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SOLAR PHOTOVOLTAIC AND STORAGE FOR DOMESTIC USE

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Bachelor of Engineering
(Electrical & Electronic Engineering)

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When Alternative energy is no longer an alternative.
-Anonymous

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ABSTRACT

Currently, the largest quantities of carbon emissions produced by any sector worldwide; are from the generation of electrical energy. The call for clean, environmentally friendly and sustainable energy has never been greater. This demand is steadily increasing, which brings the world to the hope and age of green renewable technologies. This is the massive driving force behind the solar industry and the cause of the improvements over the last 50 years, which have been remarkable. The efficiencies and improvements of solar cells, inverters, electronics and batteries have been tremendous. This wave of developments has pushed the cost of electricity down to parity and even lower in at least 19 countries. We are in an era which the electrical industry has never seen before; we are in the era of renewable technologies.

The increasing costs of electricity combined with a greater awareness and exposure to the effects of carbon dioxide emissions, have moved people towards a sustainable energy future. Solar energy is agreeable as it has no security issues or military risk such as nuclear energy. A spill of solar radiation is generally considered an agreeable day. Solar power has the advantages of a long system life-time, generally 25 years with minimal maintenance. A solar system is modular, silent, has an infinite fuel source and zero emissions. The fuel for solar systems does not need to be transported, thus providing additional economic advantages.

This project outlines the need, design, development and verification of a Matlab program, capable of receiving inputs for a solar system's requirements and appropriately sizing and optimising three selectable options for the user. This has a benefit at a household domestic level with electricity savings and the complimentary grid stabilization consequences for Ergon Energy and other electricity suppliers. This is a suitable proposition towards the government, as a margin from the budget each year is directed towards renewable technologies. This thesis is the original framework to create a suitable program and calculate the feasibility of solar technology around Australia. The city of Townsville will be the focus of this project, and it is a very suitable place for solar production as it is situated with a low latitude and large levels of solar insolation. There are currently large-scale production sun farms being built around Australia, and there is potential for the export of this power to other countries.

The need for the current up-to-date estimates and appropriate calculations for the cost and feasibility for solar installations has never been greater. This proposed program hopes to bring to light the availability and the indeed obvious decision to become a clean energy investor and promoter. Recently there have been developments in the solar industry with improved battery energy storage systems coming onto the market. The figures need to be revised and new calculations and modelling are required for the potential use of solar energy in Australia, and particularly, northern parts of Australia and Townsville.

Word Count: 20,105

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LIST OF ABBREVIATIONS AND SYMBOLS

AC	Alternating Current
AEMO	Australian Energy Market Operator
ALCC	Annualised Life Cycle Cost
ANNPMT	Annualised Payment Plan
BES	Battery Energy Storage
CO^2	Carbon Dioxide
DC	Direct Current
DER	Distributed Energy Resource
DOD	Depth of Discharge
DPB	Discounted Payback Period
EPS	Emergency Power Supply
EPBT	Energy Payback Time
F	Frequency
GUI	Graphical User Interface
GHI	Global Horizontal Irradiance
HEV	Hybrid Electric Vehicle
IC	Integrated Circuit
IRR	Internal Rate of Return
J	Joules
kWhr	Kilowatt Hour
LV	Low Voltage
LCC	Life Cycle Cost
MATLAB	Matrix Laboratory
M	Mega
NEM	National Electricity Market
NPV	Net Present Value
O	Outdoor
PSH	Peak Sun Hours
PV	Photovoltaic
PDF	Probability Density Function
RTP	Real Time Pricing
ROI	Return on Investment
STC	Standard Test Conditions
SOC	State of Charge
SPB	Simple Payback Period
SOH	State of Health
V	Volts
WAN	Wireless Area Network
γ	Temperature coefficient
$P_{PV,STC}$	Standard Test Conditions for Photovoltaic panels
T_C	Cell Temperature
I_l	is the photocurrent source
I_{SC}	is the short circuit current at 1,000W/m2 and 25 degrees Celsius
T_s	is the surface temperature of the solar cell
S_i	is the irradiation incident on the solar cell

LIST OF APPENDICES

1 INTRODUCTION

Electrical Energy has become a crucial element for human living and is essential for both social and economic development of a country states Vijayalashimi[1]. It is utilised directly or indirectly in every facet of human life. From study, occupation, education to entertainment, the ability to transform electrical energy into products and desired functions is a growing necessity. Shafiee and Topal have estimated the world's energy market to be approximately 1.5 trillion dollars, and explained that it is still dominated by fossil fuels [2]. The world's population doubled from 1927 to 1974, yet this occurred again in the following 25 years (to 1999). Cohen emphasized that until this century, people had never lived through a population doubling, yet nowadays people are living through a tripling. Over 2 billion people have arrived in a single generation [3].

