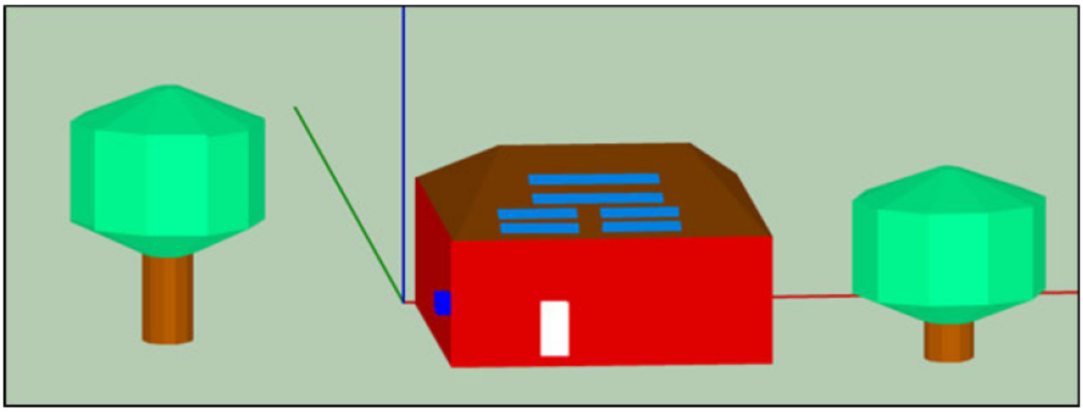


Figure 54: 3D model for Hervey Bay

Table 51: NREL SAM® Data Analysis: Hervey Bay

| Software | Battery | Battery capacity (kWh) | PV Annual Energy (kWh) | Capacity factor (%) | LCOE ($/kWh) | Bill with system ($) | Initial Capital ($) |
|---|---|---|---|---|---|---|---|
| HOMER Pro® | Tesla PW2 | 13.5 | 22,169 | 19.5 | 0.0650 | -952.6 | 19,031.3 |
| | Enphase | 1.2 | | | 0.0217 | -963.0 | 11,431.3 |
| NREL SAM® | Tesla PW2 | 13.5 | 18,310 | 15.0 | 0.0710 | -267.0 | 20,536.0 |
| | Enphase | 1.2 | 18,418 | | 0.0421 | 208.0 | 12,207.0 |
| NPV (Tesla PW2) ($) | | 21,662 | | | | | |

### 4.3.6 Battery Dispatch Model: Hervey Bay

To match the largest load profile (29.54 kWh / day) the battery dispatch was manually adjusted, comparing it against the default value, this is a better dispatch for the Lithium-ion battery as seen in Figure 55. Manual dispatch for the battery is at 10% discharge between 12 am to 5 am, charging the battery with excess electricity between 6 am to 7 am as well as discharging it 50% rate to extend the battery life, from 8 am to 3 pm the battery charges plus discharges when possible at 5% if the load hasn't been met from the PV, from 4pm to 11 pm discharge is at 15%. This is the best discharge rate used for the Hervey Bay location.

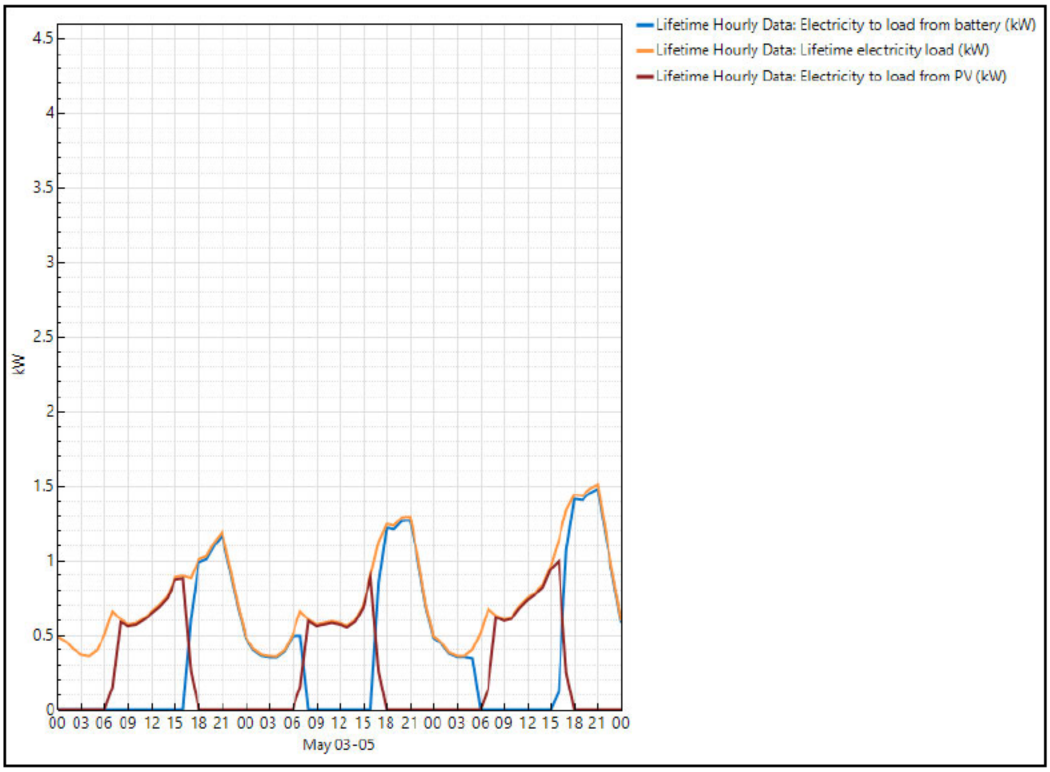
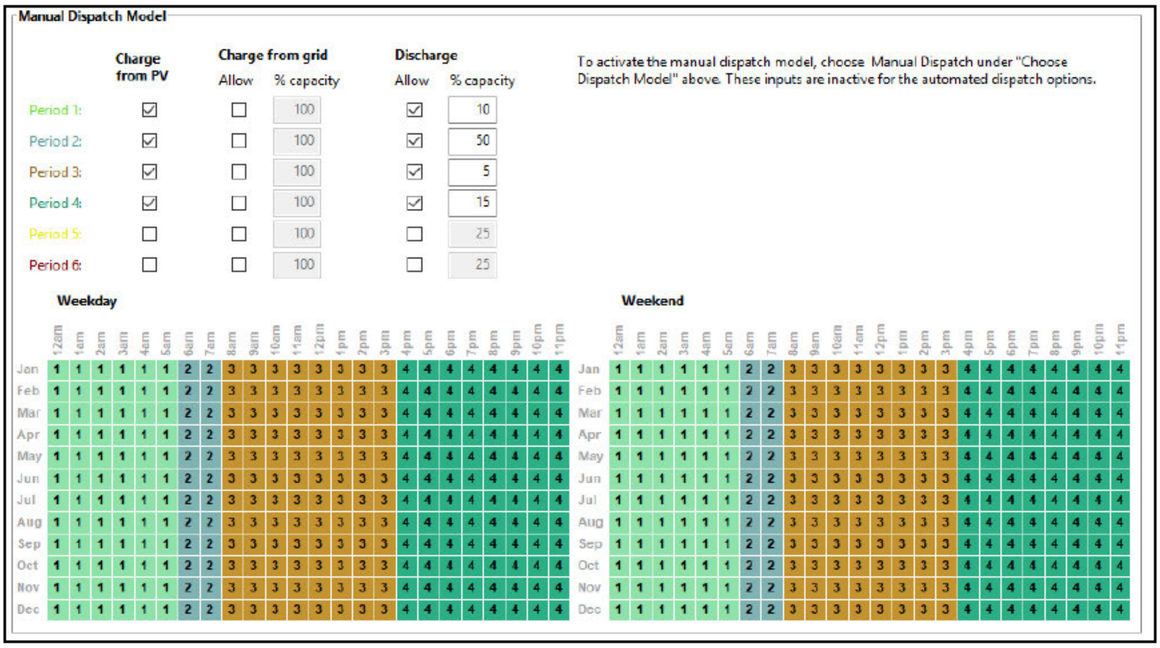


Figure 55: Battery dispatch adjusted to match load



**Manual Dispatch Model**

|  | Charge from PV | Charge from grid: Allow | Charge from grid: % capacity | Discharge: Allow | Discharge: % capacity |
|---|---|---|---|---|---|
| Period 1: | ☑ | ☐ | 100 | ☑ | 10 |
| Period 2: | ☑ | ☐ | 100 | ☑ | 50 |
| Period 3: | ☑ | ☐ | 100 | ☑ | 5 |
| Period 4: | ☑ | ☐ | 100 | ☑ | 15 |
| Period 5: | ☐ | ☐ | 100 | ☐ | 25 |
| Period 6: | ☐ | ☐ | 100 | ☐ | 25 |

To activate the manual dispatch model, choose Manual Dispatch under "Choose Dispatch Model" above. These inputs are inactive for the automated dispatch options.

**Weekday**

|  | 12am | 1am | 2am | 3am | 4am | 5am | 6am | 7am | 8am | 9am | 10am | 11am | 12pm | 1pm | 2pm | 3pm | 4pm | 5pm | 6pm | 7pm | 8pm | 9pm | 10pm | 11pm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Feb | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Mar | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Apr | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| May | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jun | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jul | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Aug | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Sep | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Oct | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Nov | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Dec | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

**Weekend**

|  | 12am | 1am | 2am | 3am | 4am | 5am | 6am | 7am | 8am | 9am | 10am | 11am | 12pm | 1pm | 2pm | 3pm | 4pm | 5pm | 6pm | 7pm | 8pm | 9pm | 10pm | 11pm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Feb | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Mar | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Apr | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| May | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jun | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jul | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Aug | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Sep | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Oct | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Nov | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Dec | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

Figure 56: Battery Dispatch: Hervey Bay

### 4.3.7 Multiyear Analysis: Hervey Bay

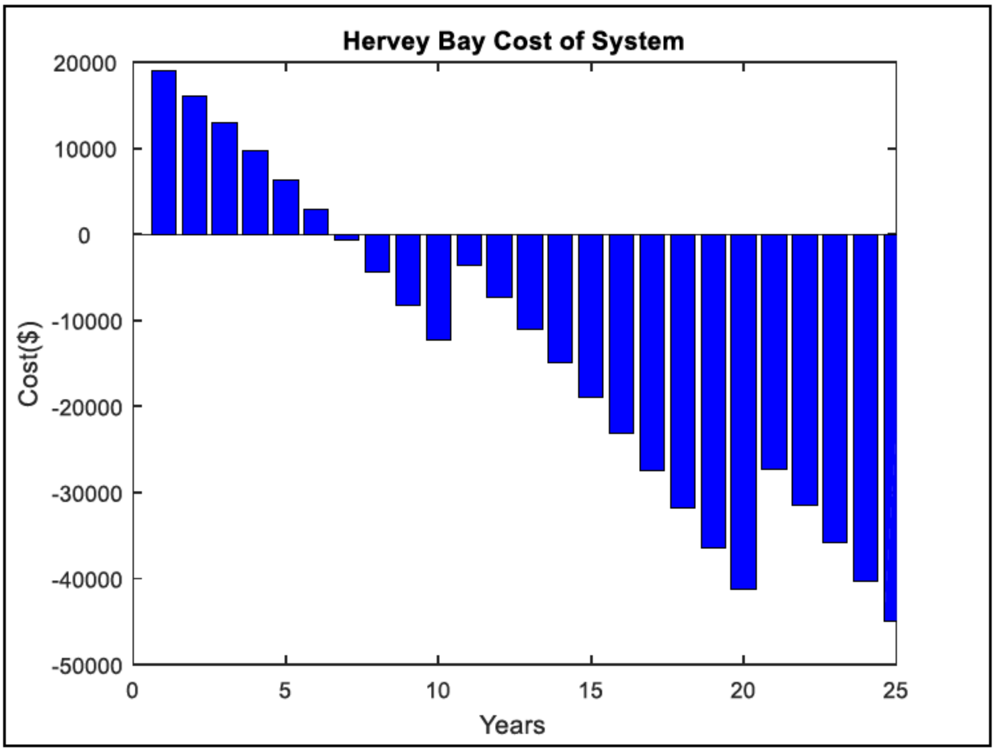


Figure 57: Payback period: Hervey Bay

Table 52: Multiyear Analysis: Hervey Bay

| Year | System Cost ($) | O&M ($) | Grid Sales ($) | Grid Purchases ($) | Money saved with PV ($) | AC Primary Load (kWh) | Ren Fraction (%) |
|---|---|---|---|---|---|---|---|
| 1 | 19,031.3 | -233.2 | 1,105.0 | 447.3 | 3,117.7 | 10,782 | 92.8 |
| 2 | 16,003.4 | -233.2 | 1,100.4 | 465.8 | 3,088.4 | 10,889 | 92.5 |
| 3 | 12,877.2 | -233.2 | 1,096.0 | 482.6 | 3,058.6 | 10,998 | 92.2 |
| 4 | 9,646.0 | -233.2 | 1,090.86 | 497.6 | 3,028.5 | 11,108 | 92 |
| 5 | 6,303.7 | -233.2 | 1,086.50 | 515.8 | 2,998.1 | 11,219 | 91.7 |
| 6 | 2,847.9 | -233.2 | 1,081.6 | 531.9 | 2,967.1 | 11,332 | 91.5 |
| 7 | -728.7 | -233.2 | 1,078.0 | 552.7 | 2,936.2 | 11,445 | 91.2 |
| 8 | -4,428.7 | -233.2 | 1,073.3 | 570.1 | 2,905.0 | 11,559 | 91 |
| 9 | -8,259.8 | -233.2 | 1,068.5 | 588.2 | 2,873.2 | 11,675 | 90.7 |
| 10 | -12,227.6 | 12,428.0 | 1,064.4 | 608.0 | 2,841.2 | 11,792 | 90.4 |
| 11 | -3,676.1 | -233.2 | 1,059.6 | 626.4 | 2,808.9 | 11,910 | 90.1 |
| 12 | -7,302.7 | -233.2 | 1,056.1 | 648.9 | 2,776.3 | 12,029 | 89.8 |
| 13 | -11,051.7 | -233.2 | 1,052.1 | 669.9 | 2,743.4 | 12,149 | 89.5 |
| 14 | -14,929.7 | -233.2 | 1,046.8 | 687.9 | 2,710.0 | 12,271 | 89.3 |
| 15 | -18,945.0 | -233.2 | 1,042.2 | 708.2 | 2,676.6 | 12,393 | 89 |
| 16 | -23,102.2 | -233.2 | 1,037.1 | 727.0 | 2,642.7 | 12,517 | 88.7 |
| 17 | -27,409.0 | -233.2 | 1,032.1 | 747.0 | 2,608.4 | 12,642 | 88.5 |
| 18 | -31,871.5 | -233.2 | 1,026.7 | 766.1 | 2,573.7 | 12,769 | 88.2 |
| 19 | -36,497.9 | -233.2 | 1,023.2 | 790.4 | 2,538.9 | 12,896 | 87.9 |
| 20 | -41,292.4 | 18,798.0 | 1,019.3 | 814.5 | 2,503.6 | 13,025 | 87.6 |
| 21 | -27,231.6 | -233.2 | 1,014.0 | 834.7 | 2,467.7 | 13,156 | 87.3 |
| 22 | -31,437.6 | -233.2 | 1,009.3 | 856.9 | 2,431.8 | 13,287 | 87 |
| 23 | -35,790.6 | -233.2 | 1,004.6 | 879.6 | 2,395.4 | 13,420 | 86.7 |
| 24 | -40,297.2 | -233.2 | 999.8 | 902.1 | 2,358.7 | 13,554 | 86.4 |
| 25 | -44,964.5 | -233.2 | 995.4 | 926.4 | 2,321.5 | 13,690 | 86.1 |

### 4.3.8 Solar Credits: Hervey Bay

Zone = 3

Rating = 1.382

Years = 12

Size (kW) = 13.0

Using the formulas from the literature, the solar credits are as follows:

$$STC\ number = 13.0 * 12 * 1.382 = 215$$

$$Value\ (\$)\ = STC\ number * 35.0 = 215 * 35 = \$7{,}525.0$$

This is applied in year 0.

Original Capital ($) = 19,031.30
New Capital ($) = 11,506.30

## 4.4 Barcaldine

Results for Barcaldine will be conducted using Ergon Energy tariffs due to the assumption that majority of residential homes would be connected to Ergon Energy as a retailer in that region, and by following the Methodology described in Chapter 3.

- Scaled Annual Average (°C) = 25.0
- Scaled Annual Average Solar Irradiance (kWh/m$^2$/day) = 6.10
- Project Lifetime (years) = 25.0
- Derating factor (%) = 85.0

### 4.4.1 Small Barcaldine Analysis

From the calculations and analysis of results for all three inverters, the best tariff used for the Barcaldine location is the **Ergon Energy tariff**, this was based on analysis for the best renewable fraction, NPC and LCOE, in addition to comparing the tariffs available for the Barcaldine location.

Nominal discount (%) = 5.0

Expected Inflation Rate (%) = 2.5

Daily Load (kWh / day) = 19.41

Table 53: Small Barcaldine Analysis

| Architecture | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inverter | | | Battery | | | Panel | | | System | | Financial | | |
| Model | Size (kW) | # | Model | Capacity (kWh) | # | Model | Size (kW) | # | Grid (Y/N) | Ren Frac. (%) | NPC ($) | LCOE ($) | Initial Capital ($) |
| Fronius | 2.5 | 1 | PHI 3.5 | 3.53 | 1 | JKM260PP | 3.30 | 12 | Y | 64.7 | 27,392 | 0.1607 | 6,813 |
| SolaX | 5.0 | 1 | Trojan SIND | 53.3 | 6 | JKM260PP | 6.60 | 25 | N | 100.0 | 34,489 | 0.2624 | 18,665 |
| Fronius | 10.0 | 1 | Trojan SIND | 35.5 | 4 | JKM260PP | 13.00 | 50 | N | 100.0 | 38,586 | 0.2936 | 16,555 |

- The SolaX 5.0 kW configuration: this is the second-best configuration for a system not connected to the grid. Return on investment of 4.3%, with an annual worth of $521.00 and Total production at 12,593 kWh / year (34.501 kWh / day).

- The Fronius 10.0 kW configuration: this is the best configuration for off-grid sustainability. Return on investment of 3.3%, with an annual worth of $300.0 and Total production at 24,804 kWh / year (67.956 kWh / day).

### 4.4.2 Medium Barcaldine Analysis

Nominal discount (%) = 5.0

Expected Inflation Rate (%) = 2.5

Daily Load (kWh / day) = 22.78

Table 54: Medium Barcaldine Analysis

| Architecture | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inverter | | | Battery | | | Panel | | | System | | Financial | | |
| Model | Size (kW) | # | Model | Capacity (kWh) | # | Model | Size (kW) | # | Grid (Y/N) | Ren Frac. (%) | NPC ($) | LCOE ($) | Initial Capital ($) |
| Fronius | 2.5 | 1 | Enphase 1.2kWh | 1.2 | 1 | JKM260PP | 3.30 | 12 | Y | 55.0 | 33,118 | 0.1688 | 5,556 |
| SolaX | 5.0 | 1 | Trojan SIND | 71.0 | 8 | JKM260PP | 6.60 | 25 | N | 100.0 | 38,309 | 0.2484 | 22,227 |
| Fronius | 10.0 | 1 | Trojan SIND | 53.3 | 6 | JKM260PP | 13.00 | 50 | N | 100.0 | 42,150 | 0.2732 | 20,117 |

- The SolaX 5.0 kW configuration: this is the best configuration for off-grid sustainability. Return on investment of 4.5%, with an annual worth of $658.00 and Total production at 12,593 kWh / year (34.501 kWh / day).

- The Fronius 10.0 kW configuration: this is the second-best configuration for off-grid sustainability. Return on investment of 3.7%, with an annual worth of $451.00 and Total production at 24,804 kWh / year (67.956 kWh / day).

### 4.4.3 Large Barcaldine Analysis

Nominal discount (%) = 5.0

Expected Inflation Rate (%) = 2.5

Daily Load (kWh / day) = 24.32

Table 55: Large Barcaldine Analysis

| Architecture | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inverter | | | Battery | | | Panel | | | System | | Financial | | |
| Model | Size (kW) | # | Model | Capacity (kWh) | # | Model | Size (kW) | # | Grid (Y/N) | Ren Frac. (%) | NPC ($) | LCOE ($) | Initial Capital ($) |
| Fronius | 2.5 | 1 | PHI 3.5 | 3.53 | 1 | JKM260PP | 3.30 | 12 | Y | 56.7 | 36,725 | 0.1893 | 6,813 |
| SolaX | 5.0 | 1 | RED ZBM2 | 10.3 | 1 | JKM260PP | 6.60 | 25 | Y | 72.9 | 19,015 | 0.0625 | 17,979 |
| Fronius | 10.0 | 1 | Trojan SIND | 53.3 | 6 | JKM260PP | 13.0 | 50 | N | 100.0 | 43,075 | 0.2615 | 20,117 |

- The SolaX 5.0 kW configuration: this is the best configuration for off-grid sustainability. Return on investment of 12.1%, with an annual worth of $1,854.00 and Total production at 12,593 kWh / year (34.501 kWh / day) + 4,432 kWh grid purchases.

- The Fronius 10.0 kW configuration: this is the second-best configuration for off-grid sustainability. Return on investment of 4.2%, with an annual worth of $557.0 and Total production at 24,804 kWh / year (67.956 kWh / day).