With the estimated population by the United Nations Population Division expected to reach 9.5-13 million by 2100, the stakes have never been so high for the supply of clean, efficient and stable electrical energy [4]. The world's energy consumption is approximately 10 terawatts per year and is expected to rise to 30 terawatts by 2050 [5]. Kannan wrote that one of the greatest goals of the 21st century is simply being able to prevent a world energy crisis, due to the demand of a rising population. [6]

1.1 Overview

The sources of this grand supply of energy must be of high quality, dependable and above all ethical. Currently, 10 Giga-tonnes of carbon dioxide is produced each year as fossil fuel emissions (as a by-product of electricity production), and it remains the largest single sector emitter [7]. In the wake of global warming and carbon emissions figures, the demand for green renewable energies has grown exponentially.

The breakdown of energy from sources can be seen in Figure 1-1. The "green" energies wind, geothermal, wave, hydroelectricity and solar are now in their greatest demand, due to their ability to produce power and their minimal to non-existent carbon footprint. Valentine's studies show that the installed wind power alone since 2000, throughout the world has doubled every three years [8].

The solution to the energy crisis is renewable energies. In particular solar is ideal as it is clean, free, theoretically unlimited, long lifetime technology, accessible, and environmentally friendly [9]. Therefore, in several countries including Australia, feed-in tariffs for Photo-Voltaic (PV) have been significantly subsidized to augment and incentivize the installation, technological advancement and use of such systems. From the start of the new millennium Australia's PV capacity rapidly increased, establishing itself as the 7th global market for PV and introduced one of the world's first renewable energy target schemes in 2001 [10].

In 2013 Australia, had over a million roofs with operating PV systems. This is due to Australia having the highest average solar radiation, sensitivity over sustainability, subsidized rebate

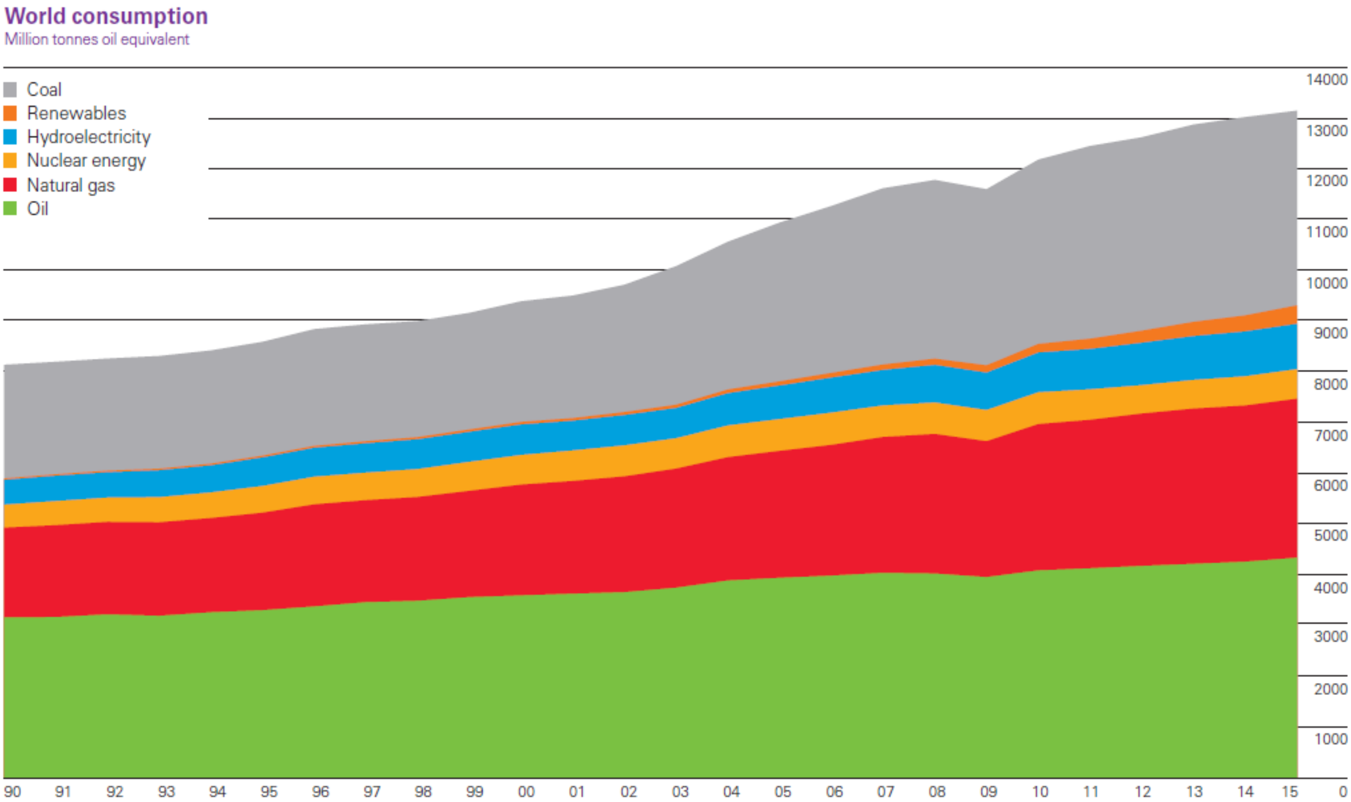

***Figure 1-1** - Worlds Energy Consumption by Source (Million Tonnes Ore Equivalent Vs. Year) [7]*

schemes, increasing electricity prices and substantially decreasing install costs. Ma demonstrated the decreasing costs from $9000/kW AUD in 2009 to $2130/kW in 2013 [11]. These feed-in tariffs from consumer based production arising from increased distributed PV sources have caused disruption for the medium/low-voltage networks through induced voltage rises. These voltage rises are from reverse power flow along the feeders from the inverters. With the inverters there is also concern for harmonic pollution from PV [12].

This implication for production and effects on the network have caused changes to be made to Australia's National Electricity Market (NEM) and state schemes for use of solar PV energy [13]. Due to the incompatibility between PV production and load-demand there is a minute potential for self-consumption. Appen and Braun show that to achieve a greater amount of self-consumption the battery energy storage (BES) systems can be utilised [14]. Hence, BES systems can be designed to reduce strain; adverse load profiles and voltage rises on the network while smoothing the grid integration and ultimately aiming towards off-grid standalone domestic systems.

An upshot of a standalone or hybrid system is that the user does not lose power when the grid does. Appen noted there was missing information and that the current requirements for sizing, performance and control need to be analysed and simulated both from technical and economical perspectives [15]. In response Ergon Energy (Queensland's Electricity Provider) is anticipating the effectiveness of the BES systems and planning revision of their tariff schemes.

1.2 Research Aims

The aim of this project is to develop a program in the Matlab workspace to size and optimise PV/BES systems for different configurations of household demand to maximize savings and disruptive outputs to the LV grid network. The investigation into the estimated production capabilities of the lower latitudes receiving higher PSH to the kWhr production per day for a given PV system will be analysed. The calculation of the cost of electricity for a domestic situation from a PV/BES system and up-front capital and lifetime payback will be modelled.

Households with combined installation of PV/BES in each location will be analysed for their reduced cost of electricity per kWhr in respect to the Australian benchmark cost. The annual payment costs of a PV/BES system will be modelled for economic feasibility in the mortgage climate rates of optimistic, likely and pessimistic at different latitudes. All simple payback periods over the project lifetimes will be assessed for net savings compared to investment cost.

1.3 Scope

Photovoltaic systems have been around for just over 50 years and their daily use and efficiency is increasing. Farmer & Lafond proposed that PV is expected, with its rapid refinements to surpass its competition in the upcoming 10-20 years [16]. Now with the introduction of BES system technologies and their decreasing costs it is a logical path for domestic energy consumers who are conscious of pricing and environmental factors.

This project will only deal with domestic PV installations. It is beyond the scope to deal with anything larger than a general domestic sized PV installation usually with a maximum capacity of 10kW. Residential households will be assessed and modelled disregarding other commercial or industrial applications, although with a working model extrapolating to other applications is possible. The different tariffs schemes throughout the world and indeed Australia will not be analysed; although the models can be applied to other tariffs schemes. The tariff schemes currently in use by Townsville's energy supplier Ergon Energy will be used. The standard consumer type solar panels will be used and not advanced super solar panels, organic, off market or other configuration tracking panels.

When referring to solar power in this paper it will be meant solar photovoltaic energy power. This paper will not deal with other forms of renewable energy or other solar energies such as solar concentration energy but principally with solar photovoltaic energy production. The term solar system will refer to the entire systems incorporating solar PV panels, the DC to AC inverter and the battery bank or BES system and no other configurations. For clarification, one cell is P-N junction. Many cells make a module (generally 36 or 72) and usually 10 or 20 modules make an array. A solar system may have one or two arrays; any panel combined with an inverter is considered a solar system in this paper. The inverter will be a grid-tie, battery backup inverter or stand-alone inverter system; all three applications will be dealt with. The battery systems described will not include lead acid batteries but instead focus on lithium ion batters such as the Tesla Powerwall and LG Chem RESU and Zinc Bromide batteries such as ZBM 2 by Redflow. The solar irradiance for Australia and principally Townsville will only be analysed.

2 LITERATURE REVIEW

This literature review examines the current and relevant literature regarding PV systems, tariff schemes, solar-related economics, sizing, current technologies, modern programs for analysis and BES systems. It will give an insight into the operation and basic understanding of why these systems are starting to dominate the electrical industry. It will identify areas where the literature is unsubstantiated or incomprehensive. The key areas which do not have sufficient data or analysis will be examined. It is important to identify these gaps, as they have the potential to decrease carbon emissions, increase stability on the grid, and save the average domestic electricity consumer thousands of dollars.

2.1 Background

The recent doubling of the world's population has caused concern around the globe. The cry to slate increased energy demands has been met with unsubstantiated claims. The electrical energy sector is turning towards clean, ethical, dependable energy sources. The renewable energy industry has had massive growth in the past few decades. But with the dependability of renewable energy being called into question due to the power crisis in South Australia in February this year (2017), which left over 90,000 people without power. The move to justify and improve renewable energy technology has never been so evident.

In the fallout of the SA blackout, the necessity to make renewable technologies more reliable and less disruptive to the grid is being researched. This review gives a general background of PV systems, how they have developed and their various types. Consequences of PV systems are then explored in load profiles, PV rise, tariffs and the rebate schemes. It will explore how electricity is charged to the consumer and sold to the supplier. The solar irradiance is examined and current market programs for the sizing and analysis of solar systems. The effects of shadowing and PV payback studies are all explored. The BES system is then explained, including its ramifications for the network and potential augmentation to the network discharge. New and emerging technologies will be noted and met with speculations of their effect on the electricity market and their benefits for consumers.