### 4.4.4 LCOE vs Renewable Fraction: Barcaldine

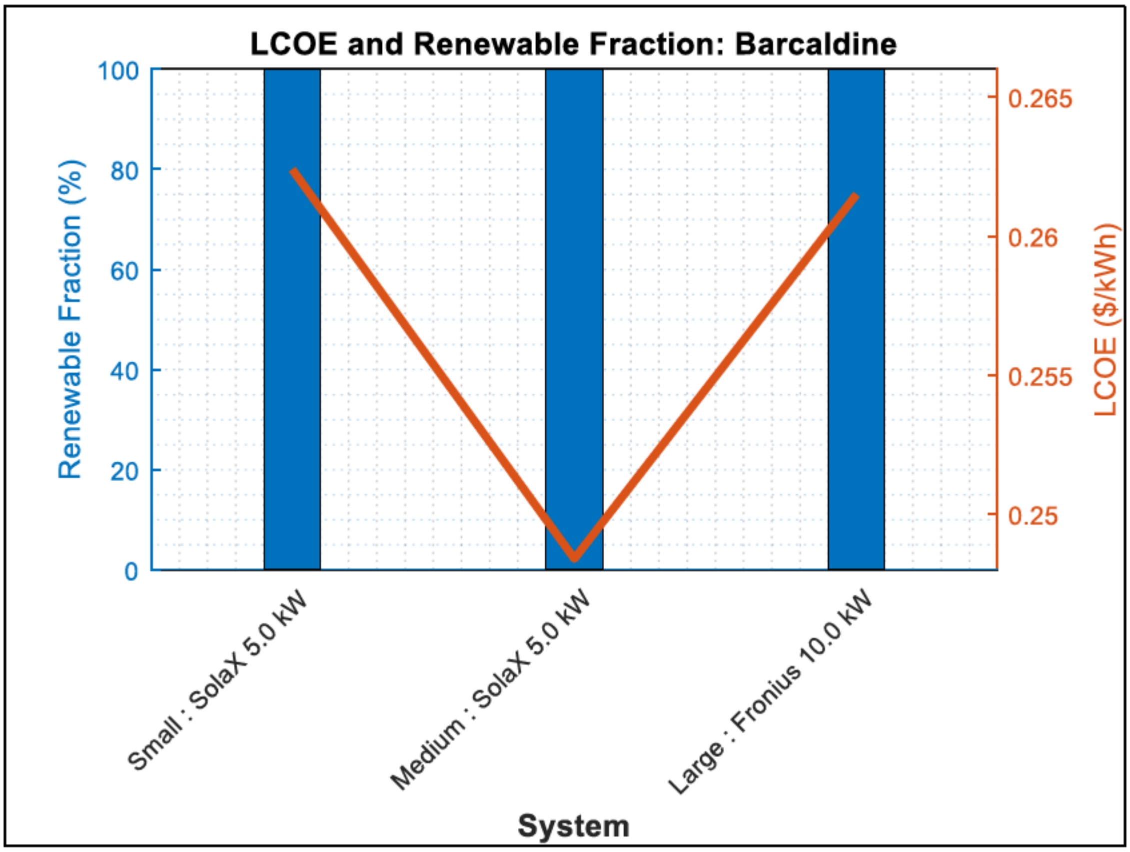


Figure 58: LCOE vs Renewable fraction: Barcaldine

As noted in Figure 58, the best system configuration will be the SolaX 5.0 kW, which is a 6.60 kW solar system with eight Trojan SIND 042145 batteries corresponding to 71.0 kWh of capacity, further analysis is conducted below using NREL System Advisor Model.

### 4.4.5 NREL SAM® Analysis: Barcaldine

Comparing all systems and load profiles, the best system that can cover all load profiles is the SolaX 5.0kW inverter to make up a 6.6 kW system with the Jinko Solar Eagle 60P (JMK260PP -60) panels with eight Trojan SIND 041245 batteries (71.0 kWh) making it as per HOMER Pro® an off grid system.

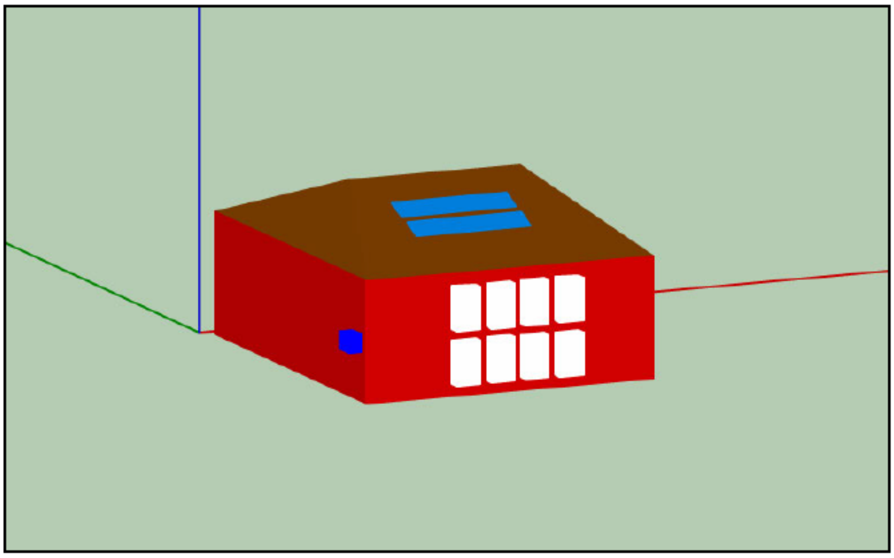


Figure 59: 3D model for Barcaldine

Table 56: NREL SAM® Data Analysis: Barcaldine

| Software | Battery | Battery capacity (kWh) | PV Annual Energy (kWh) | Capacity factor (%) | LCOE ($/kWh) | Bill with system ($) | Initial Capital ($) |
|---|---|---|---|---|---|---|---|
| HOMER Pro® | SIND 042145 | 71.0 | 12,593 | 21.8 | 0.2484 | 0.0 | 22,227.3 |
| | Enphase | 1.2 | | | 0.05436 | -322.52 | 9,979.4 |
| NREL SAM® | SIND 042145 | 71.0 | 12,362 | 22.6 | 0.1755 | 239.0 | 25,905.0 |
| | Enphase | 1.2 | 12,548 | | 0.0657 | 454.0 | 10,738.0 |
| NPV (Trojan SIND)($) | | 12,596 | | | | | |

## 4.4.6 Battery Dispatch Model: Barcaldine

To match the largest load profile (24.32 kWh / day) the battery dispatch was manually adjusted, comparing it against the default value, this is a better dispatch for the lead acid batteries as seen in Figure 60. Manual dispatch for the battery is at 10% discharge between 12 am to 5 am, charging the battery with excess electricity between 6 am to 7 am, from 8 am to 3 pm the battery charges from excess electricity, from 4pm to 11 pm discharge is at 15%. This is the best discharge rate used for the Barcaldine location for the eight lead acid batteries being used.

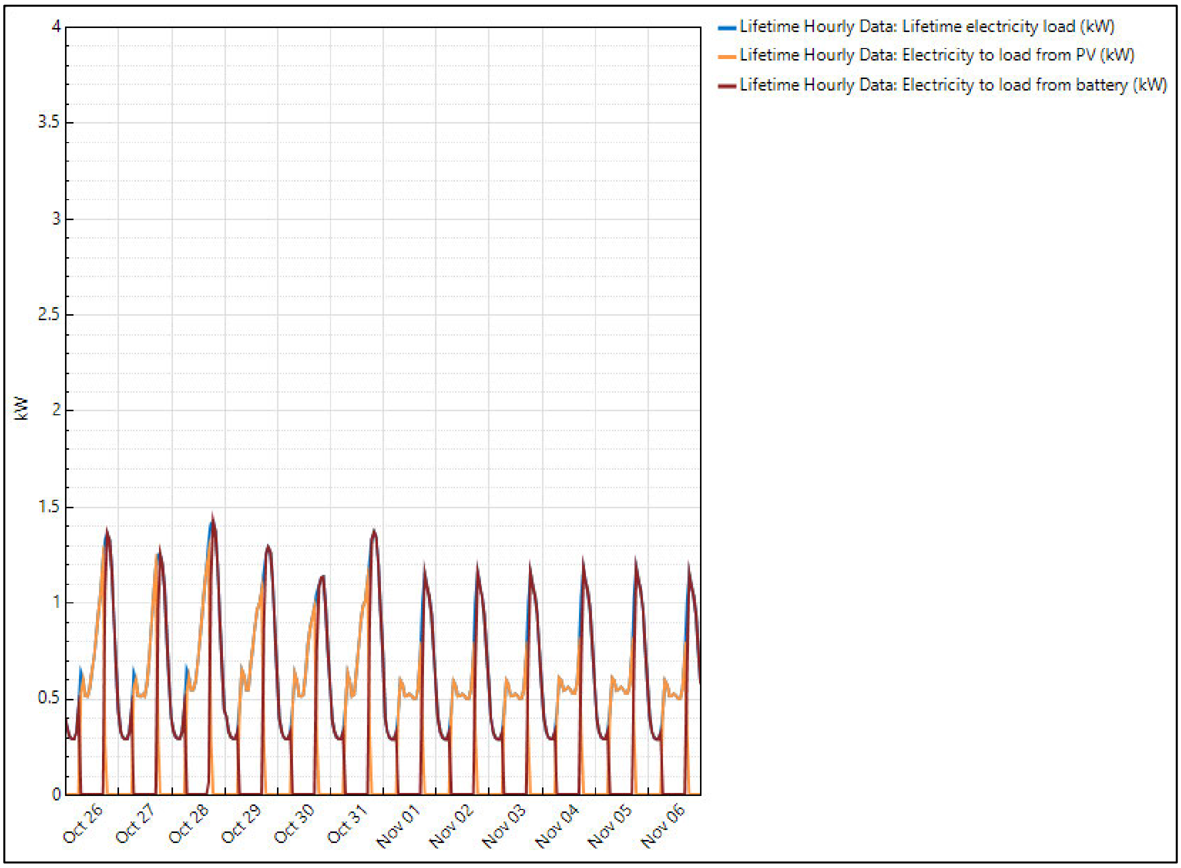
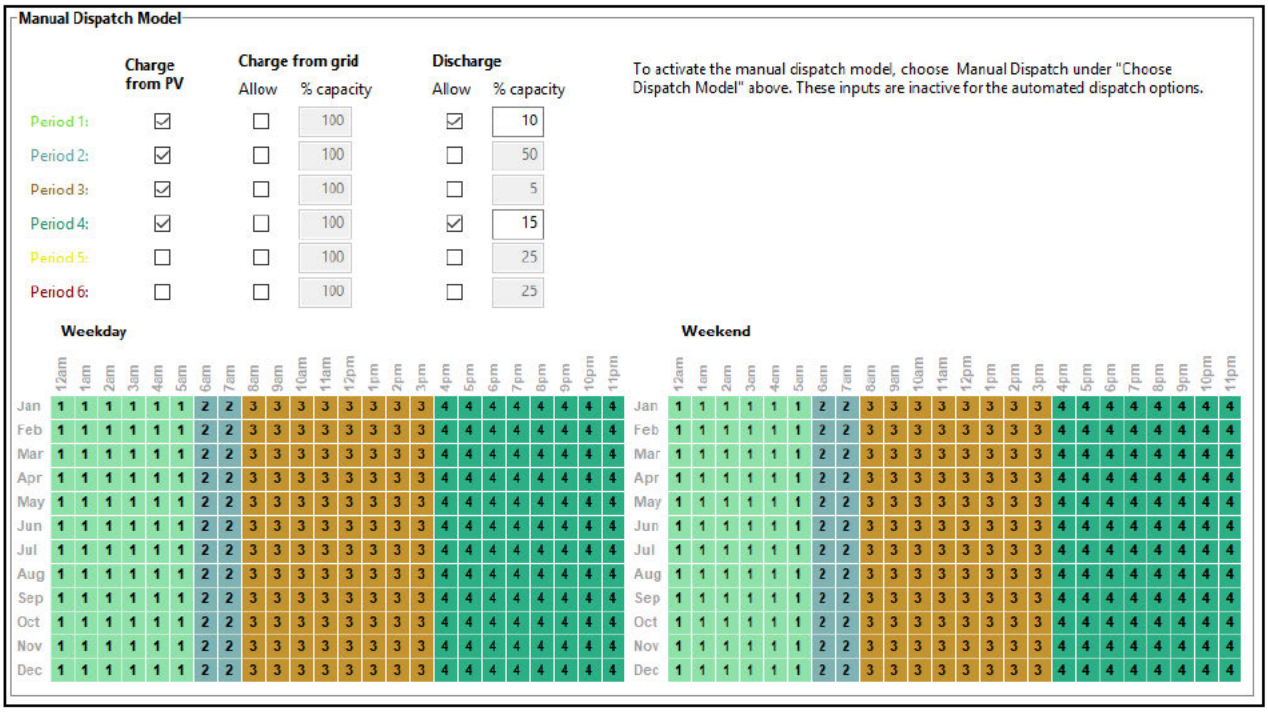


Figure 60: After adjusting battery dispatch (October 26th to November 6th)



**Manual Dispatch Model**

|  | Charge from PV | Charge from grid Allow | Charge from grid % capacity | Discharge Allow | Discharge % capacity |
|---|---|---|---|---|---|
| Period 1: | ☑ | ☐ | 100 | ☑ | 10 |
| Period 2: | ☑ | ☐ | 100 | ☐ | 50 |
| Period 3: | ☑ | ☐ | 100 | ☐ | 5 |
| Period 4: | ☑ | ☐ | 100 | ☑ | 15 |
| Period 5: | ☐ | ☐ | 100 | ☐ | 25 |
| Period 6: | ☐ | ☐ | 100 | ☐ | 25 |

To activate the manual dispatch model, choose Manual Dispatch under "Choose Dispatch Model" above. These inputs are inactive for the automated dispatch options.

**Weekday**

|  | 12am | 1am | 2am | 3am | 4am | 5am | 6am | 7am | 8am | 9am | 10am | 11am | 12pm | 1pm | 2pm | 3pm | 4pm | 5pm | 6pm | 7pm | 8pm | 9pm | 10pm | 11pm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Feb | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Mar | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Apr | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| May | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jun | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jul | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Aug | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Sep | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Oct | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Nov | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Dec | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

**Weekend**

|  | 12am | 1am | 2am | 3am | 4am | 5am | 6am | 7am | 8am | 9am | 10am | 11am | 12pm | 1pm | 2pm | 3pm | 4pm | 5pm | 6pm | 7pm | 8pm | 9pm | 10pm | 11pm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Feb | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Mar | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Apr | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| May | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jun | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jul | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Aug | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Sep | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Oct | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Nov | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Dec | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

Figure 61: Battery Dispatch: Barcaldine

### 4.4.7 Multiyear Analysis: Barcaldine

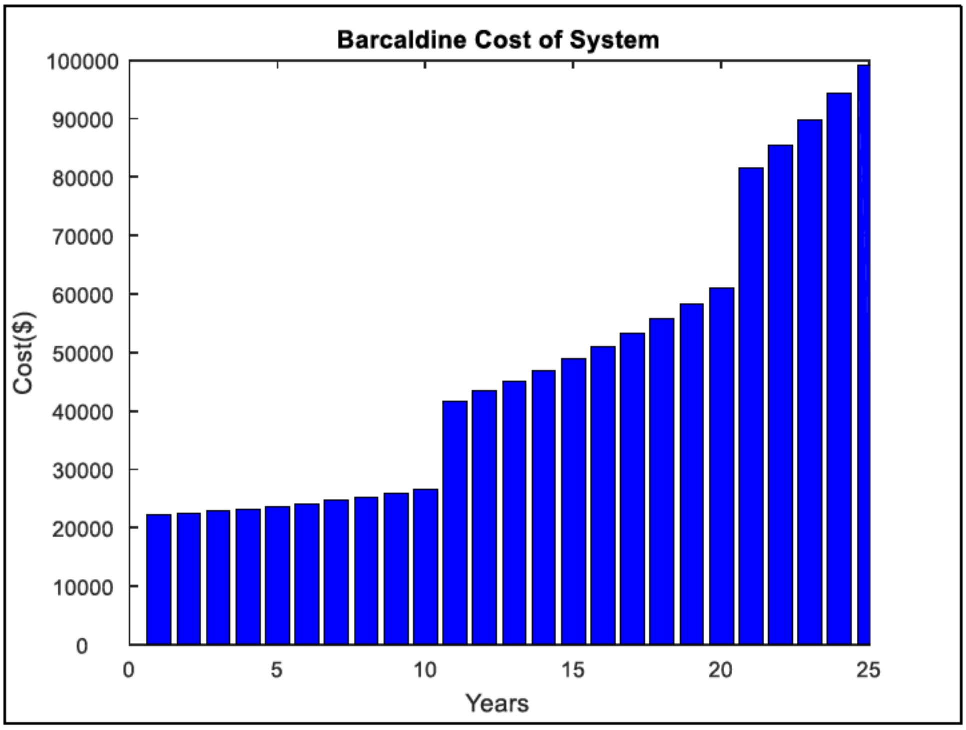


Figure 62: Payback period: Barcaldine

Table 57: Multiyear Analysis: Barcaldine

| Year | System Cost ($) | O&M ($) | Grid Sales ($) | Grid Purchases ($) | Money saved with PV ($) | AC Primary Load (kWh) | Ren Fraction (%) |
|---|---|---|---|---|---|---|---|
| 1 | 22,227.2 | 536.4 | 229.9 | 5.2 | 1,171.3 | 8,315 | 99.8 |
| 2 | 22,501.7 | 536.4 | 221.8 | 11.2 | 1,148.5 | 8,398 | 99.6 |
| 3 | 22,827.0 | 536.4 | 213.8 | 13.6 | 1,125.5 | 8,482 | 99.5 |
| 4 | 23,202.3 | 536.4 | 205.9 | 16.4 | 1,102.3 | 8,567 | 99.4 |
| 5 | 23,630.3 | 536.4 | 197.9 | 19.4 | 1,079.0 | 8,652 | 99.3 |
| 6 | 24,114.5 | 536.4 | 190.2 | 22.9 | 1,055.2 | 8,739 | 99.2 |
| 7 | 24,658.1 | 536.4 | 182.4 | 26.5 | 1,031.4 | 8,826 | 99.1 |
| 8 | 25,264.2 | 536.4 | 174.6 | 30.3 | 1,007.3 | 8,914 | 99.0 |
| 9 | 25,936.9 | 536.4 | 166.8 | 34.4 | 982.6 | 9,004 | 98.8 |
| 10 | 26,679.8 | 14,784.2 | 159.1 | 40.5 | 958.02 | 9,094 | 98.6 |
| 11 | 42,795.8 | 536.4 | 151.4 | 44.3 | 933.1 | 9,185 | 98.5 |
| 12 | 44,456.8 | 536.4 | 143.9 | 49.8 | 908.1 | 9,276 | 98.3 |
| 13 | 46,239.2 | 536.4 | 136.3 | 55.8 | 882.7 | 9,369 | 98.1 |
| 14 | 48,150.2 | 536.4 | 128.6 | 61.6 | 856.9 | 9,463 | 97.9 |
| 15 | 50,196.1 | 536.4 | 121.2 | 68.4 | 830.9 | 9,558 | 97.7 |
| 16 | 52,384.6 | 536.4 | 113.9 | 75.8 | 804.9 | 9,653 | 97.5 |
| 17 | 54,723.7 | 536.4 | 106.9 | 83.5 | 778.4 | 9,750 | 97.2 |
| 18 | 57221.1 | 536.4 | 100.0 | 92.2 | 751.8 | 9,847 | 96.9 |
| 19 | 59,886.1 | 536.4 | 94.1 | 103.4 | 724.7 | 9,946 | 96.5 |
| 20 | 62,728.5 | 18,018.2 | 88.3 | 114.9 | 697.6 | 10,045 | 96.2 |
| 21 | 84,289.4 | 536.4 | 82.6 | 127.3 | 669.9 | 10,146 | 95.8 |
| 22 | 88,442.6 | 536.4 | 77.5 | 141.0 | 642.3 | 10,247 | 95.3 |
| 23 | 92,850.2 | 536.4 | 72.1 | 154.1 | 614.4 | 10,349 | 94.9 |
| 24 | 97,525.2 | 536.4 | 66.5 | 167.8 | 585.9 | 10,453 | 94.5 |
| 25 | 102481.8 | 536.4 | 61.3 | 182.3 | 557.4 | 10,557 | 94.1 |

### 4.4.8 Solar Credits: Barcaldine

Zone = 2

Rating = 1.536

Years = 12

Size (kW) = 6.6

Using the formulas from the literature, the solar credits are as follows:

$$STC\ number = 6.6 * 12 * 1.536 = 121$$

$$Value\ (\$)\ = STC\ number * 35.0 = 121 * 35 = \$4{,}235.0$$

This is applied in year 0.

Original Capital ($) = 22,227.29
New Capital ($) = 17,992.29

## 4.5 Cairns

Results for Cairns will be conducted using Ergon Energy tariffs due to the assumption that majority of residential homes would be connected to Ergon Energy as a retailer in that region, and by following the Methodology described in Chapter 3.

- Scaled Annual Average (°C) = 24.95

- Scaled Annual Average Solar Irradiance (kWh/$m^2$/day) = 5.30

- Project Lifetime (years) = 25.0

- Derating factor (%) = 85.0

### 4.5.1 Small Cairns Analysis

From the calculations and analysis of results for all three inverters, the best tariff used for the Cairns location is the **Ergon Energy tariff**, this was based on analysis for the best renewable fraction, NPC and LCOE, in addition to of tariff comparison of available for the Cairns location.

Nominal discount (%) = 5.0

Expected Inflation Rate (%) = 2.5

Daily Load (kWh / day) = 17.54

Table 58: Small Cairns Analysis

| Architecture | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inverter | | | Battery | | | Panel | | | System | | Financial | | |
| Model | Size (kW) | # | Model | Capacity (kWh) | # | Model | Size (kW) | # | Grid (Y/N) | Ren Frac. (%) | NPC ($) | LCOE ($) | Initial Capital ($) |
| Fronius | 2.5 | 1 | Tesla PW2 | 13.5 | 1 | JKM260PP | 3.3 | 12 | Y | 70.6 | 44,547 | 0.3724 | 13,156 |
| SolaX | 5.0 | 1 | Trojan SIND | 88.8 | 10 | JKM260PP | 6.6 | 25 | N | 100.0 | 36,346 | 0.3061 | 25,789 |
| Fronius | 10.0 | 1 | Trojan SIND | 53.3 | 6 | JKM260PP | 13.0 | 50 | N | 100.0 | 39,097 | 0.3292 | 20,117 |

- The SolaX 5.0 kW configuration: this is the second-best configuration for a system not connected to the grid. Return on investment of 2.4%, with an annual worth of $231.00 and Total production at 10,092 kWh / year (27.649 kWh / day).