Finally, the economics of using the system and current developing technologies are reviewed. With this basis, the gaps in the literature will be identified, examined and evaluated. This review was written principally from primary sources published in reputable peer-reviewed journals. Secondary sources were used for compilation of ideas, some graphics and themes but were endeavoured to be used as a guide and referenced against the primary sources. Grey literature for this literature review was not used in any of the references.

2.2 Solar System Synopsis

The modern solar systems which will be the main premise of this thesis will deal exclusively with solar PV systems which are comprised of three primary components: the solar panels, the DC to AC inverter system and the battery energy storage system. The Figure 2-1 below shows the operation of solar system with the export and import of power to the grid and the conversion of DC to AC for coupling with the grid and household consumption [17].

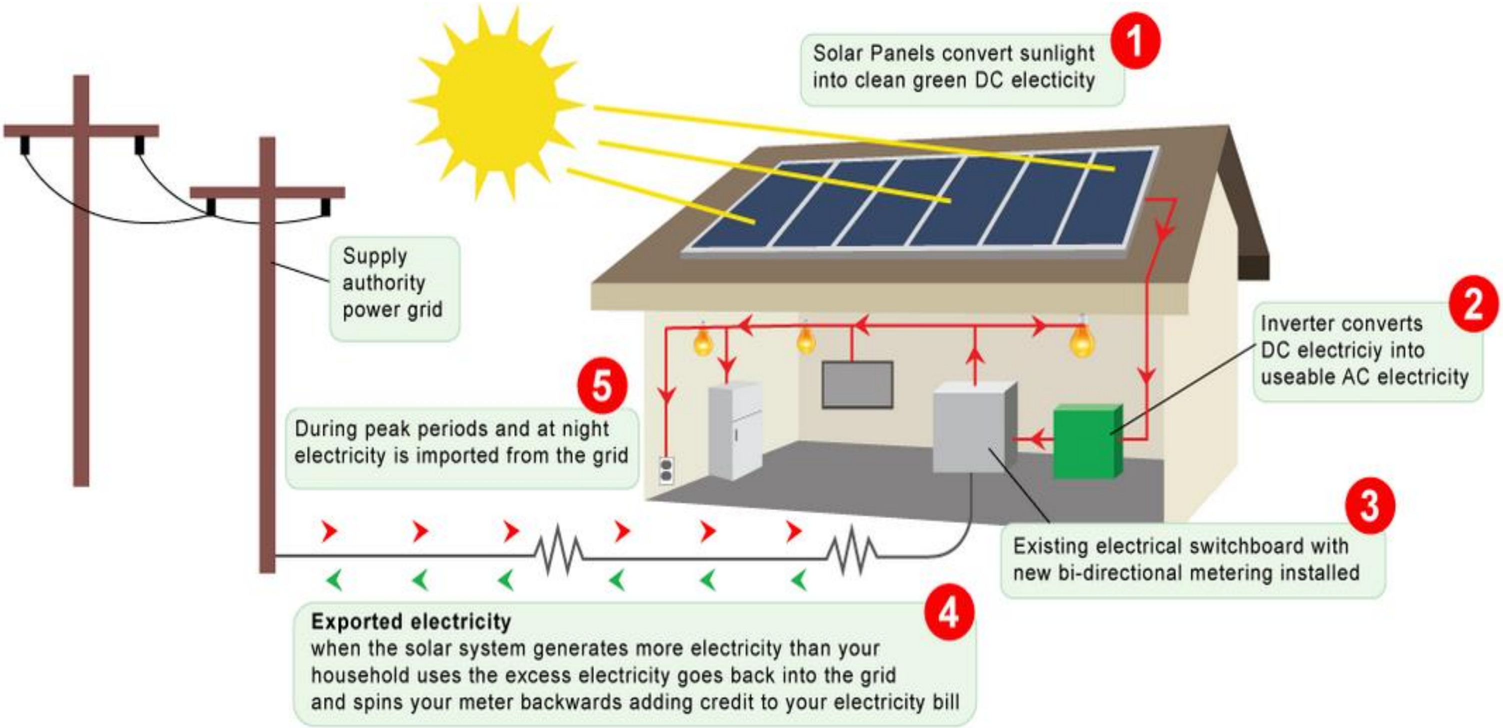

Figure 2-1 - Overview of Operation of Solar System [17]

The solar panels convert solar radiation from the sun into DC electrical energy. This DC current then flows into the inverter system. The inverter is designed to convert DC power into AC power. Usually, the inverter (in a hybrid system) is connected to the mains power for coupling with the feed frequency i.e. 50Hz. The Power is then fed from the inverter system to the house for use. The excess power which is produced during the day is fed back into the grid through a bi-directional meter to measure the different tariff rates for import and export. Each component of the solar system will now be discussed in greater depth.