- The Fronius 10.0 kW configuration: this is the best configuration for off-grid sustainability. Return on investment of 1.91%, with an annual worth of $83.0 and Total production at 19,878 kWh / year (54.4603 kWh / day).

### 4.5.2 Medium Cairns Analysis

From the calculations and analysis of results for all three inverters, the best tariff used for the Cairns location is the Ergon Energy tariff, this was based on analysis for the best renewable fraction, NPC and LCOE, in addition to of tariff comparison of available for the Cairns location.

Nominal discount (%) = 5.0

Expected Inflation Rate (%) = 2.5

Daily Load (kWh / day) = 20.05

Table 59: Medium Cairns Analysis

| Architecture | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inverter | | | Battery | | | Panel | | | System | | Financial | | |
| Model | Size (kW) | # | Model | Capacity (kWh) | # | Model | Size (kW) | # | Grid (Y/N) | Ren Frac. (%) | NPC ($) | LCOE ($) | Initial Capital ($) |
| Fronius | 2.5 | 1 | REDZBM2 | 10.3 | 1 | JKM260PP | 3.30 | 12 | Y | 53.1 | 35,132 | 0.2169 | 13,556 |
| SolaX | 5.0 | 1 | Tesla PW2 | 13.5 | 1 | JKM260PP | 6.60 | 25 | Y | 92.7 | 34,946 | 0.1859 | 17,579 |
| Fronius | 10.0 | 1 | Trojan SIND | 53.3 | 6 | JKM260PP | 13.0 | 50 | N | 100.0 | 40,750 | 0.3001 | 20,117 |

- The SolaX 5.0 kW configuration: this is the second-best configuration for a system connected to the grid. Return on investment of 4.7%, with an annual worth of $562.00 and Total production at 10,092 kWh / year (27.649 kWh / day) + grid purchases of 741 kWh.

- The Fronius 10.0 kW configuration: this is the best configuration for off-grid sustainability. Return on investment of 2.7%, with an annual worth of $249.0 and Total production at 19,878 kWh / year (54.4603 kWh / day).

### 4.5.3 Large Cairns Analysis

From the calculations and analysis of results for all three inverters, the best tariff used for the Cairns location is the Ergon Energy tariff, this was based on analysis for the best renewable fraction, NPC and LCOE, in addition to comparison of available tariffs for the Cairns location.

Nominal discount (%) = 5.0

Expected Inflation Rate (%) = 2.5

Daily Load (kWh / day) = 21.59

Table 60: Large Cairns Analysis

| Architecture | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inverter | | | Battery | | | Panel | | | System | | Financial | | |
| Model | Size (kW) | # | Model | Capacity (kWh) | # | Model | Size (kW) | # | Grid (Y/N) | Ren Frac. (%) | NPC ($) | LCOE ($) | Initial Capital ($) |
| Fronius | 2.5 | 1 | REDZBM2 | 10.3 | 1 | JKM260PP | 3.30 | 12 | Y | 50.7 | 38,311 | 0.2269 | 13,556 |
| SolaX | 5.0 | 1 | LG Chem 6.4 | 6.44 | 1 | JKM260PP | 6.60 | 25 | Y | 79.0 | 29,426 | 0.1294 | 14,758 |
| Fronius | 10.0 | 1 | Trojan SIND | 53.3 | 6 | JKM260PP | 13.0 | 50 | Y | 100.0 | 27,032 | 0.0775 | 20,117 |

- The SolaX 5.0 kW configuration: this is the second-best configuration for a system connected to the grid. Return on investment of 8.3%, with an annual worth of $1,016.00 and Total production at 10,092 kWh / year (27.649 kWh / day) + grid purchases of 2,576 kWh.

- The Fronius 10.0 kW configuration: this is the best configuration for off-grid capability. Return on investment of 10.3%, with an annual worth of $1,743.0 and Total production at 19,878 kWh / year (54.4603 kWh / day).

### 4.5.4 LCOE vs Renewable Fraction: Cairns

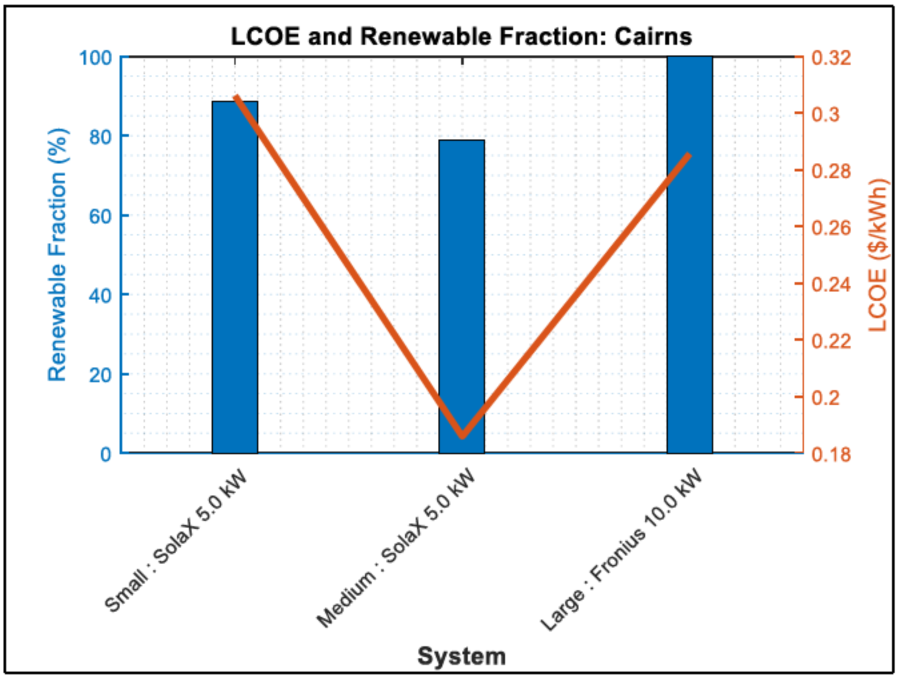


Figure 63: LCOE vs Renewable fraction: Cairns

As noted in Figure 63, the best system configuration will be the Fronius 10.0 kW inverter, which aligns with a 13.0 kW solar system and six Trojan SIND 04125 batteries, resulting in 53.3 kWh capacity of battery storage.

### 4.5.5 NREL SAM® Analysis: Cairns

Comparing all systems and load profiles, the best system that can cover all load profiles is the Fronius 10.0 kW inverter to make up a 13.0 kW system with the Jinko Solar Eagle 60P (JMK260PP-60) panels with six Trojan SIND batteries resulting in 53.3 kWh capacity, making it an off grid system but is still connected to the grid as per HOMER Pro®.

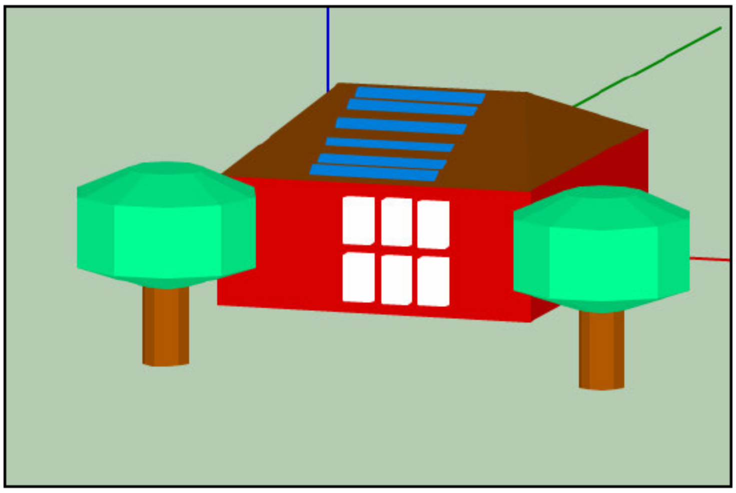


Figure 64: 3D model for Cairns

Table 61: NREL SAM® Data Analysis: Cairns

| Software | Battery | Battery capacity (kWh) | PV Annual Energy (kWh) | Capacity factor (%) | LCOE ($/kWh) | Bill with system ($) | Initial Capital ($) |
|---|---|---|---|---|---|---|---|
| HOMER Pro® | SIND 042145 | 53.3 | 19,878 | 16.4 | 0.0775 | -1,186.0 | 20,117.1 |
| | Enphase | 1.2 | | | 0.0211 | -1,060.5 | 11,431.3 |
| NREL SAM® | SIND 042145 | 53.3 | 20,233 | 16.4 | 0.0679 | -677.0 | 21,576.0 |
| | Enphase | 1.2 | 20,162 | | 0.0372 | -668.0 | 15,111.0 |
| NPV (Trojan SIND) ($) | | 26,174 | | | | | |

## 4.5.6: Battery Dispatch Model: Cairns

To match the largest load profile (21.59 kWh / day) the battery dispatch was manually adjusted, comparing it against the default value, this is a better dispatch for the lead acid batteries as seen in Figure 65. Manual dispatch for the battery is at 10% discharge between 12 am to 5 am, discharging at 50% between 6 am to 7 am, from 8 am to 3 pm the battery charges from excess electricity, from 4pm to 11 pm discharge is at 15%. This is the best discharge rate used for the Cairns location for the six lead acid batteries being used.

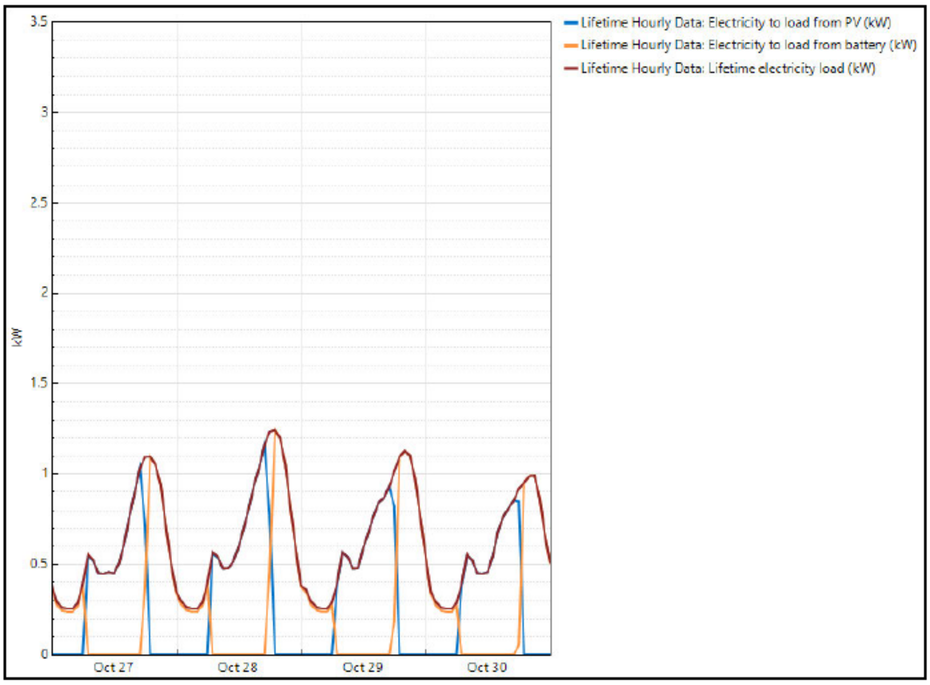
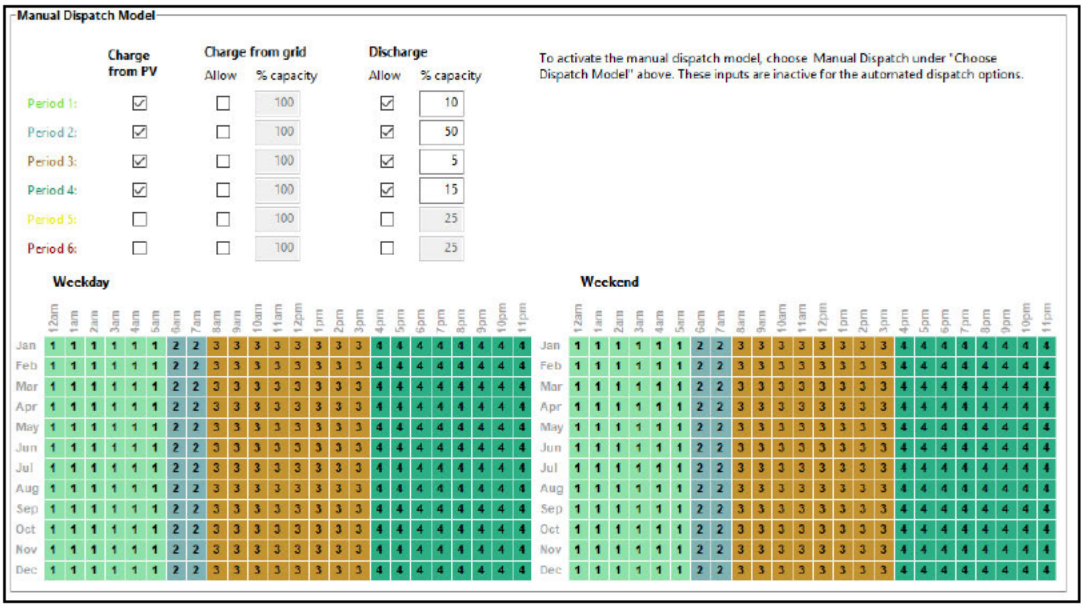


Figure 65:After adjusting battery dispatch (Oct 27th to Oct 30th)



Manual Dispatch Model

|  | Charge from PV | Charge from grid Allow | Charge from grid % capacity | Discharge Allow | Discharge % capacity |
|---|---|---|---|---|---|
| Period 1: | ☑ | ☐ | 100 | ☑ | 10 |
| Period 2: | ☑ | ☐ | 100 | ☑ | 50 |
| Period 3: | ☑ | ☐ | 100 | ☑ | 5 |
| Period 4: | ☑ | ☐ | 100 | ☑ | 15 |
| Period 5: | ☐ | ☐ | 100 | ☐ | 25 |
| Period 6: | ☐ | ☐ | 100 | ☐ | 25 |

To activate the manual dispatch model, choose Manual Dispatch under 'Choose Dispatch Model' above. These inputs are inactive for the automated dispatch options.

**Weekday**

|  | 12am | 1am | 2am | 3am | 4am | 5am | 6am | 7am | 8am | 9am | 10am | 11am | 12pm | 1pm | 2pm | 3pm | 4pm | 5pm | 6pm | 7pm | 8pm | 9pm | 10pm | 11pm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Feb | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Mar | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Apr | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| May | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jun | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jul | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Aug | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Sep | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Oct | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Nov | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Dec | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

**Weekend**

|  | 12am | 1am | 2am | 3am | 4am | 5am | 6am | 7am | 8am | 9am | 10am | 11am | 12pm | 1pm | 2pm | 3pm | 4pm | 5pm | 6pm | 7pm | 8pm | 9pm | 10pm | 11pm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Feb | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Mar | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Apr | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| May | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jun | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Jul | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Aug | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Sep | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Oct | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Nov | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Dec | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

Figure 66: Battery Dispatch: Cairns

### 4.5.7 Multiyear Analysis: Cairns

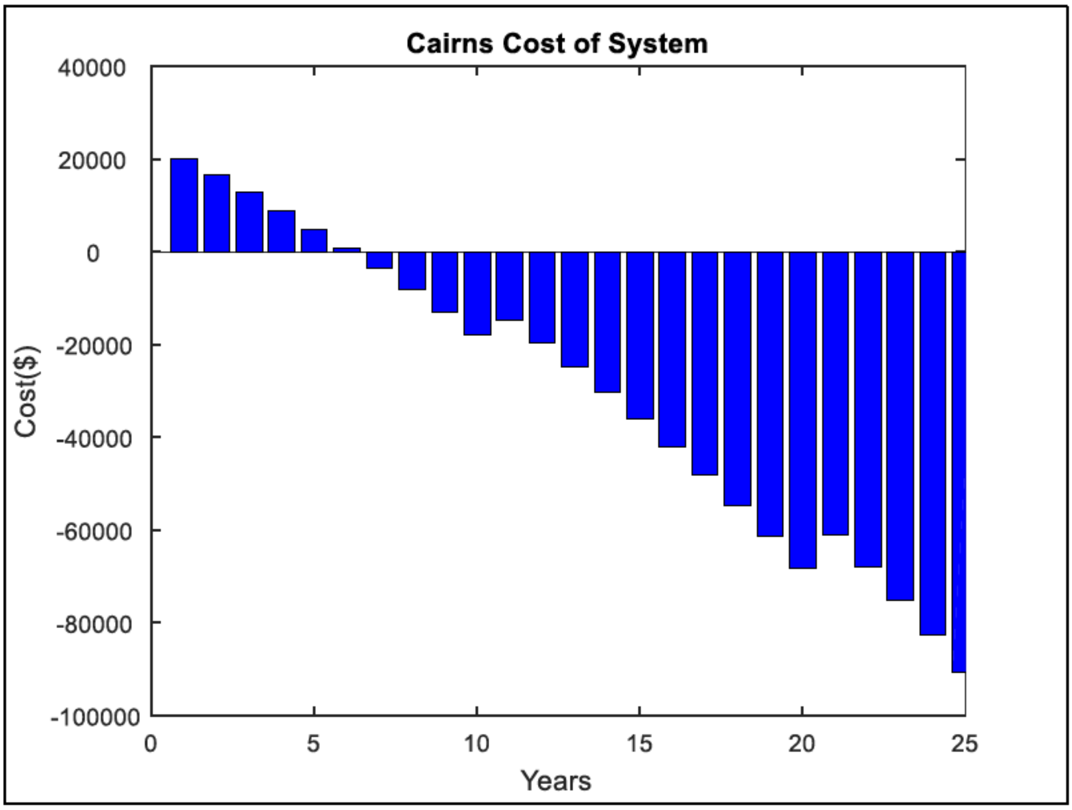


Figure 67: Payback period: Cairns

Table 62: Multiyear Analysis: Cairns

| Year | System Cost ($) | O&M ($) | Grid Sales ($) | Grid Purchases ($) | Money saved with PV ($) | AC Primary Load (kWh) | Ren Fraction (%) |
|---|---|---|---|---|---|---|---|
| 1 | 20,117.1 | -282.2 | 1,030.2 | 1.2 | 3,285.0 | 7,880 | 100 |
| 2 | 16,548.3 | -282.2 | 1,021.8 | 2.2 | 3,263.4 | 7,959 | 100 |
| 3 | 12,832.4 | -282.2 | 1,013.5 | 2.5 | 3,241.5 | 8,039 | 100 |
| 4 | 8,961.2 | -282.2 | 1,005.2 | 3.2 | 3,219.6 | 8,119 | 99.9 |
| 5 | 4,927.6 | -282.2 | 996.9 | 4.0 | 3,197.4 | 8,200 | 99.9 |
| 6 | 723.9 | -282.2 | 988.6 | 5.0 | 3,174.9 | 8,282 | 99.9 |
| 7 | -3,657.9 | -282.2 | 980.1 | 5.8 | 3,152.2 | 8,365 | 99.9 |
| 8 | -8,226.5 | -282.2 | 971.6 | 6.8 | 3,129.2 | 8,449 | 99.9 |
| 9 | -12,991.1 | -282.2 | 963.0 | 7.6 | 3,106.2 | 8,533 | 99.9 |
| 10 | -17,961.0 | 8,122.0 | 954.4 | 8.9 | 3,082.7 | 8,619 | 99.8 |
| 11 | -14,741.7 | -282.2 | 945.8 | 10.2 | 3,059.1 | 8,705 | 99.8 |
| 12 | -19,732.2 | -282.2 | 936.9 | 11.2 | 3,035.6 | 8,791 | 99.8 |
| 13 | -24,938.3 | -282.2 | 928.1 | 12.4 | 3,011.5 | 8,879 | 99.8 |
| 14 | -30,370.3 | -282.2 | 919.1 | 13.7 | 2,987.1 | 8,968 | 99.7 |
| 15 | -36,039.0 | -282.2 | 910.1 | 14.9 | 2,962.5 | 9,058 | 99.7 |
| 16 | -41,956.3 | -282.2 | 900.9 | 16.2 | 2,937.8 | 9,148 | 99.7 |
| 17 | -48,133.7 | -282.2 | 891.7 | 17.4 | 2,912.6 | 9,240 | 99.7 |
| 18 | -54,584.4 | -282.2 | 882.4 | 18.7 | 2,887.4 | 9,332 | 99.6 |
| 19 | -61,321.3 | -282.2 | 873.2 | 20.5 | 2,861.7 | 9,426 | 99.6 |
| 20 | -68,358.3 | 14,492.0 | 863.8 | 22.2 | 2,836.02 | 9,520 | 99.6 |
| 21 | -60,935.8 | -282.2 | 854.3 | 23.6 | 2,810.0 | 9,615 | 99.5 |
| 22 | -67,879.2 | -282.2 | 844.5 | 24.8 | 2,783.7 | 9,711 | 99.5 |
| 23 | -75,132.3 | -282.2 | 834.9 | 26.5 | 2,757.1 | 9,808 | 99.5 |
| 24 | -82,709.8 | -282.2 | 825.2 | 28.5 | 2,730.3 | 9,906 | 99.4 |
| 25 | -90,627.5 | -282.2 | 815.5 | 30.7 | 2,703.2 | 10,005 | 99.4 |

### 4.5.8 Solar Credits: Cairns

Zone = 3

Rating = 1.382

Years = 12

Size (kW) = 13.0

Using the formulas from the literature, the solar credits are as follows:

$$STC\ number = 13.0 * 12 * 1.382 = 215$$

$$Value\ (\$)\ = STC\ number * 35.0 = 215 * 35 = \$7{,}525.0$$

This is applied in year 0.

Original Capital ($) = 20,117.18
New Capital ($) = 12,592.18

## 4.6 Physical Size

Size of components is an important aspect of the decision process to ensure that there is adequate space where the components are being installed.

Table 63: Area size of components used

| Location | Area size for PV ($m^2$): NREL SAM® | Area size for PV ($m^2$): Datasheet | Area size for Battery ($m^2$): Datasheet | Area size for Inverter ($m^2$): Datasheet | Battery Model | PV Model | Inverter Model |
|---|---|---|---|---|---|---|---|
| Brisbane | 83.2 | 88.4 | 0.84 | 0.37 | Tesla Powerwall 2 AC | JMK260PP - 60 | Fronius-symo-10.0.3 |
| Toowoomba | 37.0 | 39.3 | 0.32 | 0.14 | Trojan SIND 042145 | JMK260PP-60 | SolaX 5.0 kW |
| Hervey Bay | 83.2 | 88.4 | 0.84 | 0.37 | Tesla Powerwall 2 AC | JMK260PP - 60 | Fronius-symo-10.0.3 |
| Barcaldine | 37.0 | 39.3 | 1.2932 | 0.14 | Trojan SIND 042145 | JMK260PP-60 | SolaX 5.0 kW |
| Cairns | 83.2 | 88.4 | 0.9699 | 0.37 | Trojan SIND 042145 | JMK260PP - 60 | Fronius-symo-10.0.3 |

## 4.7 Battery Throughput

Battery throughput is becoming an important standard to compare batteries to each other, often times it is now used to determine the life of a battery compared to traditionally measuring cycle life. Each table seen below is for the optimum system calculated through the use of HOMER Pro® and NREL's SAM® software.

Table 64: Brisbane Battery throughput

| Battery Model | Battery Capacity (kWh) | Lifetime Throughput (kWh) | Expected Life (years) | LCOE ($/kWh) | Operating Cost ($ / year) |
|---|---|---|---|---|---|
| Tesla PW2 AC | 13.5 | 44,454 | 10.0 | 0.0463 | -14.44 |
| | | 53,345 | 12.0 | 0.0386 | -180.95 |
| | | 66,681 | 15.0 | 0.0317 | -332.93 |
| | | 67,500 | 17.0 | 0.0314 | -340.25 |
| | | 67,500 | 20.0 | 0.0314 | -340.25 |

Table 65: Toowoomba Battery throughput

| Battery Model | Battery Capacity (kWh) | Lifetime Throughput (kWh) | Expected Life (years) | LCOE ($/kWh) | Operating Cost ($ / year) |
|---|---|---|---|---|---|
| Trojan SIND 04 2145 | 17.8 | 22,362 | 8.18 | 0.0917 | 336.45 |
| | | 30,000 | 11.0 | 0.0812 | 226.88 |
| | | 36,000 | 13.2 | 0.0759 | 171.32 |
| | | 44,000 | 17.3 | 0.0669 | 187.37 |
| | | 56,000 | 29.0 | 0.0561 | 75.40 |

Table 66: Hervey Bay Battery throughput

| Battery Model | Battery Capacity (kWh) | Lifetime Throughput (kWh) | Expected Life (years) | LCOE ($/kWh) | Operating Cost ($ / year) |
|---|---|---|---|---|---|
| Tesla PW2 AC | 13.5 | 28,643 | 10.0 | 0.0410 | -75.52 |
| | | 34,372 | 12.0 | 0.0370 | -242.05 |
| | | 42,965 | 15.0 | 0.0298 | -394.02 |
| | | 48,693 | 17.0 | 0.0264 | -466.52 |
| | | 57,286 | 20.0 | 0.0223 | -552.96 |

Table 67: Barcaldine Battery throughput

| Battery Model | Battery Capacity (kWh) | Lifetime Throughput (kWh) | Expected Life (years) | LCOE ($/kWh) | Operating Cost ($ / year) |
|---|---|---|---|---|---|
| Trojan SIND 04 2145 | 71.0 | 89,448 | 17.8 | 0.2484 | 639.04 |
| | | 120,000 | 23.8 | 0.1503 | 420.27 |
| | | 144,000 | 28.6 | 0.1423 | 334.65 |
| | | 176,000 | 88.4 | 0.0842 | 92.45 |
| | | 224,000 | 112.0 | 0.08257 | 66.96 |

Table 68: Cairns Battery throughput

| Battery Model | Battery Capacity (kWh) | Lifetime Throughput (kWh) | Expected Life (years) | LCOE ($/kWh) | Operating Cost ($ / year) |
|---|---|---|---|---|---|
| Trojan SIND 04 2145 | 53.3 | 67,086 | 14.9 | 0.0775 | 133.60 |
| | | 90,000 | 19.9 | 0.0549 | -47.80 |
| | | 108,000 | 23.9 | 0.0497 | -146.33 |
| | | 132,000 | 53.4 | 0.0352 | -290.82 |
| | | 168,000 | 96.3 | 0.0284 | -423.14 |

## 4.8 Peak shaving / peak lopping

Load and peak shaving are at times a last resort when attempting to optimise a solar system, typically before selecting a system, a household would calculate what they are consuming and have done the necessary measures to reduce the load as reasonable as they could. HOMER Pro® will be used for each site to reduce the highest peak of grid purchases in which can subsequently reduce demand charge. In the Demand Rates tab, the "charge battery as much as possible" option will be selected, and the purchase capacity will be matched to the annual peak demand of the load. Note: All done with the largest load selected. All locations are using the optimised system for each location, hence LCOE for some locations will be different as the largest load is being analysed.

Table 69: Peak shaving for each location

| Location | Current Peak Demand (kW) | Adjusted Peak Demand (kW) | Current NPC ($) | Adjusted NPC ($) | Current LCOE ($/kWh) | Adjusted LCOE ($/kWh) | Current Operating cost ($/year) | Adjusted Operating cost ($/year) |
|---|---|---|---|---|---|---|---|---|
| Brisbane | 6.0 | 3.0 | 18,763 | 18,665 | 0.0463 | 0.0404 | -14.44 | -19.7 |
| Toowoomba | 6.0 | 6.0 | 30,395 | 22,099 | 0.1239 | 0.0719 | 1,016.1 | 569.0 |
| Hervey Bay | 6.0 | 3.0 | 27,261 | 27,198 | 0.0650 | 0.0572 | 443.5 | 440.2 |
| Barcaldine | 5.0 | 5.0 | 36,082 | 21,901 | 0.1805 | 0.0718 | 746.7 | -17.5 |
| Cairns | 2.0 | 2.0 | 27,032 | 13,560 | 0.0775 | 0.0327 | 133.5 | -353.3 |

Modifications can be made to adjust the peak demand beyond the results seen above, however this is beyond the scope of this project and will not be included, as battery numbers have been simulated already previously and new results would contradict current.

## 4.9 Current Packages

Current available packages as of (17/07/19) with similar system sizes or components used are as follows, these don't include cost of installation, which will typically range from $1,000 to $2,900 depending on the system and if batteries are to be installed.

Table 70: Current solar packages

| Size (kW) | Inverter | Panel | Battery | Average Quote ($) |
|---|---|---|---|---|
| 3.0 | Enphase IQ7 | Trina Solar Honey Mono | 1.2 kWh Enphase AC | 7,000.0 |
| 5.0 | SolaX 5.0 kW | Q. POWER-G5 270W | N/A | 6,000.0 |
| 6.0 | Generic 5.0 kW | CEC approved panel | Nickel Iron | 29,190.0 |
| 6.6 | Fronius 5.0 kW | JKM275W | N/A | 4,545.0 |
|  | Fronius 5.0 kW | JKM275W | Tesla Powerwall 2 AC | 14,340.0 |
| 8.0 | SolaX 5.0 kW | Trina Solar Honey Mono | LG RESU 10 kWh | 18,595.0 |
| 15.0 | Enphase IQ7 | Trina Solar Honey Mono | 1.2 kWh Enphase AC | 22,810.0 |
| 20.0 | Fronius Symo 10.0 kW | Q. POWER-G5 270W | N/A | 11,995.0 |

## 4.10 Environmental Impacts

The environment impacts of solar PV are relatively reduced compared to a traditional grid connected system, however a system still connected to the grid, may suffer increased $CO_2$ released due to the batteries, whether it being outright $CO_2$ released from manufacturing or just the battery efficiency reducing the amount of clean energy lost from the PV charging the battery. N/A: signifies no data available. As per the default values for HOMER PRO®, the $CO_2$ is as follows for each location, any additional environmental impacts weren't analysed within this research project as it was beyond the scope of the project and its main objectives.

Table 71: Carbon dioxide emissions: Brisbane

| Load size (kWh / day) | Grid (kg / year) | Grid + Battery (kg / year) | Grid + PV (kg / year) | Grid + PV + Battery (kg / year) | PV + Battery (kg / year) |
|---|---|---|---|---|---|
| 12.6 | 2,907 | 2,901 | 1,503 | 2.74 | N/A |
| 14.8 | 3,423 | 3,418 | 1,804 | 10.6 | 0 |
| 29.5 | 6,814 | 6,809 | 3,902 | 1,069 | N/A |

Table 72: Carbon dioxide emissions: Toowoomba

| Load size (kWh / day) | Grid (kg / year) | Grid + Battery (kg / year) | Grid + PV (kg / year) | Grid + PV + Battery (kg / year) | PV + Battery (kg / year) |
|---|---|---|---|---|---|
| 12.6 | 2,913 | 2,908 | 1,612 | 45.4 | 0 |
| 13.3 | 3,073 | 3,067 | 1,715 | 70.1 | 0 |
| 28.1 | 6,491 | 6,486 | 4,022 | 1,883 | N/A |

Table 73: Carbon dioxide emissions: Hervey Bay

| Load size (kWh / day) | Grid (kg / year) | Grid + Battery (kg / year) | Grid + PV (kg / year) | Grid + PV + Battery (kg / year) | PV + Battery (kg / year) |
|---|---|---|---|---|---|
| 12.6 | 2,913 | 2,908 | 1,500 | 1.94 | 0 |
| 14.8 | 3,423 | 3,418 | 1,787 | 9.95 | N/A |
| 29.5 | 6,814 | 6,809 | 3,878 | 1,033 | N/A |

Table 74: Carbon dioxide emissions: Barcaldine

| Load size (kWh / day) | Grid (kg / year) | Grid + Battery (kg / year) | Grid + PV (kg / year) | Grid + PV + Battery (kg / year) | PV + Battery (kg / year) |
|---|---|---|---|---|---|
| 19.4 | 4,477 | 4,454 | 2,579 | 0 | 0 |
| 22.8 | 5,255 | 5,232 | 3,099 | 11.9 | N/A |
| 24.3 | 5,610 | 5,587 | 3,334 | 51.3 | N/A |

Table 75: Carbon dioxide emissions: Cairns

| Load size (kWh / day) | Grid (kg / year) | Grid + Battery (kg / year) | Grid + PV (kg / year) | Grid + PV + Battery (kg / year) | PV + Battery (kg / year) |
|---|---|---|---|---|---|
| 17.54 | 4,046 | 4,028 | 2,149 | 0 | 0 |
| 20.1 | 4,625 | 4,607 | 2,504 | 0.968 | 0 |
| 21.6 | 4,980 | 4,963 | 2,728 | 2.87 | 0 |

# Chapter 5. Discussion

## 5.1 Optimised Systems

### 5.1.1 HOMER Pro®

Results displayed in Table 35 on page 72 and Table 36 on page 73 reveal the optimised systems for each load size and important trends for each location tested. Azimuth and PV tilt angle was optimised for all locations before testing began, increasing / decreasing the angles of both the azimuth and PV angles, resulted in losses or minute gains at best. For all locations using HOMER Pro® the average renewable fraction is 98.24%, ranging from 92.7% at Cairns (medium) to 100.0% at Hervey Bay (small, large), Barcaldine (all sizes) and Cairns (small, large); a difference of 7.3%. The choice of solar panel for 93% of all locations and load profiles, is the Jinko Solar JKM260PP-60 (260 W) panel, this is due to the panel having the lowest LCOE. The average LCOE is $ 0.1502 / kWh, ranging from $0.0080 / kWh at Brisbane (medium) to $0.3061 / kWh at Cairns (small); a difference of 97.38%, this is an interesting result as there is a 0.1% difference in renewable fraction between the two locations. As noted in Table 39 on page 75 and Table 58 on page 108, a clear comparison between the two systems can be seen, the single Tesla Powerwall 2 AC is used for the Brisbane (medium), and 10 Trojan SIND 042145 for Cairns, both using the JKM260PP-60 panels, comparing load profiles for each, shows a 15.39% difference in the favour of the Brisbane location. The average scaled temperature value based on the BOM data, additionally aids the Brisbane location due to decreased derating factors associated with temperature as a result of an average temperature of 21.75°C compared to 24.95°C for Cairns.

Typically, a higher renewable fraction would often mean that a lower LCOE is present as HOMER Pro® calculates the LCOE, in majority of the cases through analysing each system this matched the literature, however 100% renewable fraction was often not required in order to meet the load and may not be necessary to achieve equivalent results, as will now be discussed. For Brisbane the best system will be the 13.0 kW system with a single Tesla Powerwall 2 AC (13.5 kWh), this results in 92.2% renewable fraction, however when looking at the yearly production of the Jinko solar panels, the solar system produce 58.16 kWh / day of energy, when compared against the largest load at Brisbane (29.54 kWh / day), this amounts to just under double the load profile. With an average 1.23 kW / per hour used throughout an ordinary day, between 5am to 5pm the load is total to 14.76 kW, during that time the output from the solar panels is left with excess of 44.63 kWh. Between 5pm and 6pm the panels would reduce output and then afterwards from 6 pm to 5 am (the next day) the battery would take over the load, so therefore based on the average 1.23 kW / per hour, the battery will meet 96% of the average based on 10.73 hours of discharging the battery fully. Given that the system is still connected to the grid, the excess energy can be sold to the grid to offset grid connection fees, reduce the initial capital and any energy required to match the load, which essentially makes it a partially off-grid system, as the electricity bill would be non-existent.

The other systems calculated that has various configurations of battery numbers, is using the Trojan SIND 042145 battery, at Toowoomba, Barcaldine and Cairns. For Toowoomba the best system will be the 6.6 kW system (SolaX 5.0 kW inverter) with 2 Trojan SIND 042145 batteries, this results in 98.9% renewable fraction, when looking at the yearly production for the Jinko solar panels, the solar system produces 30.94 kWh / day, comparing against the medium load (13.32 kWh / day for Toowoomba), system produces over double the load profile. With an average 0.53 kWh used throughout an ordinary day, between 5 am to 5pm the load is total to 6.63 kW, so during that time the output from the solar panels is left with excess of 24.31 kWh, during the day the excess would charge the battery / sell to the grid. Between 5pm and 6pm the panels reduce their output and then afterward from 6 pm to 5 am (the next day) the battery would take over the load, based on the average 0.53 kWh load, the batteries will cover the load with excess 11.97 kWh based on the battery fully charged. Given that the system is still connected to the grid, the excess energy can be sold to the grid to offset grid connection fees and any energy required to match the load, which essentially makes it a partially off-grid system, as the electricity bill would be non-existent. When performing the simulations, there was an option to have 100% renewable fraction (off-grid) with four trojan batteries with the same load (see Appendix F, Figure 82 on page 161), as per HOMER Pro® calculations.

Comparing NPC, LCOE and operating costs, as well as initial capital, shows that for a 1.1% rise in renewable fraction, it will cost an additional $3,561.96 and operating costs double, and the NPC for the 2x Trojan SIND 042145 is $17,783.71 whilst the 4x batteries has a NPC of $29,096.81, therefore the logic is to go with 2x battery configuration for the Toowoomba location. This therefore shows another interesting trend, with the grid connection, excess energy of 5,591 kWh is sold every year, compared to the off-grid system the excess energy is essentially wasted as it will be charging batteries that won’t have the load to discharge. It would be beneficial to use the 4x battery configuration for the largest load at Toowoomba however this would require the batteries to have a substantial capacity installed upon installation in order to make it viable or a diesel generator on location due to the largest load being matched evenly with the panel output or even further optimisation with home appliances would be required to charge the batteries.

For Hervey Bay, as seen in section 4.3.1 to 4.3.3 (page 91 to 93) , from the results in Table 48 and Table 49, the 13.0 kW system with the Tesla Powerwall 2 AC will meet the daily load profile (14% difference) between both small and medium households, however for the large load profile (29.54 kWh / day) HOMER Pro® suggests the use of 10 Trojan SIND 042145 batteries to go off-grid, with a LCOE of $0.2767 / kWh, renewable fraction of 100% and initial capital of $31,583.10. However as seen in the Brisbane location, switching to the single Powerwall 2 AC reduces the renewable fraction to 92.8%, but the total production from the solar system is 60.7369 kWh / day, which as described previously, the solar system will cover the load throughout the day and excess will charge the battery and sell to the grid accordingly, this matches the Brisbane location as the load profiles are the same, even given the distance between the two locations.

For Barcaldine, comparing between the small, medium and large load profiles, the system for the medium load has the capability to meet all three loads, and be off grid. The system as per Table 54 on page 100, the medium Barcaldine load, has 8 Trojan SIND 042145 with a capacity of 71.0 kWh, with a 6.6 kW solar system made up of 25 x JKM260PP-60 panels, this system produces 34.501 kWh / day. This system has a LCOE of $0.2484 / kWh the maximum load at the location is, 24.32 kWh / day, the 6.6 kW system has the capability to meet all three loads and has excess of 10.181 kWh to charge the batteries. This functions correctly due to the initial state of charge being set to 70% (49.7 kWh for the battery system), anything less than that the system will not deliver the necessary supply for all load profiles and the PV system will need increasing in order to charge the batteries, upon review it will most likely be better to reduce the number of batteries and return to a grid connected system to take advantage of feed in tariffs while they still exist at their current rate.

Cairns location has the lowest load profile compared to all locations, since the goal of the project was to optimise for off grid solar power and battery storage 100% renewable fraction was desired. This location while having 100% renewable fraction, still remained connected to the grid and was substantially more cost effective than going off grid. The optimised system as seen in section 4.5.3 on page 110, had 6 Trojan SIND 042145 batteries and a 13.0 kW system using 50 x JKM260PP-60 panels. With solar production at 54.4603 kWh / day, excess energy after the load profile is served, is 32.87 kWh / day, this can be perfectly used to charge the batteries and sell excess energy back to the grid.

Smaller systems (3.3 kW system) could be utilised for the smallest load profile (17.54 kWh / day), where the renewable fraction will be 70.6% with an LCOE of $0.3724 / kWh and initial capital of $13,156.00. With the solar panel system producing 13.825 kWh / day, this could be an alternative for smaller systems in Cairns. The smaller system however isn’t that much cost effective wise to the straight grid connected system ($0.3724 / kWh compared to $0.3421 / kWh), this adds more to the point that a small system is probably a disadvantage compared to the larger choices, based on the assumption that the tariff doesn’t increase during the simulation period (in which would swing to the advantage of a smaller system). The grid connection comparison is important in the optimisation process, it can be seen on the next page in Table 76 for each optimised system at the largest load. This shows that there is still some work to be done to match the grid + PV only connection however, compared against the LCOE of just the grid connection, the investment for the battery system is worthwhile, but should be noted that the PV is offsetting the LCOE.

Return on Investment (ROI) for each location at the largest load, is as follows as per Table 37 on page 73, Brisbane 14.7%, Toowoomba 15.6%, Hervey Bay 11.7%, Barcaldine 7.5% and Cairns at 10.3%. The return on investment of a project as per section 2.6 on page 46, is the most common profitability ratio. Comparing these sites with just the PV connected to the grid shows that they have a considerably smaller ROI, with the largest gap for the Barcaldine system. This aligns with what was expected from the introduction of the battery into a system, as return on investment would suffer the most due to the increased cost of the battery that doesn’t necessarily pay for itself and relies on money saved from not purchasing from the grid or PV feed-in tariffs if still connected to the grid. As noted in Table 37 on page 73, the systems with a smaller number of batteries have a higher ROI or with similar size battery system installed the system with a lower PV size has the highest ROI as noted for the Toowoomba location.

Table 76: LCOE comparison (Largest load)

| Location | Brisbane ($/kWh) | Toowoomba ($/kWh) | Hervey Bay ($/kWh) | Barcaldine ($/kWh) | Cairns ($/kWh) |
|---|---|---|---|---|---|
| LCOE (optimised system) | 0.0463 | 0.1239 | 0.0650 | 0.1805 | 0.0775 |
| LCOE (grid + PV) | 0.0149 | 0.0653 | 0.0134 | 0.0454 | 0.0150 |
| LCOE (grid connection only) | 0.358 | 0.318 | 0.452 | 0.324 | 0.364 |

Throughout this project a wide variety of batteries from different manufacturers were compared against one another in the simulation environment, including the Enphase Energy AC 1.2 kWh battery was a main objective of this project, to determine if the new small battery is cost effective compared to the alternatives. In 2018 - 2019 the price per kWh for the Enphase AC battery is considerably higher compared to alternatives. As seen in Figure 84 on page 162, the Enphase battery to ensure 100% renewable fraction and be off grid would require 13 batteries (maximum units per string 20 A branch circuit), and has a NPC of $82,535.38 and LCOE of $0.9663 with operating costs of $2,538.82, which when compared against the Brisbane optimised solution, has a 20x larger LCOE and 4x larger NPC.

This was an ongoing trend across all sites and load profiles, hence why the Enphase AC battery isn't a battery of choice in the optimised systems, unless its capacity increases substantially and /or the price of a single unit decreases. To ensure a thorough investigation was performed, shade analysis as well as a worse-case scenario was conducted for each site on the chosen systems, this was lacking from past studies and research papers into Home Based Solar Power design and battery storage systems.