2.3 Photovoltaic (PV) Systems

2.3.1 Review of PV

Every day there is approximately 100 000 terawatts of energy provided by the sun. Currently, the Earth's energy demand is 10 000 terawatts; Grätzel emphasized that this is a 10 time surplus. [18] There is a way to tap into this vast energy source and that is with the humble solar panel. The solar panel or photo-voltaic panel is a device which converts light energy into electrical energy. The word "photovoltaic" which originated in 1849 came from the Greek word "Phos" meaning "light" and from the English word "volt" (which is) a measure of electro-motive force. The photovoltaic effect was first observed in 1839 by French physicist A. E Becquerel [19].

A Photovoltaic panel or PV panel or solar panel is any solid state electrical device which converts light energy to electrical energy by using the photovoltaic effect. Solar panels consist of a simple PN junction which is a P-doped layer and an N-doped layer. Both layers usually consist of Silicone with the P (positive) layer being doped usually with Boron or Gallium and the N (negative) layer is doped with usually Phosphorus or Lithium [20]. Light which arrives from the sun comes in the form of photons and can do one of three things once it reaches the PN junction.

Firstly, they can pass straight through; which lower energy photos usually do. Secondly, they can reflect off. Thirdly, they can hit the electrons in the silicon and move them out of their current orbital up to a higher energy band as seen in Figure 2-2. These electrons can either convert the energy to heat and return to their original orbital or travel through the cell until they reach an electrode. This flow of electrons is photo current flow and is the electricity produced by a solar cell. If many solar cells are connected in series they form a solar panel or module [21].

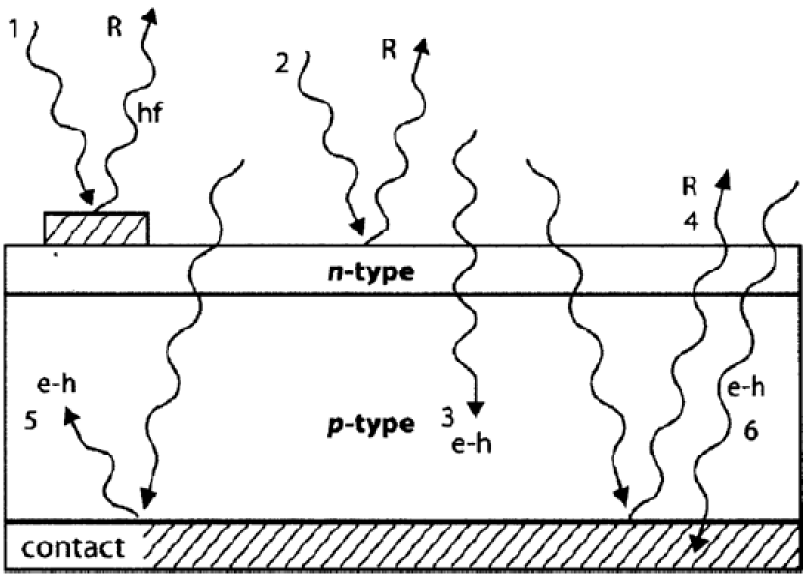

Figure 2-2 - Behaviour of light shining on a solar cell. 1/2/4/5.) Reflection 3/6.) Absorption [21]

The generation output for a solar cell is dependent upon many variables such as Global Horizontal Index (GHI), temperature data and the type of PV cell or module. The following equation is used to calculate PV generation [22]:

$$P_{PV} = \frac{P_{PV,STC} * GHI[1 - \gamma(T_C - 25)]}{1000} * N_{PV,S} * N_{PV,P} \tag{2-1}$$

Where:

- $P_{PV,STC}$ – is the solar output under STC (See below for definition)
- GHI – Global Horizontal Irradiance
- γ – is the temperature coefficient (generally -0.41%/°C)
- T_C -is the cell temperature
- $N_{PV,S}$ & $N_{\mathrm{PV},P}$- are determined by the system design.

Standard Test Conditions (STC) for the performance of PV modules is an industry-wide standard and specifies a cell temperature of 25°C and an irradiance of 1000 W/m2 with an air mass 1.5 (AM1.5) spectrum. These conditions correspond to the irradiance and spectrum of sunlight incident on a clear day upon a sun-facing 37°-tilted surface with the sun at an angle of 41.81° above the horizon at sprint and autumn equinoxes in the US [23].

2.3.2 Types of PV

There are many solar cells which make up solar panels or modules. The different types of cell material and configuration are what create the different types of solar panels. Below is a list of the most common types of cell arrangement:

- Amorphous Silicon solar cell (a-Si)
- Concentrated PV cell (CVP and HCVP)
- Crystalline silicon solar cell (c-Si)
- Multi-junction solar cell (MJ)
- Nanocrystal solar cell
- Perovskite solar cell
- Photo-electrochemical cell (PEC)
- Plasmonic solar cell
- Polycrystalline solar cell (multi-Si)
- Thin-film solar cell (TFSC)
- Organic solar cell (OPV)

The main types of solar panels in use in the domestic sector are shown above in Figure 2-3 and are Monocrystalline, Polycrystalline and Thin Film Silicone. The classification of solar panels is shown in Figure 2-4 below.