### 5.1.2 NREL's SAM®

NREL's System Advisor Model (SAM®) was used to perform detailed and comprehensive analysis, shade analysis using the diurnal analysis was utilised for each location, as noted in Figure 44, Figure 49, Figure 54, Figure 59 and Figure 64 for each location. Shading losses is important to simulating real world effects caused by shadows on the PV modules in the array.

HOMER Pro® hasn't incorporated shading losses, the appropriate annual energy for all optimised sites are as follows. Brisbane produces 17,554 kWh / year, Toowoomba produces 10,305 kWh / year, Hervey Bay at 18,130 kWh / year, Barcaldine at 12,362 kWh / year and Cairns at 20,233 kWh / year. For Brisbane three varying size trees have been used to simulate shading, the resulting annual energy when compared to the output from HOMER Pro® is 82.68%, which results in 48.09 kWh / day compared to 58.167 kWh / day. Comparing to a single Enphase AC battery, the annual energy is 17,621 kWh compared to the optimised system at 17,554 kWh, is at 99.62%. The increase in kWh is most likely due to the configuration of the battery system, in which will be discussed in the software discrepancies section in part 5.3 for all locations. As a result of including example installation costs that include (labour and overhead), the initial capital as per Table 41 has increased by 7.32%, resulting in an increase to the LCOE by 25%, NPV is $28,387.0.

Toowoomba has two medium sized trees to simulate shading, the resulting annual energy when compared to the output from HOMER Pro® is 91.25%, which results in 28.23 kWh / day compared to 30.94 kWh / day. Comparing to a single Enphase AC battery, the annual energy is 10,541 kWh vs the optimised system at 10,305 kWh, is at 97.69%. As a result of including example installation costs that include (labour and overhead), the initial capital as per Table 46 on page 87 has increased by 2.8%, resulting in an increase to the LCOE by 39.23 %, NPV is $15,050.

Hervey Bay has two large sized trees to simulate shading, the resulting annual energy when compared to the output from HOMER Pro® is 82.59%, which results in 50.164 kWh / day compared to 60.737 kWh / day. Comparing to a single Enphase AC battery, the annual energy is 18,418 kWh vs the optimised system at 18,310 kWh, is at 99.41%. As a result of including example installation costs that include (labour and overhead), the initial capital as per Table 51 has increased by 7.906%, resulting in an increase to the LCOE by 9.23 %, NPV is $21,662.0. Barcaldine has no trees used to simulate shading, the resulting annual energy when compared to the output from HOMER Pro® is 98.165%, which results in 33.86 kWh / day compared to 34.501 kWh / day. Comparing to a single Enphase AC battery, the annual energy is 12,548 kWh vs the optimised system at 12,362 kWh, is at 98.52%. As a result of including example installation costs that include (labour and overhead), the initial capital as per Table 56 has increased by 16.54%, resulting in an decrease to the LCOE by 29.3%, NPV is $12,596.

Cairns has two trees used to simulate shading, the resulting annual energy when compared to the output from HOMER Pro® is 101.78%, which results in 55.43 kWh / day compared to 54.460 kWh / day. Comparing to a single Enphase AC battery, the annual energy is 20,162 kWh vs the optimised system at 20,233 kWh, is at 99.65%. As a result of including example installation costs that include (labour and overhead), the initial capital as per Table 61 has increased by 7.25%, but the LCOE has decreased by 12.4%, NPV is $26,174.

Additional optimisation will now be discussed, this includes battery dispatch models, throughput and any additional components that has the possible to increase or decrease the LCOE based on real world effects not often analysed in the process.

### 5.1.3 MATLAB®

MATLAB® has been used to verify system outputs from HOMER Pro®, calculate average home electricity usage, LCOE and renewable fraction comparison and multiyear analysis for calculating payback period. As noted in Appendix E on page 158, the system output was coded to compare against the output from HOMER Pro® using equation 14 on page 44.

Table 77: PV System Output comparison

| Location | HOMER Pro® PV system output (kWh / year) | NREL's SAM® PV system output (kWh / year) | MATLAB® PV system output (kWh / year) |
|---|---|---|---|
| Brisbane | 21,231 | 17,554 | 19,920 |
| Toowoomba | 11,293 | 10,305 | 10,668 |
| Hervey Bay | 22,169 | 18,310 | 21,116 |
| Barcaldine | 12,593 | 12,362 | 11,677 |
| Cairns | 19,878 | 20,233 | 19,989 |

As noted in Table 77 above, comparing the system outputs, shows a clear comparison between the different calculations that have been used in order to find system output. A conservative average derating of 85% has been used in HOMER Pro® across all systems analysed in order to focus on panel output and battery capacity for optimisation. NREL's SAM® utilises the derating calculated through MATLAB® (80% derating), this has allowed a worse-case scenario to be analysed in order to ensure that the optimised system for each location can maintain the largest load even with greater derating. The slight variances between the system output can be put down to variances in the weather data and solar irradiance between NREL's SAM® and HOMER Pro®; without the ability to scale the weather and solar irradiance data in SAM®, the results had to remain the same.

## 5.2 Additional Optimisation

### 5.2.1 Battery Dispatch Models

Battery dispatch models were modified to determine when the battery is charging or discharging. Leaving it at automatic dispatch in NREL's SAM® didn't use the battery to its full capacity and manual dispatch strategy was used for all locations. For the locations using the Tesla Powerwall 2 AC (Brisbane, Hervey Bay), similar dispatch modes are being used. For Brisbane as seen in Figure 45 on page 79, the dispatch strategy is as follows, between 12 am to 5 am the battery is discharging at a 10% rate, 6 am to 7 am the battery discharges at 50% per hour to meet the load as well allow the battery to go through discharge cycle and ensure a charge routine is in place and the Lithium-ion battery is operating correctly. Between 8 am and 3 pm the battery is only discharging at 5%, and between 4 pm to 11 pm the battery is discharged at a 15% rate. This was the best strategy to employ for Brisbane and as depicted in Figure 45 on page 79, shows when the electricity load from the PV decreases, simultaneously the battery begins discharging and the grid isn’t used. Hervey Bay incorporates the same dispatch model (Figure 55, page 95) and is clear the battery is being used to its fullest capacity to meet the load demands.

Toowoomba, Barcaldine and Cairns all use some variant of the Trojan SIND 041245, Toowoomba dispatch as noted in Figure 50 on page 87, is set at 10% discharge between 12 am to 5 am, charging the battery with excess electricity between 6 am and 2 pm with no discharge, 10% discharge has been set between 3 pm and 11 pm, this is the best discharge model for the Toowoomba location for two lead acid batteries being used. Barcaldine as noted in Figure 60 on page 104 uses a similar approach, but slightly changing the 3 pm and 11 pm to 15% discharge. Cairns was similar as noted in Figure 65 on page 112, however between 6 am and 7 am 50% per hour discharge was used, as well discharging between 4 pm and 11 pm was set to 15% discharge, this was done to obtain a better performance (as noted a smaller number of batteries are being used compared to Barcaldine, so a slightly larger discharge will be needed to meet the load). Difficulties with applying a dispatch model include that as the battery capacity decreases throughout the years, the manual dispatch model can’t be adjusted accordingly, to even out the distribution as the available capacity is decreased. However, applying a month to month manual dispatch model is beyond the scope and finances available of the project and will be left for the future work aspect of this project.

### 5.2.2 Battery Throughput

In order to be more closely matched with the better priced LCOE of just a PV installation as noted in Table 76 on page 124, the battery throughput was increased to determine how much longer batteries should last before they get close enough to the grid + PV connection. As noted in section 4.7 on page 116, in Table 64 for Brisbane the battery used has a default value of LCOE of $0.0463 / kWh with an expected life of 10 years, increasing life expectancy and lifetime throughput (kWh) results in 17 years expected life with the LCOE at $0.0314 / kWh. This has decreased the LCOE by 32% and is just 2x larger compared to originally 3x larger compared to the LCOE of the grid + PV connection, anymore increases to throughput doesn’t decrease the LCOE by a substantial amount and is beyond the realistic reach of the battery’s lifetime. For Toowoomba as noted in Table 65, with the default value of LCOE at $0.0917 / kWh and default expected life of 8.18 years, increasing the lifetime throughput, to achieve an expected life of 17.3 years, results in a LCOE of $0.0669 / kWh which is within 3% of the grid + PV connection, increasing that lifetime to 29 years (pushing the boundaries of the life of the battery and its capacity) results in a LCOE of $0.0561 / kWh.

For Hervey Bay system as noted in Table 66, extending the expected life to 20 years, results in the best LCOE of $0.02237 / kWh, which is around 1.7x larger, this is the best LCOE for Hervey Bay with the optimised system. The Barcaldine system as noted in Table 67, extending the expected life to 28.6 years, results in the best LCOE of $0.1423/ kWh, which is around 3x larger, this is the best LCOE for Barcaldine with the optimised system. Any additional results as shown in Table 67, are beyond reasonable of what is expected with the current technology. For the Cairns system as noted in Table 68 on page 118, extending the expected life to 23.9 years, results in the best LCOE of $0.0497/ kWh, which is less than 10% to the grid + PV LCOE, this is the best LCOE for Cairns with the optimised system. These calculations were completed with the tariff price of electricity staying the same at the year of this project, obviously the LCOE values would be better for the battery system if the price of electricity increased throughout the 25-year analysis.

### 5.2.3 Physical Size of Components

As noted in section 4.6 on page 116, the size of components to be installed is an important aspect of the optimisation process to ensure that there is adequate space where the components are being installed, for Brisbane as depicted in Table 63, the total area size for the optimised system (PV system, inverter and battery) will be 89.61 $m^2$, Toowoomba will be 39.76 $m^2$, Hervey Bay will be 89.61 $m^2$, Barcaldine with 40.73 $m^2$ and Cairns with 89.73 $m^2$. However, the size of the components can be reduced for the systems that use Lithium-Ion, as a main selling point for the Powerwall 2 and even the Enphase AC battery is the fact that they are manufactured to be used inside a house, whereas the lead acid batteries will require a ventilated area and shouldn’t be kept inside a house as it goes against manufacturer instructions and will void warranty.

### 5.2.4 Peak shaving / lopping

An additional feature of HOMER Pro® is the ability to set up the battery to perform load and peak shaving if the battery doesn’t have capacity to meet the whole load. As described in section 4.8 on page 118, the purchase capacity has been matched to the annual peak demand of the load. For Brisbane, Toowoomba and Hervey Bay the current peak demand is 6.0 kW, and Barcaldine has a peak demand of 5.0 kW and Cairns a peak demand of 2.0 kW. Brisbane’s best adjusted peak demand is at 3.0 kW, at the time of testing the current NPC was $18,763.4, for the adjusted peak demand only provided a $100 difference, which amounts to an adjusted LCOE of $0.0404 / kWh. Hervey Bay, Toowoomba, Barcaldine, Cairns saw a reduction to the NPC by $63, $8,295.87, $14,181.19 and $9,035.36 respectively. These reductions are all a result of the fact the adjusted peak demand has been set for all months throughout the year and therefore increased sales to the grid result in those decreases in the NPC, these locations utilised the lead acid batteries for solar storage. These increases in the sales are a bit unrealistic but display how much the LCOE can be affected by adjusting the peak demand and not keeping it at the default value. The best value for all locations was achieved by having the dispatch strategy set in HOMER Pro® to charge the battery as much as possible instead of discharging the battery as much as possible.

### 5.2.5 Multiyear Analysis & Solar Credits

Multiyear analysis was conducted for each system at each location, this was done to calculate the payback period, in which takes into account the money saved with the PV with that being used to reduce the system costs each year, solar credits were also calculated at the time of writing this project (years used for all sites is 12), as per the guidelines these only apply to the PV system as batteries are not part of the solar credit scheme. For Brisbane as per Table 42 on page 81, the calculated payback period is between 8 and 9 years from initial installation date. The solar credits as per section 4.1.8 on page 82, are $7,525.0 in total leading to a new capital of $11,506.30, which results in a new LCOE of $0.0280 / kWh. For Toowoomba as per section 4.2.7 on page 88, given the largest load size is analysed, there is no payback period. The solar credits are $3,815.0 resulting in a new initial capital of $7,726.40 resulting in a new LCOE of $ 0.0731 / kWh. For Hervey Bay as per section 4.3.7 on page 96 the payback period is between 6 and 7 years. The solar credits are $7,525.0 resulting in a new initial capital of $11,506.30 resulting in a new LCOE of $ 0.0317 / kWh. For Barcaldine as per section 4.4.7 on page 105, given the largest load size is analysed, there is no payback period. The solar credits are $4,235.0 resulting in a new initial capital of $17,992.29 resulting in a new LCOE of $ 0.0159 / kWh. For Cairns as per section 4.5.7 on page 113 the payback period is between 6 and 7 years. The solar credits are $7,525.0 resulting in a new initial capital of $12,592.18 resulting in a new LCOE of $ 0.0499 / kWh. In addition, the payback period relies heavily on the residential homeowners using the money saved with the PV on the cost of the system, if not then payback period would be substantially longer.

These all take advantage of the system still being connected to the grid and being able to sell that excess energy after charging of the battery but without using any of the grid to power the load, this will be a good strategy to incorporate to pay off the system cost and then the decision for home owner would be whether they costs associated with staying on grid outweigh the costs going off grid as the feed-in tariffs are lost when off-grid. Additionally, the higher PV system achieves greater solar credits and thus can be seen as an advantage to obtaining a larger system compared to the smaller system, but the difference of taking into consideration the solar credits, for example Brisbane new capital is $11,506.30 and the original capital for Toowoomba is $11,541.40, comparing the two as they are the closest locales to each other and you can essentially for the cost of a 6.6 kW system, obtain a 13.0 kW system through offsetting the costs with the solar credits.

## 5.3 Environmental Impacts, Current Packages, Alternative Techniques and Vision

### 5.3.1 Current Packages

The current packages seen in section 4.9 on page 119 in Table 70, are those concerned around the systems with similar sizes to the optimised systems, that could be purchased at the current time of writing (7/08/19), for a 3 kW system an Enphase IQ7 inverter, Trina Solar Honey Mono panels and the Enphase AC 1.2 kWh battery can be bought for around $7,000.0.

An equivalent 6.6 kW system can be brought for $14,340.0 which comes with a Fronius 5.0 kW inverter, JKM275W solar panels and a single Tesla Powerwall 2. An 8.0 kW system can be bought for $18,595.0 which comes with SolaX 5.0 kW inverter, Trina Solar Honey Mono panels and the LG RESU 10.0 kWh battery. There are other systems included in Table 70, however there was no packages for the components analysed and researched in this project, therefore had to use what was available at the time, and other packages not included, required an actual quote to be undertaken before prices were given, these quotes required an address and a representative of the company to attend the address to complete the quote, as there was no particular address used for each location, this wasn't feasible to be performed for this project. This also falls under one of the aspects of the project that could be performed as future work, as discussed later there is no genuine pricing for components, and prices obtained for components are reflecting those in 3rd party selling websites and prices from overseas sources, and require some flexibility to be taken on the accuracy of these prices.

### 5.3.2 Environmental Impacts

The environmental impact of the PV, battery and inverter compared to the grid connection, is an aspect of future work that could be conducted but will briefly discussed here to complete the optimisation of the systems. The environmental impacts that was recorded was $CO_2$ released from the system usage, this also includes the grid connection without any renewable components. As seen in Section 4.10 on page 119, for Brisbane the $CO_2$ released for the optimised system is 2.74 kg / year for the small load, 10.6 kg / year for the medium load and 1,069 kg / year for the largest load. Toowoomba's $CO_2$ released for the optimised system is 45.4 kg / year for the small load, 70.1 kg / year for the medium load and 1,883 kg / year for the largest load. Hervey Bay's $CO_2$ released for the optimised system is 1.94 kg / year for the small load, 9.95 kg / year for the medium load and 1,033 kg / year for the largest load. Barcaldine's $CO_2$ released for the optimised system is 0.0 kg / year for the small load, 11.9 kg / year for the medium load and 51.3 kg / year for the largest load. Cairns has $CO_2$ released for the optimised system at 0.0 kg / year for the small load, 0.968 kg / year for the medium load and 2.87 kg / year for the largest load. All systems for all locations and load profiles produced less $CO_2$ than a straight grid connection, however the future concern would be related to the recyclability of the components that will require replacement whether that be outright replacement due to a fault or replacement after efficiency has dropped below a set threshold.

### 5.3.3 Alternative Techniques

As discussed in the literature review there are a variety of techniques that can be employed for further optimisation, these will be discussed qualitatively and thus no results have been performed for these techniques, however it is beneficial to keep in mind as the market changes and better optimisation techniques get introduced. One study in the literature review focused on cooling techniques for the PV panels, as temperature is a main factor in a PV panels efficiency and thus affects its output (around 12% loss states Moharram, KA, Abd-Elhady, MS, Kandil, HA & El-Sherif, H 2013 p.873) , the study found that a design was implemented that resulted in a cooling rate of 2°C / minute, and the panel yields the highest output energy if cooling of the panel starts when the temperature of the PV panels reaches the maximum allowable temperature (Moharram, KA, Abd-Elhady, MS, Kandil, HA & El-Sherif, H 2013 p.876).

Another study utilised the same method but ensured the heat removed from the PV panel from the water film was recycled, both studies agreed that due to the water flow and additional cooling by water evaporation, the panel's operating temperature measured is much lower than a conventional panel (Hosseini, R, Hosseini, N & Khorasanizadeh, H 2011 p.2996), some hours up to a total difference of more than 33%. When the water is running through a heat exchanger, thermal energy is obtained and can be used as a utility for heating purposes. Due to the introduction of thermal energy, the combined system efficiency increases substantially, as noted in the study. Depending on location, and the average temperature of the area, would determine if this is feasible or not on a case by case basis, however it has the potential to improve panel efficiency or assist an already installed solar hot water system, as the thermal energy will assist the utility and ensure the main system is running at optimal efficiency and the water will be recycled through the system to ensure waste is kept to a minimum. This is an alternative technique that has the chance for further work beyond this project (i.e. testing and implementing on a full setup not just the single panel like that seen in both studies mentioned).

Whilst completing the simulations for the models, HOMER Pro® provided results that utilised two solar arrays of the twice the total PV size, whilst still having a single inverter (as noted in Appendix D: Figure 83), the total kWh per year is now 42,608 kWh and 26.0kW solar system is being used, NPC is -14,490.06 and LCOE at -$0.02139 / kWh which beats any alternative mentioned. However, this is where the results need to be analysed and not taken at face value, since there is still only one inverter being used, essentially the panels in comparison to the inverter are overclocked at 260% which is around double of what is allowed of a system if it is oversized. Therefore, within the guidelines of the CEC mentioned in section 2.3.4 on page 28 wouldn't be installed by a credited installer, and therefore wouldn't receive any small-scale technology certificates and in addition wouldn't have any insurance associated with it. As well since the inverter is sized for a 10 kW the system is losing based on standard test conditions, 16 kW of power due to having to essentially step down when it reaches the inverter.

### 5.3.4 Vision of Market

The overall vision for the microgrid market including batteries, is that as the market expands as seen with solar panels, prices per capacity will decrease, capacity will increase (see Tesla Powerwall 1(6.4 kWh, released 2015) to the Powerwall 2 AC (14 kWh, released 2017)) in two years the capacity increased by over double, this shows potential for not just the Tesla brand batteries, but batteries from all manufacturers. As electricity prices rise, and subsequently subsidies decrease (feed in tariffs and solar credits), battery storage is becoming more viable every year. It will be interesting to note if a large number of residential homes went off grid, thus easing the network strain, whether electricity prices would continue to rise or reduce.

## 5.4 Software Model and General Discrepancies

The models developed using both HOMER Pro® and NREL's SAM® provided slightly different results even though the systems used for the simulations were the exact same. Unfortunately, due to the fact that NREL's SAM® program is lacking a database for the batteries that are used in the analysis, and the fact that manufacturers don't include all details required to manually model the battery, there is a gap of knowledge on the accurate values for the batteries used. Therefore, the batteries were modelled as best as possible to represent the real values used and that used from the battery database for HOMER Pro®, regardless the battery data was modified to realistically represent the real battery in the System Advisor Model and results were satisfactory as information has been inputted as best as possible, but must be taken into consideration when comparing the programs used in this project. Weather data used for both software was compromised as HOMER Pro® is unable to change weather data from year to year for the multiyear analysis and is based on an average over a 22-year period (July 1983 – June 2005 to be exact).

Even with scaling to the BOM weather data, it is only based on a single year of scaling and therefore doesn't allow a more consistent base for optimisation over the life of a system. The same can be reflected with NREL's SAM® software, which use typical meteorological year (TMY) data, which contains one year of hourly data that best represents weather conditions over a multiyear period, and as such since they are typical data they don't represent extreme conditions, therefore systems can't be designed to meet the worst case scenario for temperature related losses per location. In addition, the data can't be scaled for NREL's SAM®, since PV output is related to temperature and solar irradiance, the results will differ between the two-modelling software's and since these values can't be changed, the discrepancies will remain.

A final point concerning the weather data, is that for the TMY used for each location, there is no distinct features to be able to determine the year that the TMY is representing, and could only be alleviated through extending the financial budget of the project and purchasing the weather data from reputable sources to ensure all locations are on the same year being analysed.

Another discrepancy found was that NPC and NPV by definition should only differ by the sign, as costs are positive, and revenue is negative for NPC. NPV is calculated in NREL's SAM® and NPC is calculated in HOMER Pro®, comparing result in each section of Chapter 4, shows that the values for some of the locations are heavily skewed to be different and not just the sign is the difference, which can be noted for reiteration below, comparing NPV and NPC between the two modelling programs.