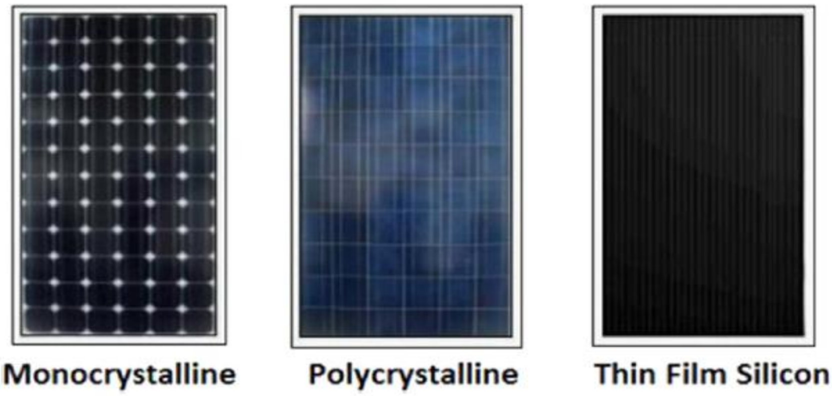

Figure 2-3 - Photovoltaic Panel Types [21]

The main difference between monocrystalline and polycrystalline is that for the same wattage polycrystalline is slightly larger than monocrystalline. Thin Film panels are larger than both Monocrystalline and Polycrystalline.

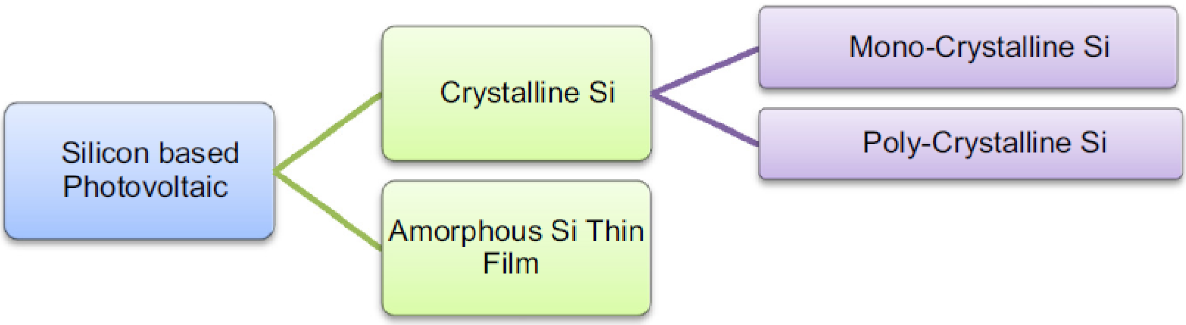

Figure 2-4 - Classification of the silicon PV panels. [21]

2.3.3 Growth of PV

Moore's Law is a Law well-known to the semiconductor industry. This law observes that approximately every two years the number of transistors on an integrated circuit (IC) will double. What Moore is to the semiconductor industry, Swanson is to the PV industry. Richard Swanson in the 1970's observed that for every doubling of global shipments the price for solar photovoltaic modules drops by 20%. The decrease in cost is due to the scale of materials needed i.e. silicon prices dropped and decreased cost of labour due to automation of processes [24]. The below ***Figure 2-5*** trends the decrease in PV modules. From the Figure 2-5 it shows that the cost in 1976 was approximately 100.00$/W and in 2014 it is approximately 0.80$/W.

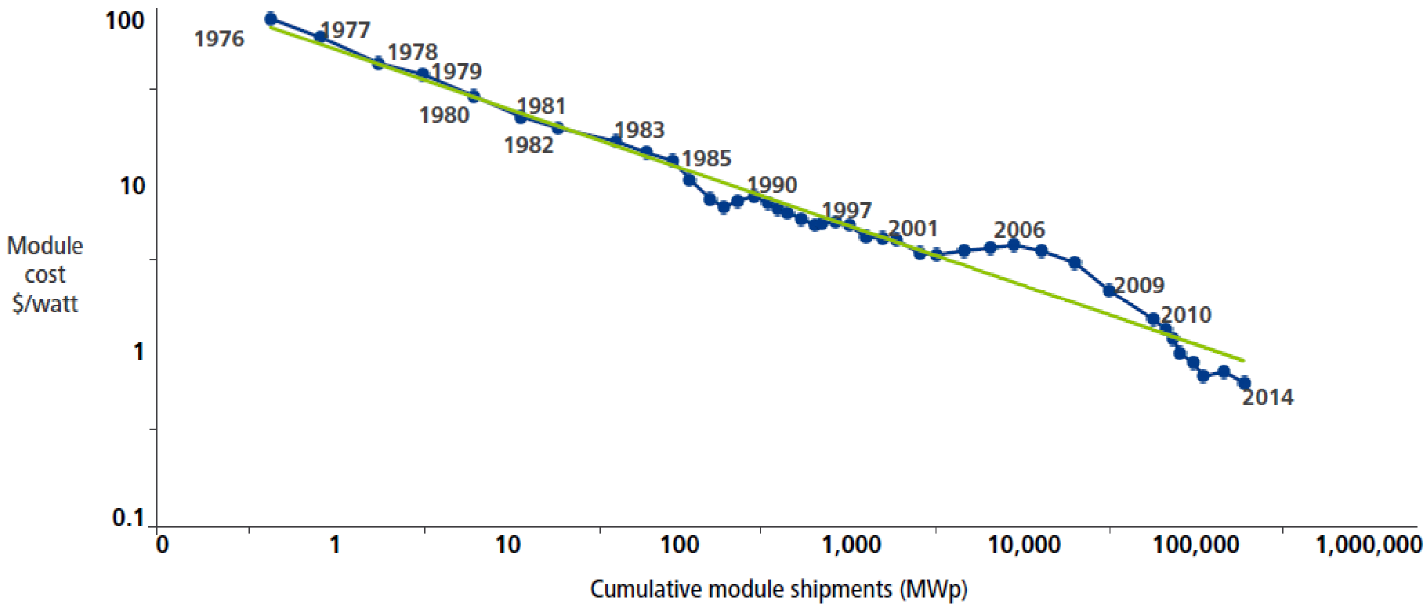

Figure 2-5 - Swanson's Law: Module costs decline as shipments increase [23]

The massive growth in renewables is borne from an economic shrewdness and increasing sensitivity to sustainability and greenhouse gas emissions. The increasing price of electricity and the non-existent cost of fuel for renewable technology contribute to the growth of renewables. The magnitude of the growth of renewables can be seen on the below Figure 2-6 which compares renewables to other sources of energy [25].

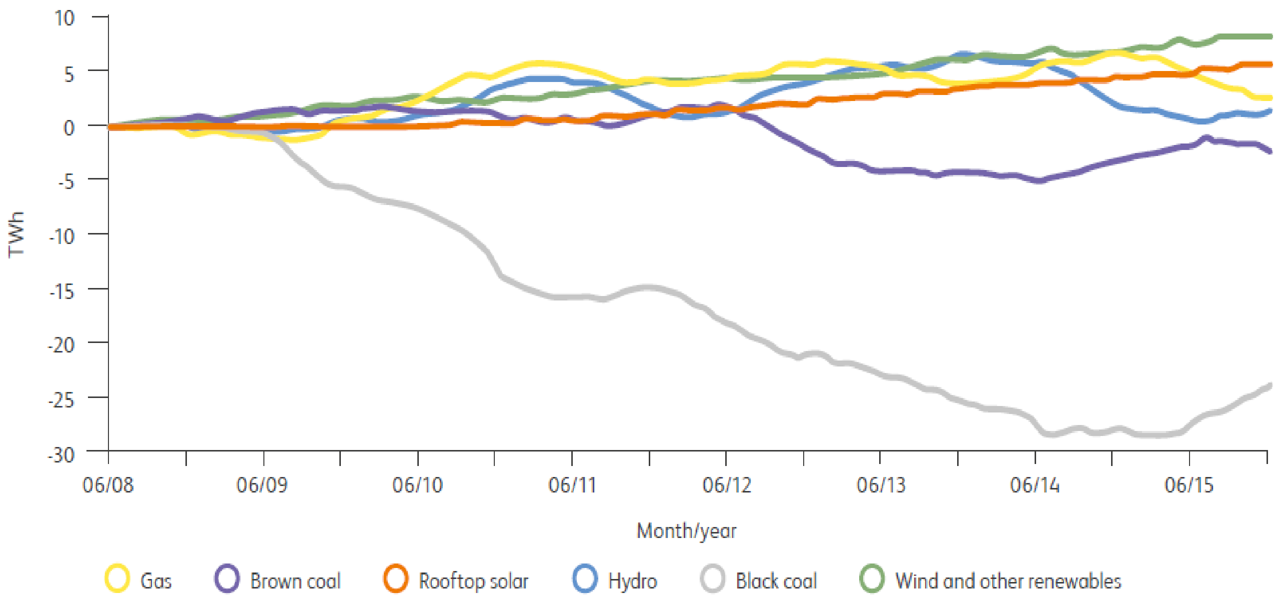

Figure 2-6 - Changes in Electricity Generation by Fuel type [24]

The renewable energy industry is growing substantially each year and is comprised of wind, solar PV and solar concentration, wave, geothermal, bio and hydroelectricity. This paper will principally comment on solar photovoltaic technologies. In the below Figure 2-7, which trends the last decade of growth for PV production from 5.1GW to 227 GW in 2015. This clearly demonstrates the growth of PV technologies all over the world [26].