Table 78: NPC vs NPV

| Location | Brisbane | Toowoomba | Hervey Bay | Barcaldine | Cairns |
|---|---|---|---|---|---|
| NPC ($) | 18,763 | 17,783 | 16,128 | 38,309 | 27,032 |
| NPV ($) | 28,387 | 15,050 | 21,662 | 12,596 | 26,174 |

These values calculated for NPV, are reliant on variety of financial parameters, that are heavily skewed towards an American market, project tax, property tax and federal income tax all have a positive or negative impact which is dependent on the inflation rate and real discount rate used (which was the same used in HOMER Pro®), additionally NREL's SAM® always is connected to the grid and there is no option for it to go off grid like that seen in HOMER Pro®, this problem is only related to the financial side and doesn't affect the performance output of the system. Debugging the program, yielded no outcomes that had the correct NPV for each system even with changing components or pricing. Discrepancies in relation to PV annual energy for Brisbane and Hervey Bay location through simulation of NREL's SAM® and comparing against the output from HOMER Pro®, will be considered outliers (or even worst case scenarios) due to the locations used, as implementing the same system in other locations yielded output results similar to expected results.

This is most likely a result of the weather data not being updated as regularly due to NREL's SAM® being more focused towards American locales. Pricing of components was another huge discrepancy in this project as noted previously, there is no global pricing for components used and the prices used were an average of what was attainable at the time of writing. Alleviating this issue would be an entire project in itself, and therefore the figures used in the project are assumed to be approximate figures for the sake of completion of the optimisation and the project itself.

# Chapter 6. Conclusions

## 6.1 Conclusion

The focus of this project was analysing a variety of different solar panels, inverters and battery storage systems, to optimise a system to be able to meet load sizes that vary substantially. Subsequently a comparison was made between the two programs used for this project, in which based on the current versions of both programs used had advantages and disadvantages when compared to each other. Investigating current techniques and technology related to off grid / grid connected solar power systems was an essential objective for this project, having inverter sized to the system appropriately based on CEC guidelines, allowed systems to be optimised fully whilst still being able to receive renewable solar credits (if applicable). These solar credits can be used to reduce the initial capital of the system, reducing payback period and decreasing the LCOE. Comparing newer technology with existing and established components (Enphase 1.2 kWh vs Teslas Powerwall 2 13.5 kWh), concludes that the Enphase battery based on the average cost / kWh requires more capacity with lower costs, to be considered a genuine battery to provide off grid capability. This could possibly come from the rumoured residential battery product line up which is expected to be available in capacities of 3.3 kWh, 10 kWh and 13.2 kWh in the near future. To summarise all locations and load profiles, throughout analysing the results from the developed models from HOMER Pro® and NREL's SAM®, it was found that for a better payback and lower LCOE, it is more beneficial to remain connected to the grid, whilst still serving 100% of the load from renewable resources, therefore solar feed-in tariffs can be utilised to offset the cost of remaining on grid as well as paying the system back quicker.

Battery throughput was essential to reducing LCOE to match that closest to a PV only system, extending lifetime of the batteries also assisted in reducing LCOE, but the current batteries optimised (Tesla Powerwall AC 2, Trojan SIND 041245), reached their limitations even when extending to their realistic lifetime limits. Another optimisation level was related to peak shaving / peak lopping, which allowed for analysis into whether reducing peak demand using the battery would achieve a better reduction to the LCOE, however the results from performing this analysis was negligible and improved the LCOE and NPC by a small margin. In addition to this, a medium sized system was optimised for the Toowoomba and Barcaldine system, additionally it also had the highest return on investment while Barcaldine had the lowest ROI, whilst having average load profiles across the size variations. For Toowoomba this was most likely a result of the initial state of charge for all batteries being set to 70% (see Table 34 on page 61) before calculations were conducted. As well having the lowest temperature (Toowoomba) out of all the sites would have helped decrease temperature related losses, that would subsequently increase the system output as per equation 9 on page 29 and subsequently equation 14 on page 44 in the literature review regarding temperature and system output respectively. Barcaldine's low ROI is a result of the number of batteries utilised to be off grid for the largest load and thus as discussed previously cannot take advantage of feed in tariffs which was vital to making the project sustainable and economically viable, but without them they wouldn’t be able to cope with the largest load without the number of lead acid batteries used. NREL SAM® and HOMER Pro® also showed it is a considerably more powerful tool to utilise for microgrid systems, however this isn’t taking away the advantages of NREL SAM®, which has performed in this project, is able to simulate shade losses and manually modify the battery dispatch to determine if a battery could be utilised better than the default dispatch. In addition, being able to go completely off grid, have an updated battery database, being able to scale all data (weather, solar and load profiles) gives the advantage to HOMER Pro®. When NREL SAM® eventually is updated with a battery database similar to HOMER Pro® and scaling, then the difficulties associated and general discrepancies with each program used would be significantly diminished and would probably be an equivalent tool to HOMER Pro®. Based on the information gathered and past studies, the results for each location and load profile are reasonable and demonstrate that using existing solar credits and still being connected to the grid to take advantages of feed in tariffs in the current market is vital to reducing LCOE and making it economically viable to include a battery for a new system. An economic comparison between just a PV system and the PV + battery, based on the financial parameters, system output and current feed-in tariffs, its best to wait on the battery market to expand as well as overall cost of electricity to significantly increase (and decrease feed-in tariffs) in order to make the batteries more financially viable.

## 6.2 Future Work

With the results aligning with expectations and similar studies based on the equations and theory around system output for solar systems, throughout this project several recommendations that could be implemented for future work that was discussed briefly in the discussion section are as follows:

- Use actual load data for each load profile to properly reflect realistic loads instead of a simulated load
- Environmental impacts on a large scale from replacing system components as necessary throughout the project lifetime
- Implement alternative techniques (water cleaning the panels, which can be used to compliment a hot water system, to save on power used for hot water systems)
- If project budget were unlimited, focus on one location, obtain an optimised system and test for an extended period to compare against simulated results

- Azimuth and tilt angle could be greater analysed to determine if any further optimisation could be found

- Translate to a commercial setting, incorporate additional energy sources (thermal energy, wind turbines) to broaden the scope of the analysis and test the limitations of the programs used for this project

- An update to the 2013 CEC guidelines, as more battery technology gets implemented into the market

- Perform an additional optimisation after the RECs expire in 2030 as there wouldn't be any solar credits available to offset the initial capital of the project and determine effect on the NEM.

## 6.3 Reflection

### Reflection on project idea

The project was originated from the idea of Professor Paul Wen, originally being a preliminary research in the area to focus on existing products and how they work. The project manifested into performing a modelling system to compare and contrast not only the components used but the modelling programs used in order to perform the analysis, as well to determine the best optimised technique for each location within the scope of the project. At the start of the project there was no experience with solar systems, battery dispatch modelling or the micro-grid programs used, this was essential to ensure learning was being undertaken throughout the duration of the project.

### Objectives and aims achieved

Finally, the objectives and aims of the project as noted in Appendix A on page 150 have been met given the time and financial constraints of the project.

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# Appendix A: Project Specification

ENG4111/2 Research Project

**Project Specification**

For: **Jason Hooper**

Topic: Home Based Solar Power Grid Design and Optimisation

Dissertation Title: Off-grid Solar Power Design and Battery Storage Optimisation

Supervisors: **Professor Paul Wen**

Major: Electrical and Electronic Engineering

Sponsorship: Faculty of Health, Engineering & Sciences

Project Aim: The aim is to provide preliminary research and simulation into home based solar power generation and battery storage, in order to optimise techniques and battery storage from multiple manufacturers: including Enphase Energy and Tesla. Existing products will be analysed to find the ideal system across multiple locations and load demands, this is all done in accordance with long term sustainability and return on investment.

Programme: Version 1, February 2019

1. Investigate current techniques related to off-grid / grid connected solar power systems, emphasis on battery banks for off-grid solutions.
2. Research techniques used for the installations of localised energy grids and provide available alternatives to achieve maximum power generation and storage.
3. Develop a model using a HOMER Pro® software, NREL’s SAM® software (using MATLAB® to verify results), to simulate the analysis of generation / storage / consumption.
4. Analyse results and provide the best optimised solution for a small, medium and large household regardless of season with varying locations.
5. Provide conclusions that details comparison between techniques and performance in efficiency and capacity for each scenario / load profile and identify the techniques that have the potential to be improved.
6. Recommend best products, most sustainable, the ideal system as well the best Return on Investment (ROI) and economic investment within a reasonable time expectancy based on results.

*As time and resources permit:*

7. Investigate household utilities that could further optimise electricity usage (hot water systems, floor heating).
8. Analyse impact on the network and environment of residential properties going off-grid.

# Appendix B: Project Timeline

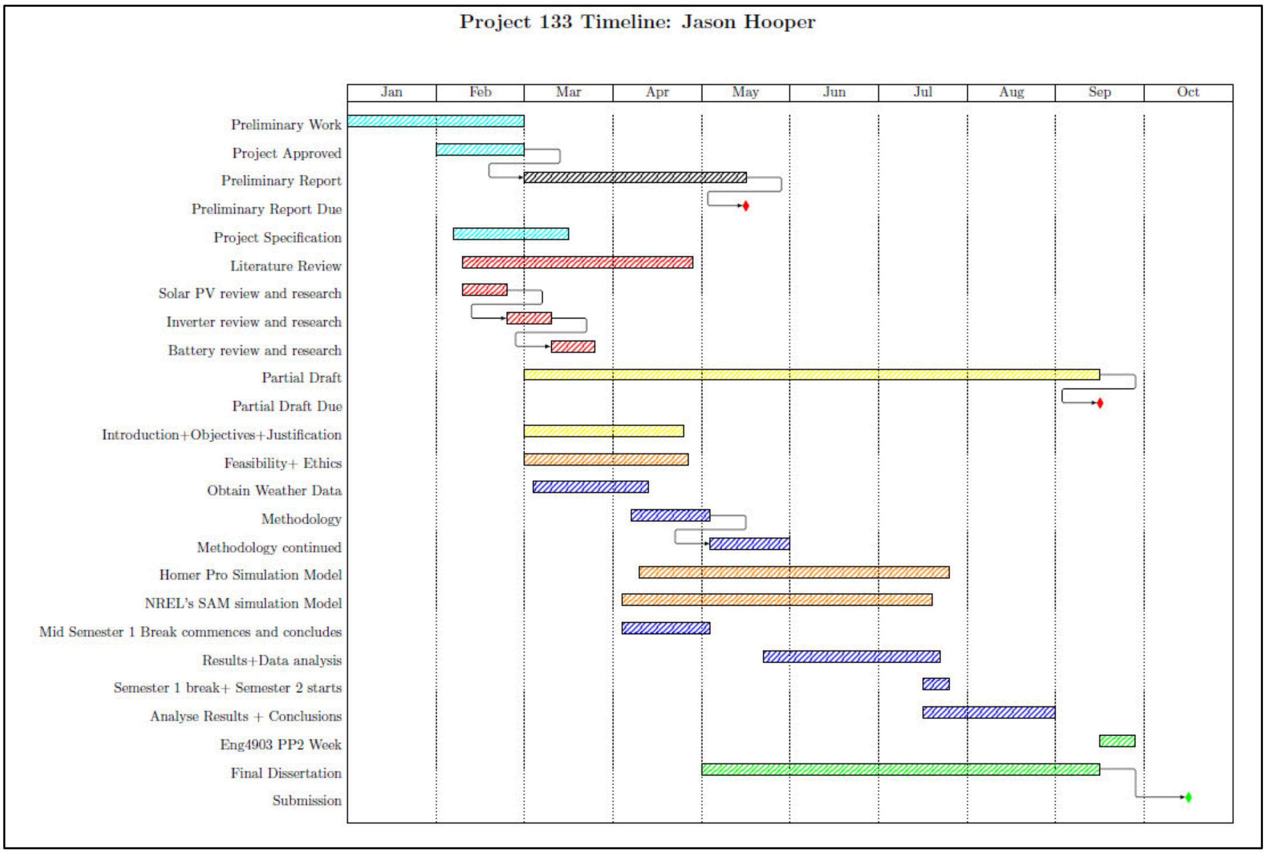


Figure 68: Project 133 Timeline

# Appendix C: Risk assessment

Table 79: Key to the risk assessment

| **Level** | **A. Insignificant** | **B. Moderate** | **C. Major** | **D. Critical** |
|---|---|---|---|---|
| 1. Certain | Low | High | Extreme Caution | Extreme Caution |
| 2. Likely | Low | Medium | High | Extreme Caution |
| 3. Possible | Low | Medium | Medium | Extreme Caution |
| 4. Unlikely | Low | Low | Low | Extreme Caution |

Table 80: Risk assessment

| Risk Level | Description | Hazard | Minimisation |
|---|---|---|---|
| 1C | High | Driving to University or Residential school | Plan to complete as much work in one sitting, to mitigate time on the road. Do project work at home, to avoid having to travel to university. |
| 2B | Medium | Fatigue from reading / analysing large amounts of data, sitting too long | Minimise time on computer, use blue light filter to reduce strain on eyes, 15-minute break every 2 hours. |
| 3B | Medium | Loss of focus due to repeatedly doing the same calculations over and over, resulting in wrong data being calculated | Ensure work is broken up into blocks to ensure data is being accurately recorded and reported. |
| 3D | Extreme Caution | Computer might crash due to strenuous calculations on the computer / loss of data | Ensuring backups are made, computer is well ventilated, data is accurately recorded and reported. |
| 4B | Medium | Drafts could be not satisfactory and result in having to rework the project in order to deliver on time | Ensure small stages of work are in for drafts to the supervisor. |

# Appendix D: Figures / Graphs

## D.1: Australian PV installed

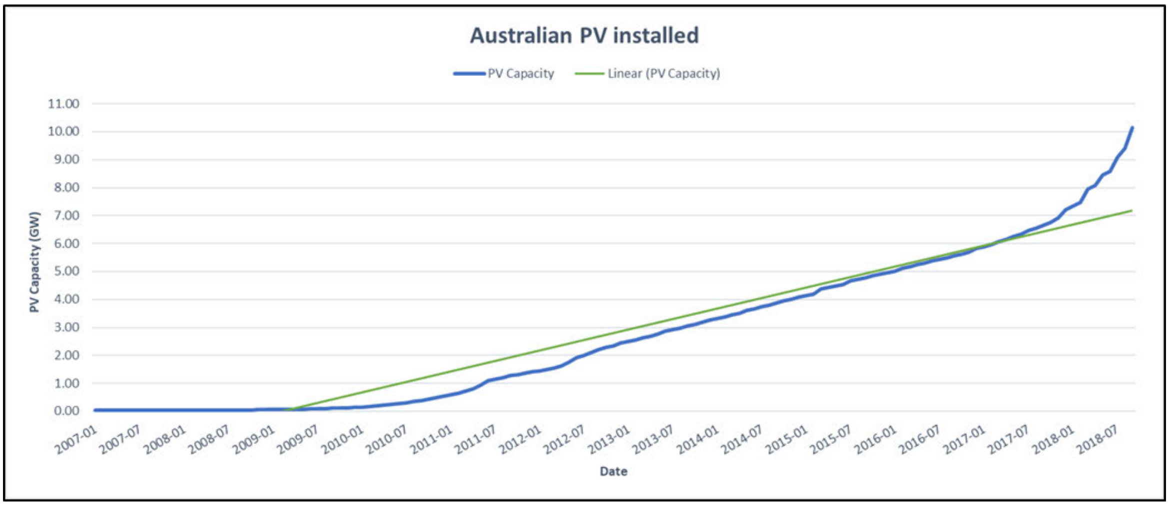


Figure 69: Australian PV installed (*Australian PV market since 2001* 2018)

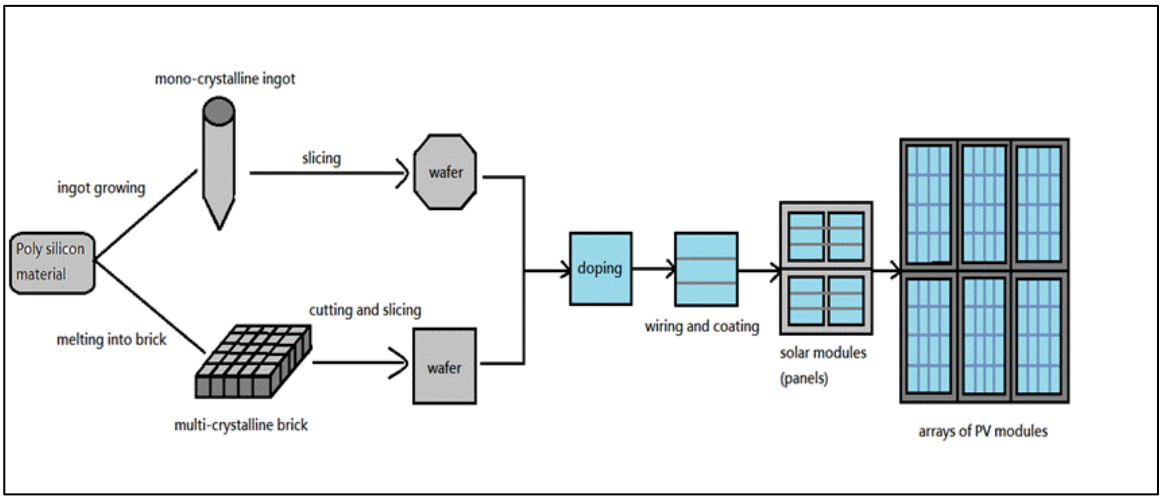
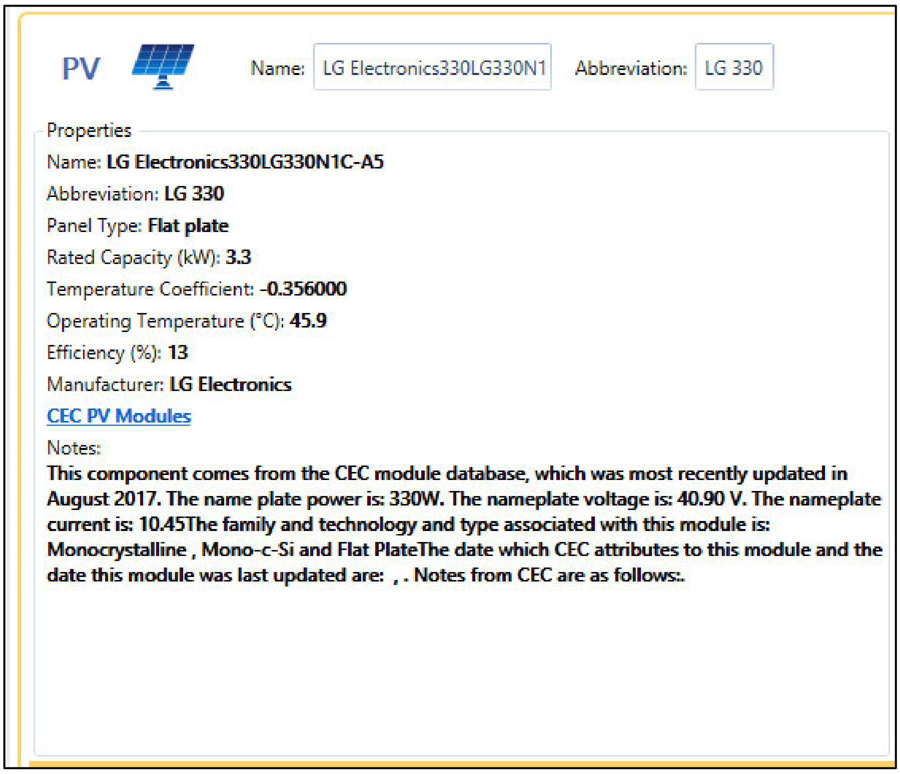


Figure 70: Creation of a solar module from raw material to finished project (Walsh, C 2016)

## D.2: Solar modules



Properties

Name: **LG Electronics330LG330N1C-A5**

Abbreviation: **LG 330**

Panel Type: **Flat plate**

Rated Capacity (kW): **3.3**

Temperature Coefficient: **-0.356000**

Operating Temperature (°C): **45.9**

Efficiency (%): **13**

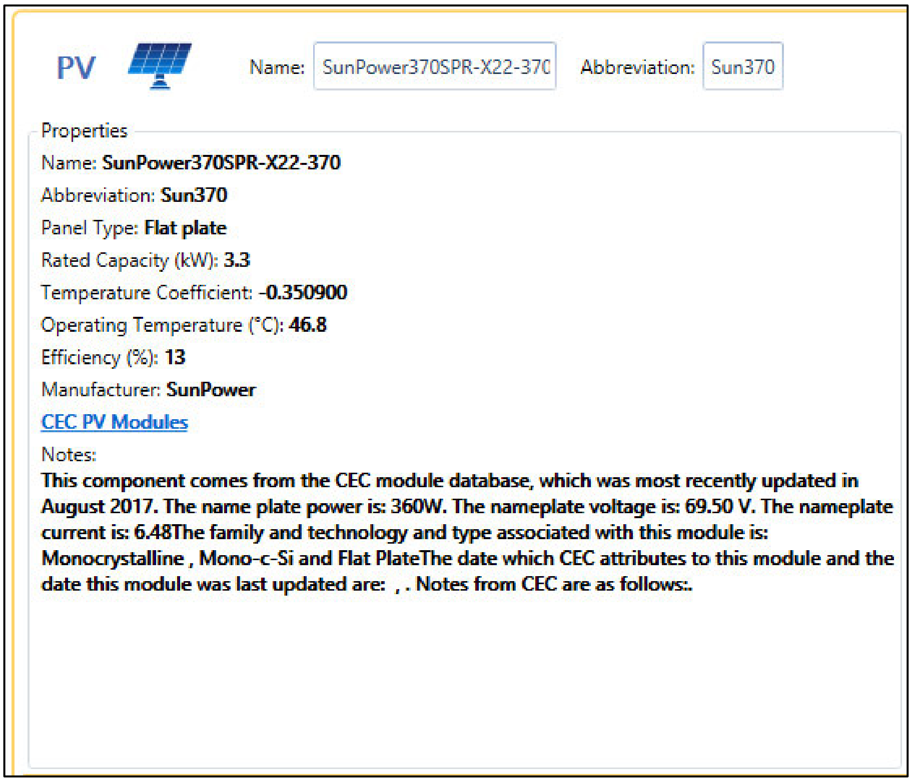
Manufacturer: **LG Electronics**

CEC PV Modules

Notes:

**This component comes from the CEC module database, which was most recently updated in August 2017. The name plate power is: 330W. The nameplate voltage is: 40.90 V. The nameplate current is: 10.45The family and technology and type associated with this module is: Monocrystalline , Mono-c-Si and Flat PlateThe date which CEC attributes to this module and the date this module was last updated are: , . Notes from CEC are as follows:.**

Figure 71: LG330W Neon 2 (HOMER Pro® 2019)



Properties

Name: **SunPower370SPR-X22-370**

Abbreviation: **Sun370**

Panel Type: **Flat plate**

Rated Capacity (kW): **3.3**

Temperature Coefficient: **-0.350900**

Operating Temperature (°C): **46.8**

Efficiency (%): **13**

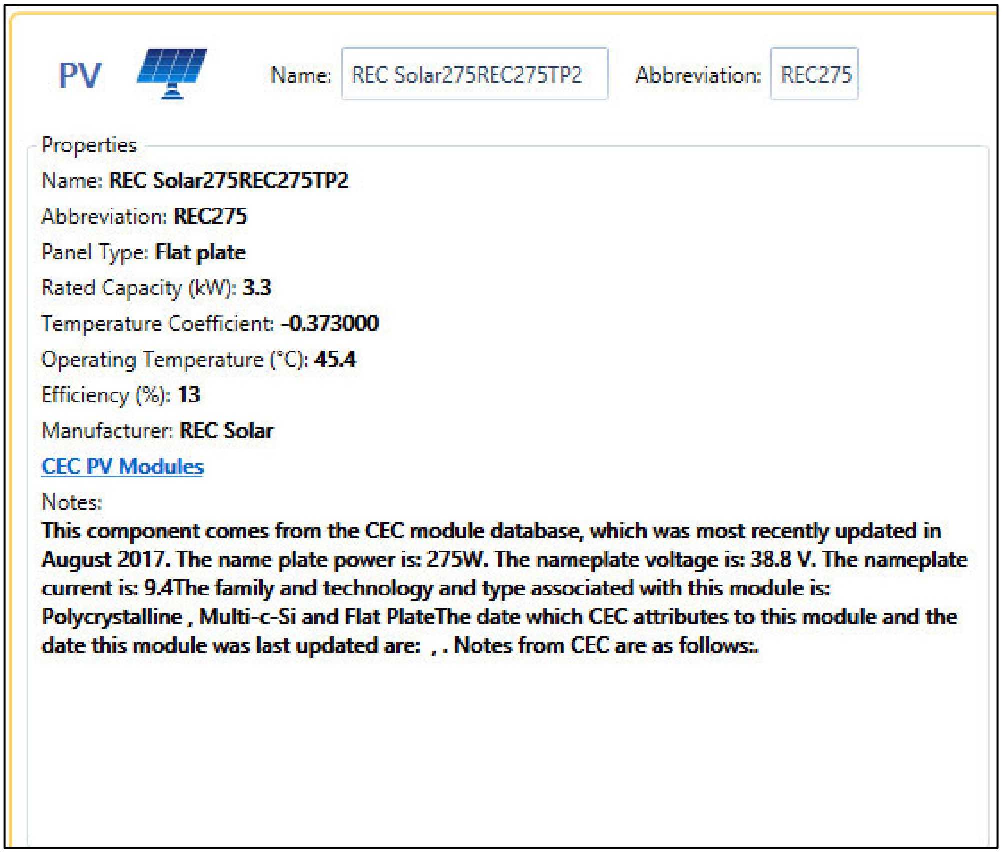
Manufacturer: **SunPower**

CEC PV Modules

Notes:

**This component comes from the CEC module database, which was most recently updated in August 2017. The name plate power is: 360W. The nameplate voltage is: 69.50 V. The nameplate current is: 6.48The family and technology and type associated with this module is: Monocrystalline , Mono-c-Si and Flat PlateThe date which CEC attributes to this module and the date this module was last updated are: , . Notes from CEC are as follows:.**

Figure 72: Sun370W (HOMER Pro® 2019)



Name: REC Solar275REC275TP2 Abbreviation: REC275

Properties

Name: **REC Solar275REC275TP2**

Abbreviation: **REC275**

Panel Type: **Flat plate**

Rated Capacity (kW): **3.3**

Temperature Coefficient: **-0.373000**

Operating Temperature (°C): **45.4**

Efficiency (%): **13**

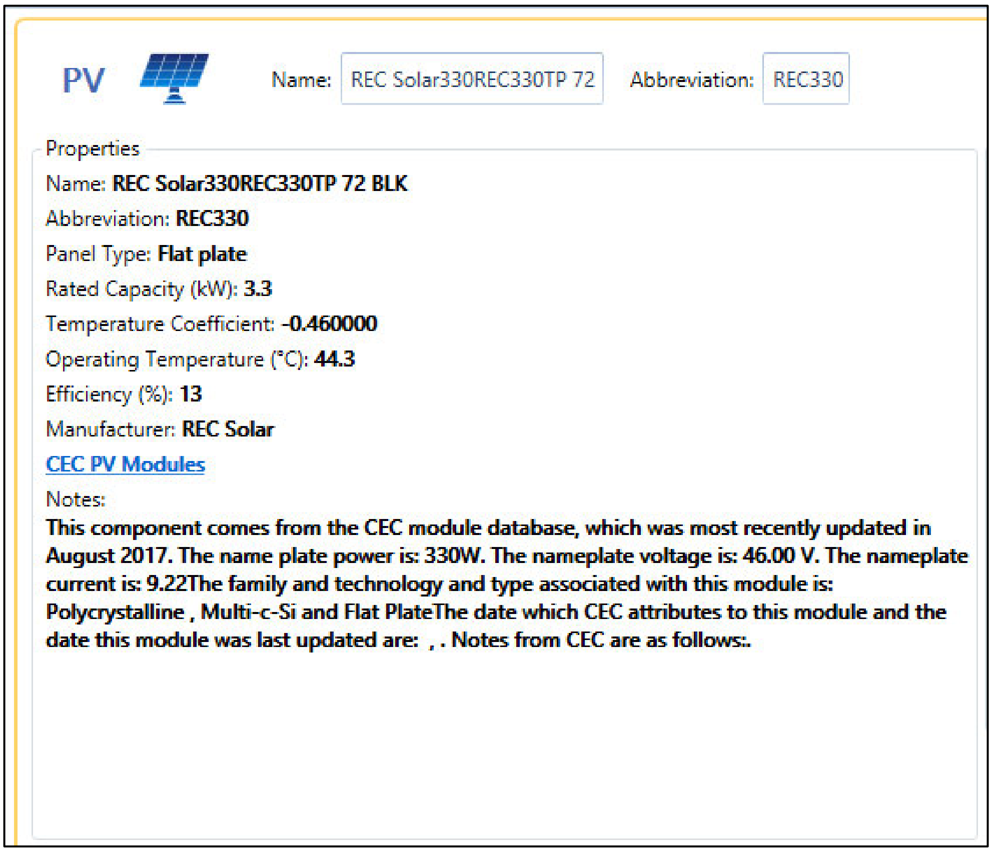
Manufacturer: **REC Solar**

CEC PV Modules

Notes:

**This component comes from the CEC module database, which was most recently updated in August 2017. The name plate power is: 275W. The nameplate voltage is: 38.8 V. The nameplate current is: 9.4The family and technology and type associated with this module is: Polycrystalline , Multi-c-Si and Flat PlateThe date which CEC attributes to this module and the date this module was last updated are: , . Notes from CEC are as follows:.**

Figure 73: REC275W (HOMER Pro® 2019)



Name: REC Solar330REC330TP 72 Abbreviation: REC330

Properties

Name: **REC Solar330REC330TP 72 BLK**

Abbreviation: **REC330**

Panel Type: **Flat plate**

Rated Capacity (kW): **3.3**

Temperature Coefficient: **-0.460000**

Operating Temperature (°C): **44.3**

Efficiency (%): **13**

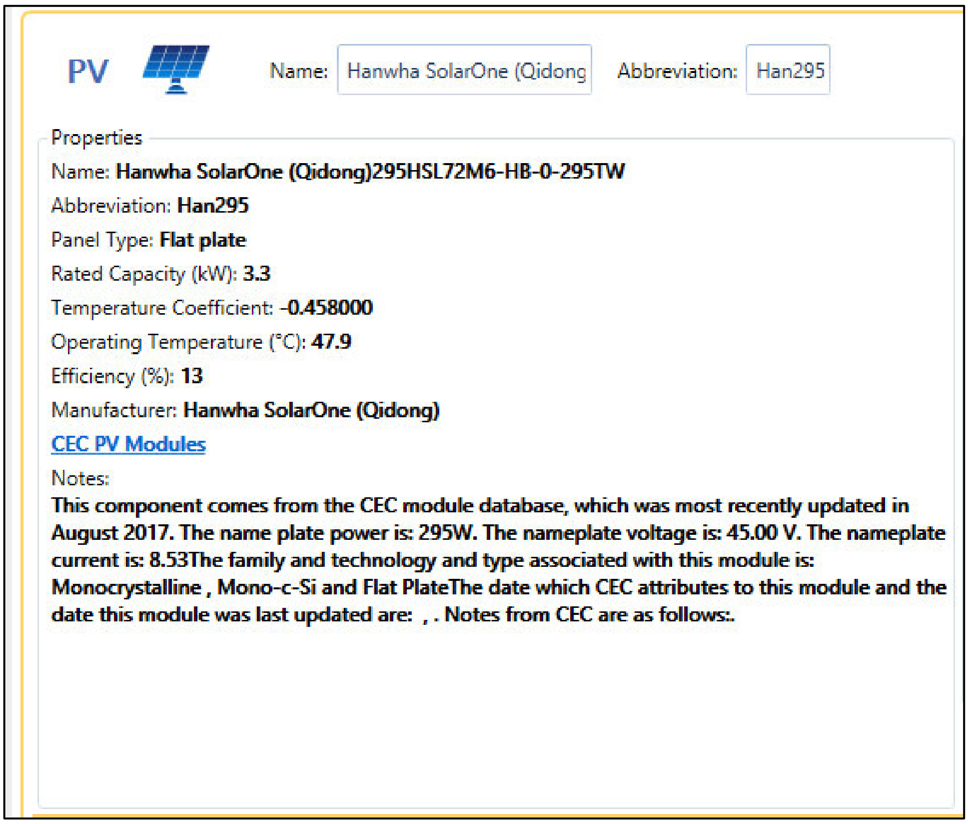
Manufacturer: **REC Solar**

CEC PV Modules

Notes:

**This component comes from the CEC module database, which was most recently updated in August 2017. The name plate power is: 330W. The nameplate voltage is: 46.00 V. The nameplate current is: 9.22The family and technology and type associated with this module is: Polycrystalline , Multi-c-Si and Flat PlateThe date which CEC attributes to this module and the date this module was last updated are: , . Notes from CEC are as follows:.**

Figure 74: REC330W (HOMER Pro® 2019)



Properties

Name: **Hanwha SolarOne (Qidong)295HSL72M6-HB-0-295TW**

Abbreviation: **Han295**

Panel Type: **Flat plate**

Rated Capacity (kW): **3.3**

Temperature Coefficient: **-0.458000**

Operating Temperature (°C): **47.9**

Efficiency (%): **13**

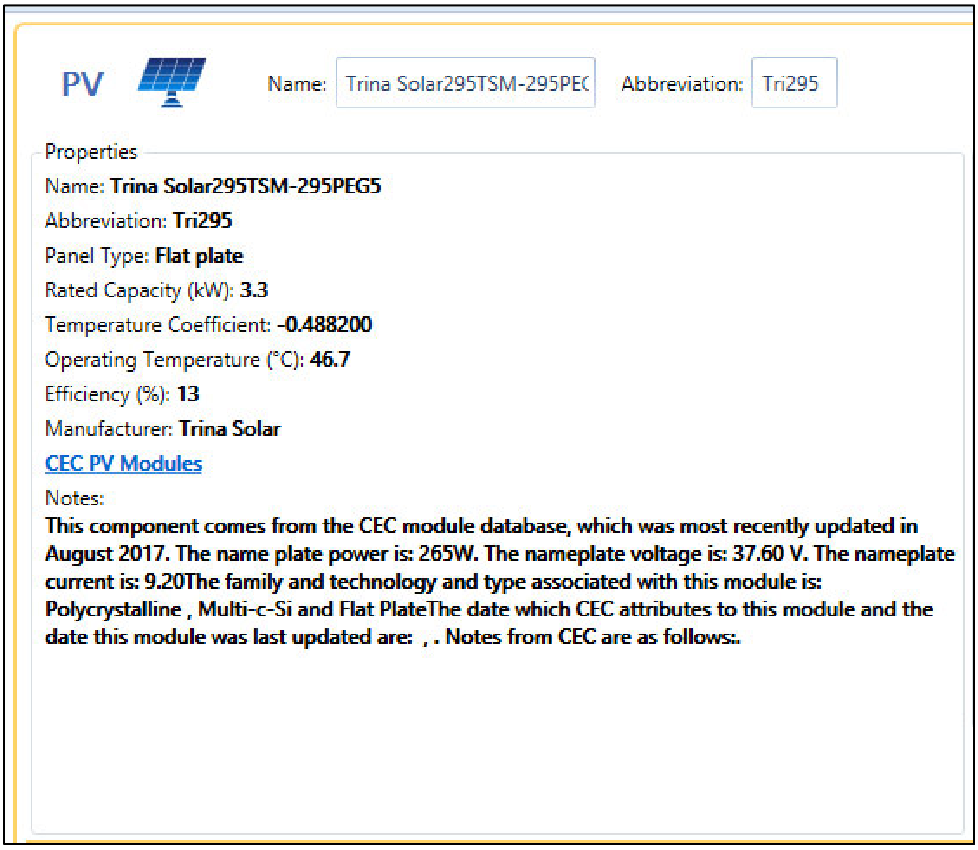
Manufacturer: **Hanwha SolarOne (Qidong)**

CEC PV Modules

Notes:

**This component comes from the CEC module database, which was most recently updated in August 2017. The name plate power is: 295W. The nameplate voltage is: 45.00 V. The nameplate current is: 8.53The family and technology and type associated with this module is: Monocrystalline , Mono-c-Si and Flat PlateThe date which CEC attributes to this module and the date this module was last updated are: , . Notes from CEC are as follows:.**

Figure 75: Han295W (HOMER Pro® 2019)



Properties

Name: **Trina Solar295TSM-295PEG5**

Abbreviation: **Tri295**

Panel Type: **Flat plate**

Rated Capacity (kW): **3.3**

Temperature Coefficient: **-0.488200**

Operating Temperature (°C): **46.7**

Efficiency (%): **13**

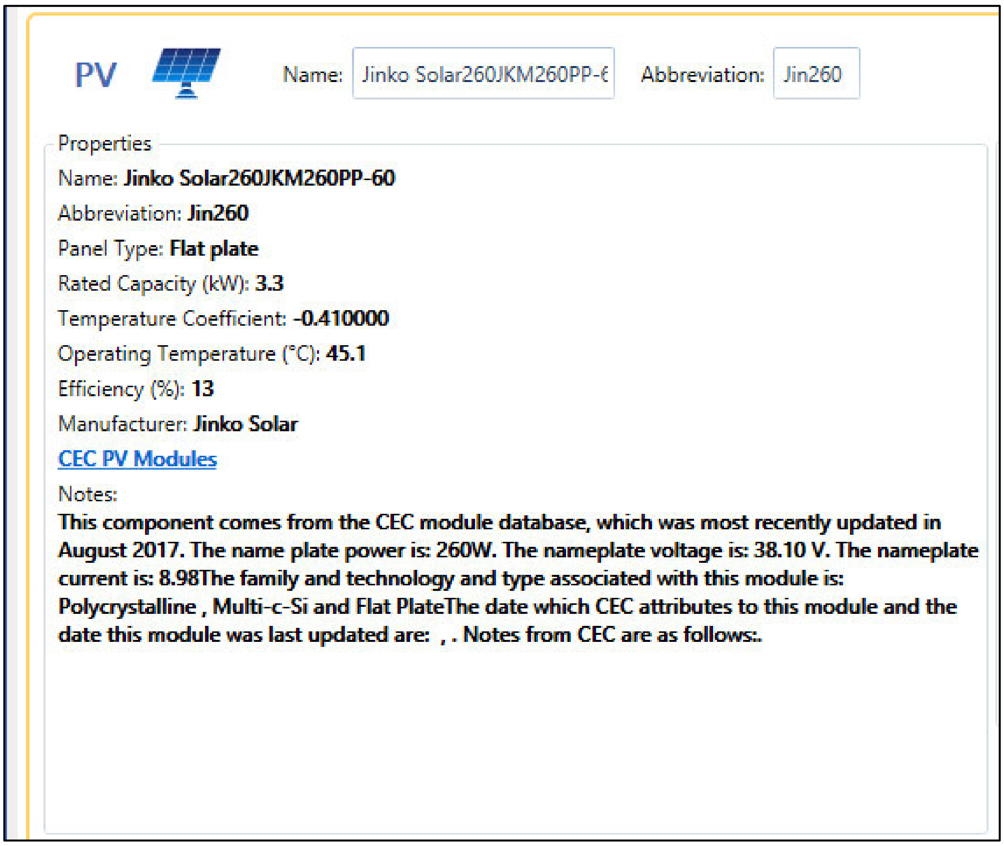
Manufacturer: **Trina Solar**

CEC PV Modules

Notes:

**This component comes from the CEC module database, which was most recently updated in August 2017. The name plate power is: 265W. The nameplate voltage is: 37.60 V. The nameplate current is: 9.20The family and technology and type associated with this module is: Polycrystalline , Multi-c-Si and Flat PlateThe date which CEC attributes to this module and the date this module was last updated are: , . Notes from CEC are as follows:.**

Figure 76: Tri295W (HOMER Pro® 2019)



Name: Jinko Solar260JKM260PP-6

Abbreviation: Jin260

Properties

Name: **Jinko Solar260JKM260PP-60**

Abbreviation: **Jin260**

Panel Type: **Flat plate**

Rated Capacity (kW): **3.3**

Temperature Coefficient: **-0.410000**

Operating Temperature (°C): **45.1**

Efficiency (%): **13**

Manufacturer: **Jinko Solar**

CEC PV Modules

Notes:

**This component comes from the CEC module database, which was most recently updated in August 2017. The name plate power is: 260W. The nameplate voltage is: 38.10 V. The nameplate current is: 8.98The family and technology and type associated with this module is: Polycrystalline , Multi-c-Si and Flat PlateThe date which CEC attributes to this module and the date this module was last updated are: , . Notes from CEC are as follows:.**

Figure 77: JKM260W (HOMER Pro® 2019)

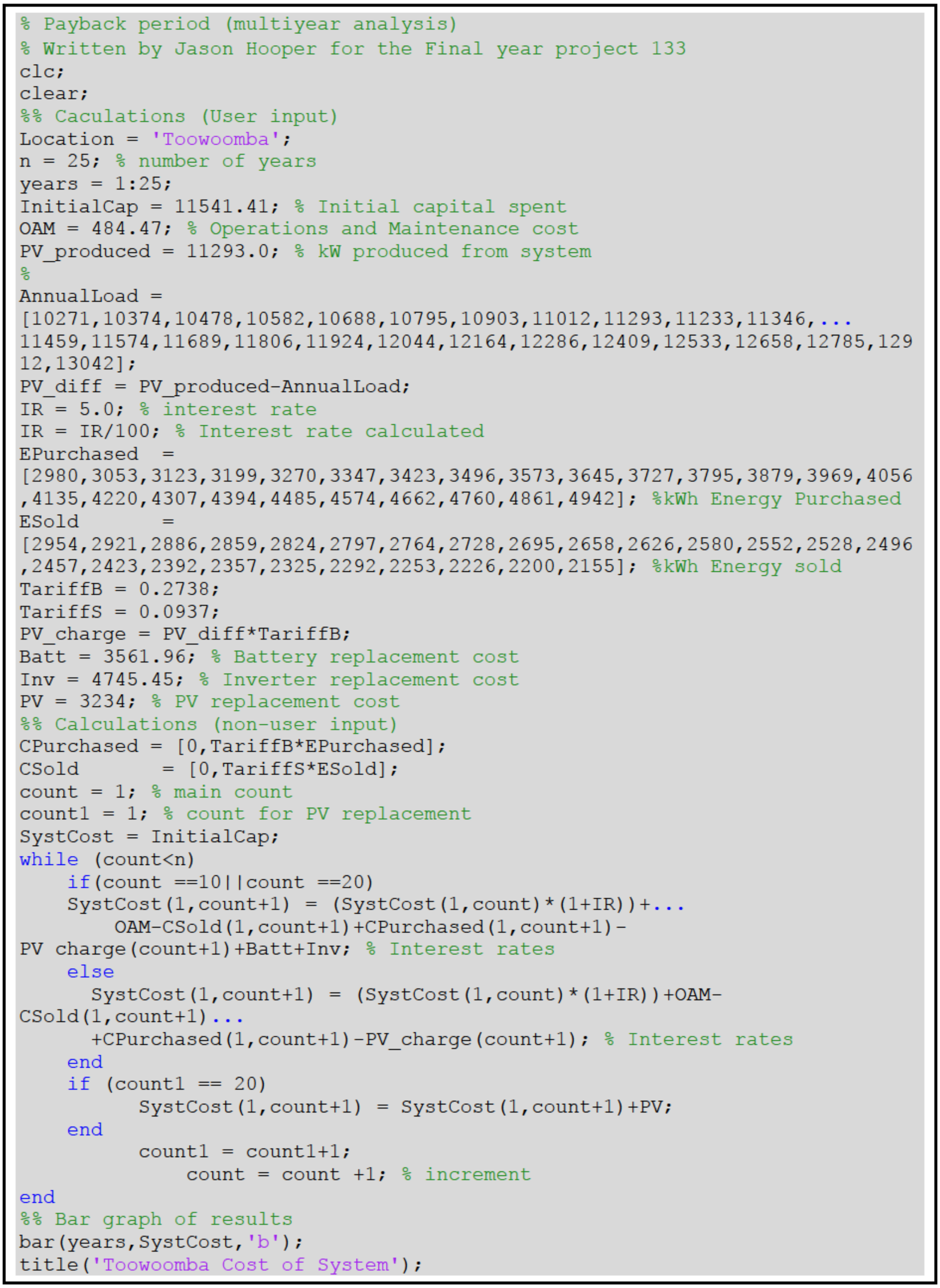
# Appendix E: MATLAB® Code

```
% Home Electricity Usage Average
% Written by Jason Hooper for the Final year project 133
clc;
clear;
%% User prompt for input of total periods
SummerTotal = input('Please enter Summer total:');
AutumnTotal = input('Please enter Autumn total:');
WinterTotal = input('Please enter Winter total:');
SpringTotal = input('Please enter Spring total:');
%
L = 4; % length
Year = [SummerTotal,AutumnTotal,WinterTotal,SpringTotal];
Total = 0; % Total Consumption
for n = 1:L
    Total = Total + Year(n);
end
DailyUsage = Total/365; % daily usage
```

Figure 78: Electricity usage code

```
% LCOE vs Renewable Fraction
% Written by Jason Hooper for the Final year project 133
clear;
clc;
close all;
%
%% Renewable fraction and LCOE
RenF = [98.8 99.9 92.3];
%
LCOE = [0.0724 0.0080 0.0463];
names = {'Small : SolaX 5.0 kW','Medium : Fronius 10.0 kW','Large : Fronius
10.0 kW'};
%% Plotting
grid minor;
yyaxis left
RenFBar     = bar(RenF);
yyaxis right
LCOEBar     = plot(LCOE);
set(gca,'xticklabel',names);
%*******************************Formatting***********************************
title ('LCOE and Renewable Fraction:
Brisbane','fontweight','bold','fontsize',12);
xlabel('System','fontweight','bold','fontsize',12);
yyaxis left
ylabel('Renewable Fraction (%)');
yyaxis right
ylabel('LCOE ($/kWh)');
LCOEBar.LineWidth = 3; % plot line colour
RenFBar.FaceColor = [0 0.447 0.741]; % Bar graph colour
RenFBar.BarWidth = 0.2; % Bar graph width
set(gca,'XTickLabelRotation',45);
```

Figure 79: LCOE and Renewable fraction code



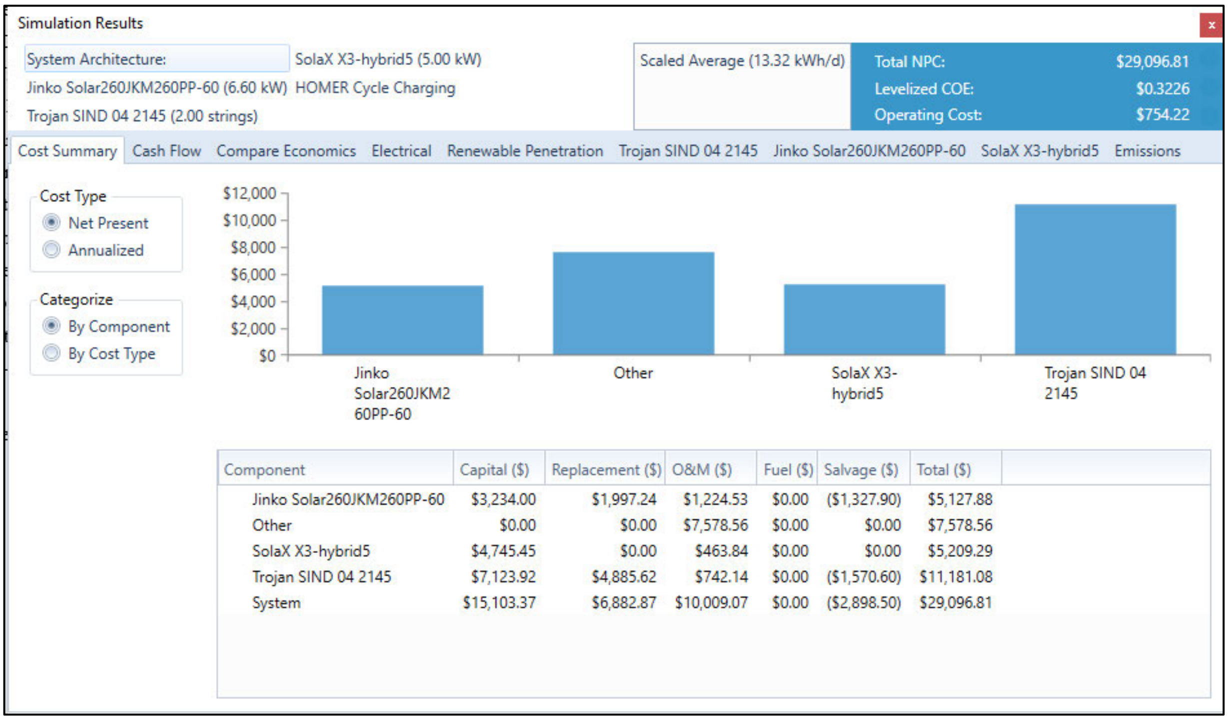
```
% Payback period (multiyear analysis)
% Written by Jason Hooper for the Final year project 133
clc;
clear;
%% Caculations (User input)
Location = 'Toowoomba';
n = 25; % number of years
years = 1:25;
InitialCap = 11541.41; % Initial capital spent
OAM = 484.47; % Operations and Maintenance cost
PV_produced = 11293.0; % kW produced from system
%
AnnualLoad =
[10271,10374,10478,10582,10688,10795,10903,11012,11293,11233,11346,...
11459,11574,11689,11806,11924,12044,12164,12286,12409,12533,12658,12785,129
12,13042];
PV_diff = PV_produced-AnnualLoad;
IR = 5.0; % interest rate
IR = IR/100; % Interest rate calculated
EPurchased  =
[2980,3053,3123,3199,3270,3347,3423,3496,3573,3645,3727,3795,3879,3969,4056
,4135,4220,4307,4394,4485,4574,4662,4760,4861,4942]; %kWh Energy Purchased
ESold       =
[2954,2921,2886,2859,2824,2797,2764,2728,2695,2658,2626,2580,2552,2528,2496
,2457,2423,2392,2357,2325,2292,2253,2226,2200,2155]; %kWh Energy sold
TariffB = 0.2738;
TariffS = 0.0937;
PV_charge = PV_diff*TariffB;
Batt = 3561.96; % Battery replacement cost
Inv = 4745.45; % Inverter replacement cost
PV = 3234; % PV replacement cost
%% Calculations (non-user input)
CPurchased = [0,TariffB*EPurchased];
CSold       = [0,TariffS*ESold];
count = 1; % main count
count1 = 1; % count for PV replacement
SystCost = InitialCap;
while (count<n)
    if(count ==10||count ==20)
    SystCost(1,count+1) = (SystCost(1,count)*(1+IR))+...
        OAM-CSold(1,count+1)+CPurchased(1,count+1)-
PV charge(count+1)+Batt+Inv; % Interest rates
    else
      SystCost(1,count+1) = (SystCost(1,count)*(1+IR))+OAM-
CSold(1,count+1)...
      +CPurchased(1,count+1)-PV_charge(count+1); % Interest rates
    end
    if (count1 == 20)
          SystCost(1,count+1) = SystCost(1,count+1)+PV;
    end
          count1 = count1+1;
              count = count +1; % increment
end
%% Bar graph of results
bar(years,SystCost,'b');
title('Toowoomba Cost of System');
```

Figure 80: Multiyear analysis code (Barcaldine)

```
%System Output Yields
% written by Jason Hooper for FYP 133
clc;
clear;
% Inputting in known parameters for the location being tested
Pstc = 13*10^3;
ftemp = 21.75+35;
ftemp = 1+(-0.42/100*(ftemp-25));
fman = 0.97;
fdirt = 0.98;
Htilt = 5.2;
CableEfficiency  = 1;
InvEfficiency = 0.98;
SwitchboardEff = 1;
%
%% Calculating System Output yields as per CEC guidelines
Esys
=Pstc*fman*fdirt*ftemp*Htilt*CableEfficiency*InvEfficiency*SwitchboardEff;
Esys = Esys*365/1000
```

Figure 81: System Output code (Brisbane)

# Appendix F: Additional Results



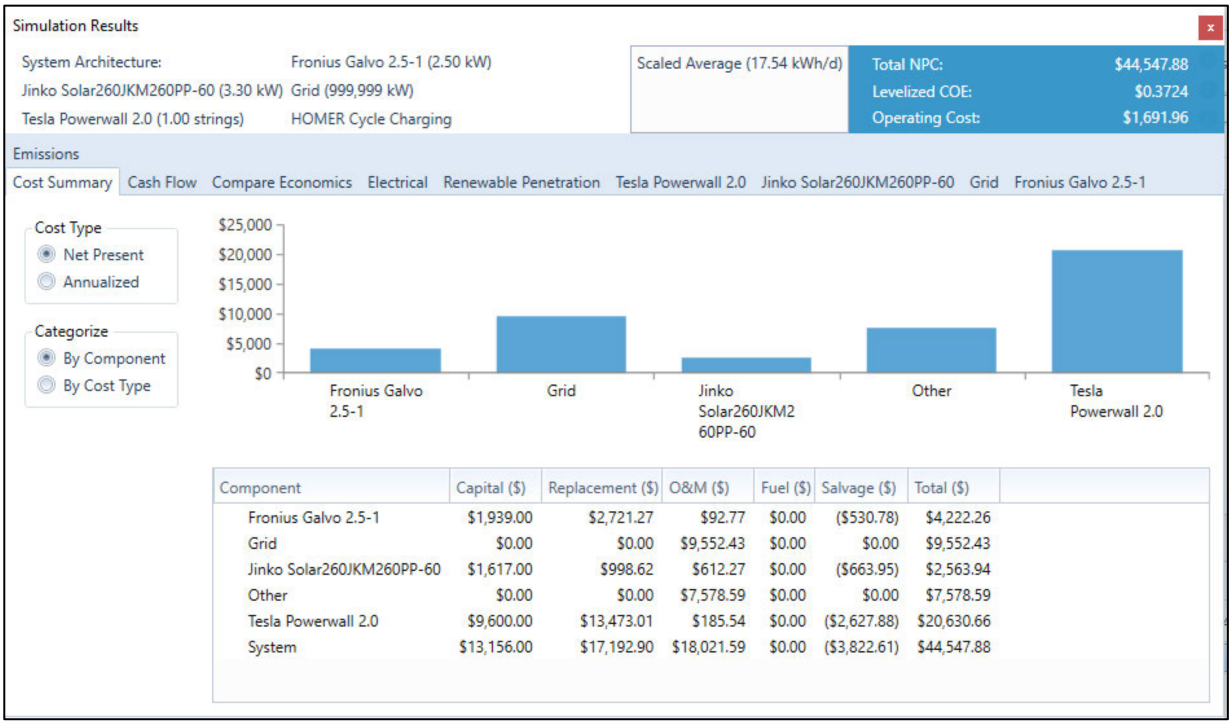
System Architecture: SolaX X3-hybrid5 (5.00 kW)
Jinko Solar260JKM260PP-60 (6.60 kW) HOMER Cycle Charging
Trojan SIND 04 2145 (2.00 strings)

Scaled Average (13.32 kWh/d)

Total NPC: $29,096.81
Levelized COE: $0.3226
Operating Cost: $754.22

| Component | Capital ($) | Replacement ($) | O&M ($) | Fuel ($) | Salvage ($) | Total ($) |
|---|---|---|---|---|---|---|
| Jinko Solar260JKM260PP-60 | $3,234.00 | $1,997.24 | $1,224.53 | $0.00 | ($1,327.90) | $5,127.88 |
| Other | $0.00 | $0.00 | $7,578.56 | $0.00 | $0.00 | $7,578.56 |
| SolaX X3-hybrid5 | $4,745.45 | $0.00 | $463.84 | $0.00 | $0.00 | $5,209.29 |
| Trojan SIND 04 2145 | $7,123.92 | $4,885.62 | $742.14 | $0.00 | ($1,570.60) | $11,181.08 |
| System | $15,103.37 | $6,882.87 | $10,009.07 | $0.00 | ($2,898.50) | $29,096.81 |

Figure 82: Toowoomba 6.6 kW system (Trojan SIND 042145, SolaX 5.0kW)



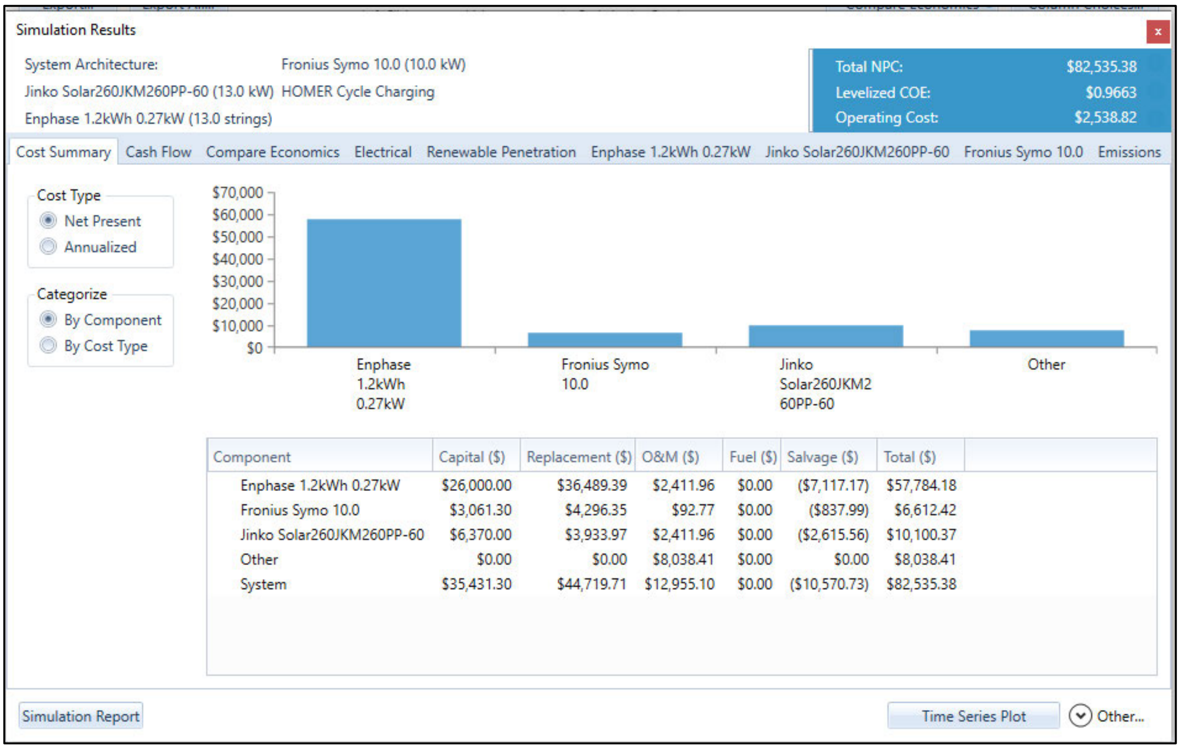
System Architecture: Fronius Galvo 2.5-1 (2.50 kW)
Jinko Solar260JKM260PP-60 (3.30 kW) Grid (999,999 kW)
Tesla Powerwall 2.0 (1.00 strings) HOMER Cycle Charging

Scaled Average (17.54 kWh/d)

Total NPC: $44,547.88
Levelized COE: $0.3724
Operating Cost: $1,691.96

| Component | Capital ($) | Replacement ($) | O&M ($) | Fuel ($) | Salvage ($) | Total ($) |
|---|---|---|---|---|---|---|
| Fronius Galvo 2.5-1 | $1,939.00 | $2,721.27 | $92.77 | $0.00 | ($530.78) | $4,222.26 |
| Grid | $0.00 | $0.00 | $9,552.43 | $0.00 | $0.00 | $9,552.43 |
| Jinko Solar260JKM260PP-60 | $1,617.00 | $998.62 | $612.27 | $0.00 | ($663.95) | $2,563.94 |
| Other | $0.00 | $0.00 | $7,578.59 | $0.00 | $0.00 | $7,578.59 |
| Tesla Powerwall 2.0 | $9,600.00 | $13,473.01 | $185.54 | $0.00 | ($2,627.88) | $20,630.66 |
| System | $13,156.00 | $17,192.90 | $18,021.59 | $0.00 | ($3,822.61) | $44,547.88 |

Figure 83: Cairns 3.3 kW system (Tesla PW2, Fronius 2.5 kW)



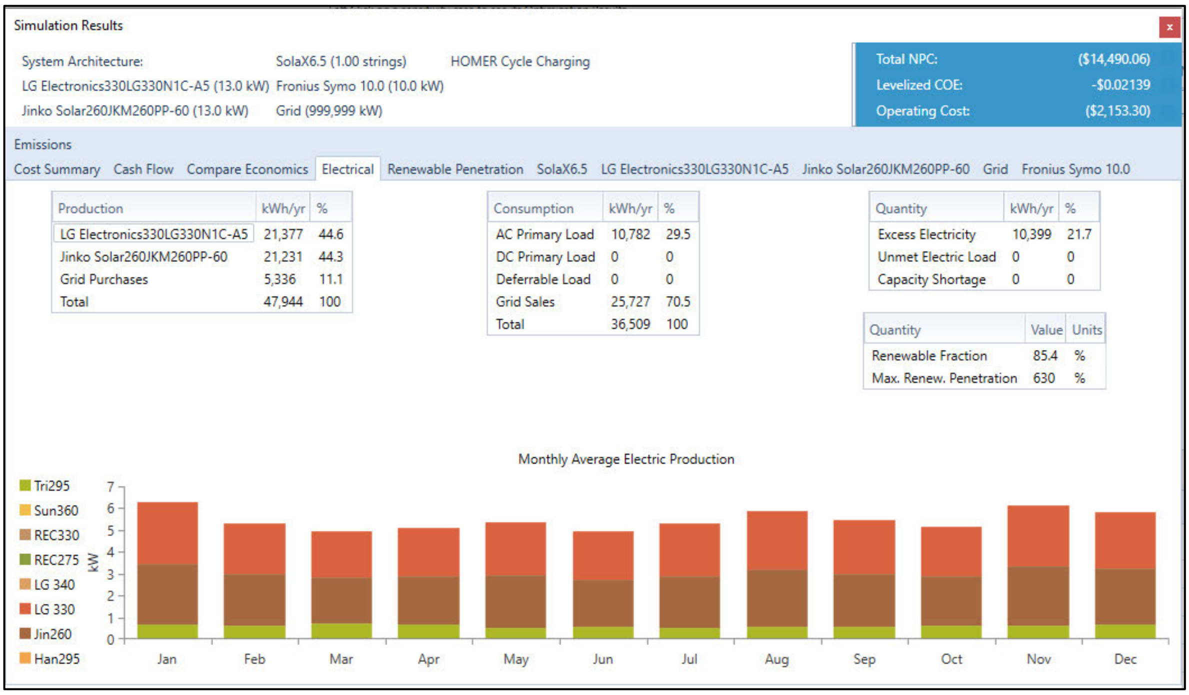
Simulation Results

System Architecture: Fronius Symo 10.0 (10.0 kW)
Jinko Solar260JKM260PP-60 (13.0 kW) HOMER Cycle Charging
Enphase 1.2kWh 0.27kW (13.0 strings)

Total NPC: $82,535.38
Levelized COE: $0.9663
Operating Cost: $2,538.82

| Component | Capital ($) | Replacement ($) | O&M ($) | Fuel ($) | Salvage ($) | Total ($) |
|---|---|---|---|---|---|---|
| Enphase 1.2kWh 0.27kW | $26,000.00 | $36,489.39 | $2,411.96 | $0.00 | ($7,117.17) | $57,784.18 |
| Fronius Symo 10.0 | $3,061.30 | $4,296.35 | $92.77 | $0.00 | ($837.99) | $6,612.42 |
| Jinko Solar260JKM260PP-60 | $6,370.00 | $3,933.97 | $2,411.96 | $0.00 | ($2,615.56) | $10,100.37 |
| Other | $0.00 | $0.00 | $8,038.41 | $0.00 | $0.00 | $8,038.41 |
| System | $35,431.30 | $44,719.71 | $12,955.10 | $0.00 | ($10,570.73) | $82,535.38 |

Figure 84: Enphase 1.2 kWh (Brisbane Small)



Simulation Results

System Architecture: SolaX6.5 (1.00 strings) HOMER Cycle Charging
LG Electronics330LG330N1C-A5 (13.0 kW) Fronius Symo 10.0 (10.0 kW)
Jinko Solar260JKM260PP-60 (13.0 kW) Grid (999,999 kW)

Total NPC: ($14,490.06)
Levelized COE: -$0.02139
Operating Cost: ($2,153.30)

| Production | kWh/yr | % |
|---|---|---|
| LG Electronics330LG330N1C-A5 | 21,377 | 44.6 |
| Jinko Solar260JKM260PP-60 | 21,231 | 44.3 |
| Grid Purchases | 5,336 | 11.1 |
| Total | 47,944 | 100 |

| Consumption | kWh/yr | % |
|---|---|---|
| AC Primary Load | 10,782 | 29.5 |
| DC Primary Load | 0 | 0 |
| Deferrable Load | 0 | 0 |
| Grid Sales | 25,727 | 70.5 |
| Total | 36,509 | 100 |

| Quantity | kWh/yr | % |
|---|---|---|
| Excess Electricity | 10,399 | 21.7 |
| Unmet Electric Load | 0 | 0 |
| Capacity Shortage | 0 | 0 |

| Quantity | Value | Units |
|---|---|---|
| Renewable Fraction | 85.4 | % |
| Max. Renew. Penetration | 630 | % |

Figure 85: Alternative Techniques (Brisbane Large)