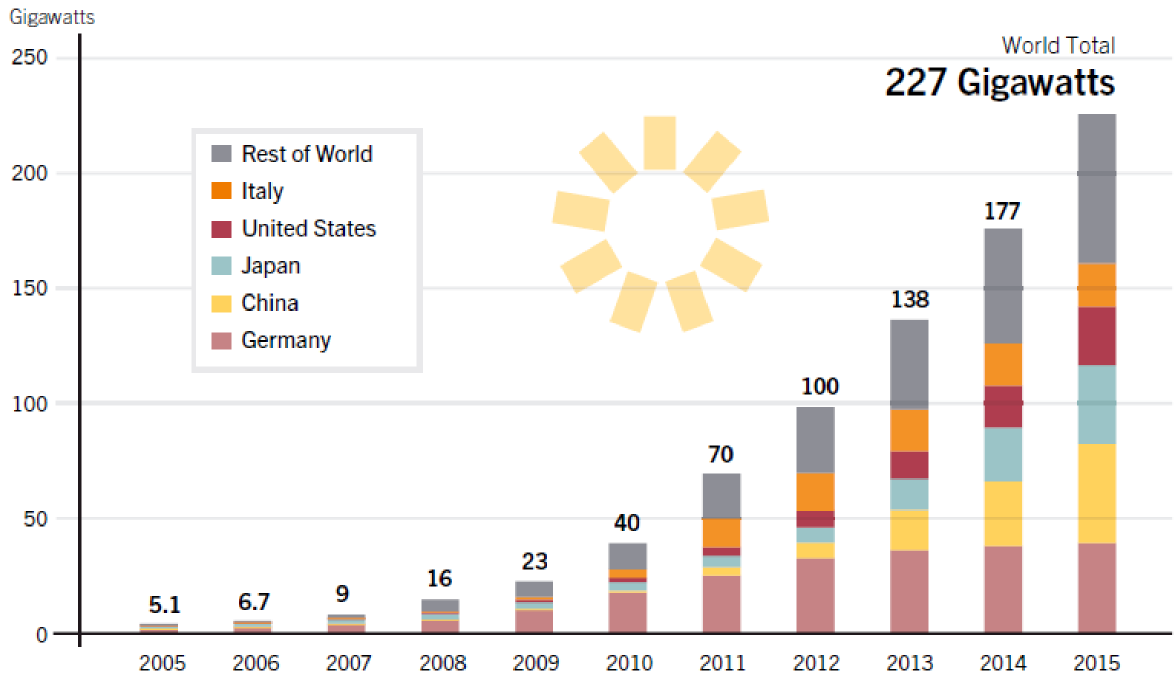

Figure 2-7 - Solar PV Global Capacity, by Country/Region, 2005-2015 [25]

The growth in solar PV is occurring all over the world and Australia has seen huge increases in the amount of solar installations. The Figure 2-8 below shows the amount of installations per year in Australia. The peak noted in the years 2011 and 2012 were due to the rebate programs [25].

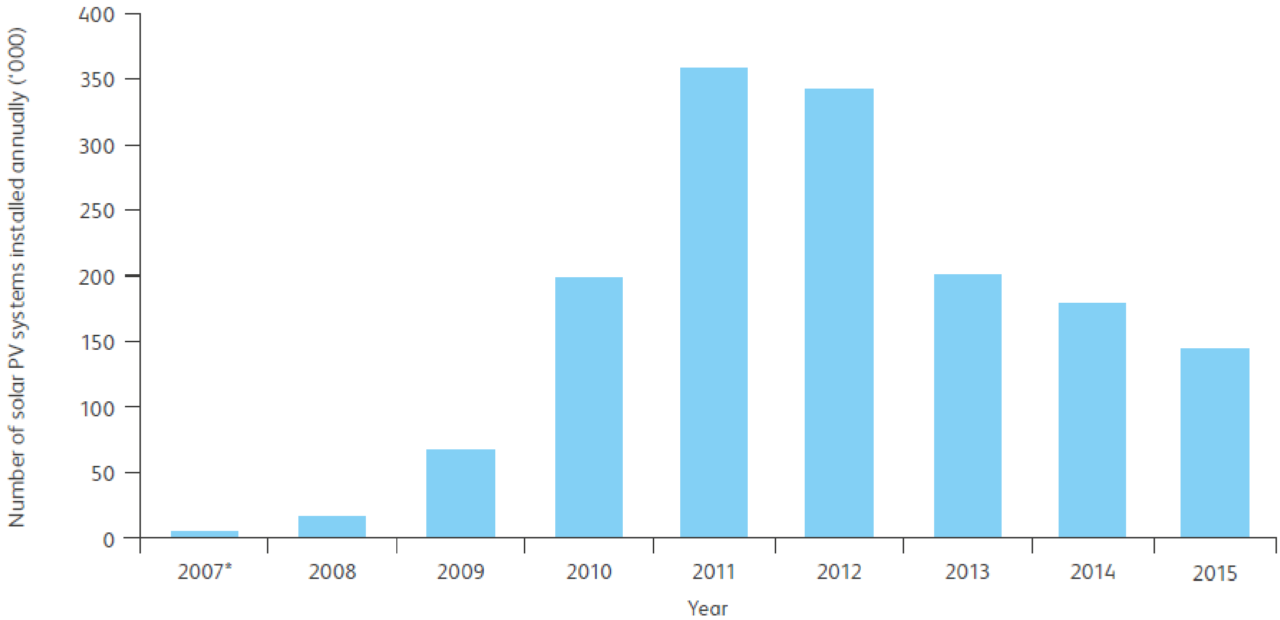

Figure 2-8 - Annual Solar PV Installations in Australia [24]

While the amount of installations has started to decrease, the size of the installation has increased. The Figure 2-9 below shows that the average kW capacity of the systems installed has increased and is due to price decreases and better technology [25].

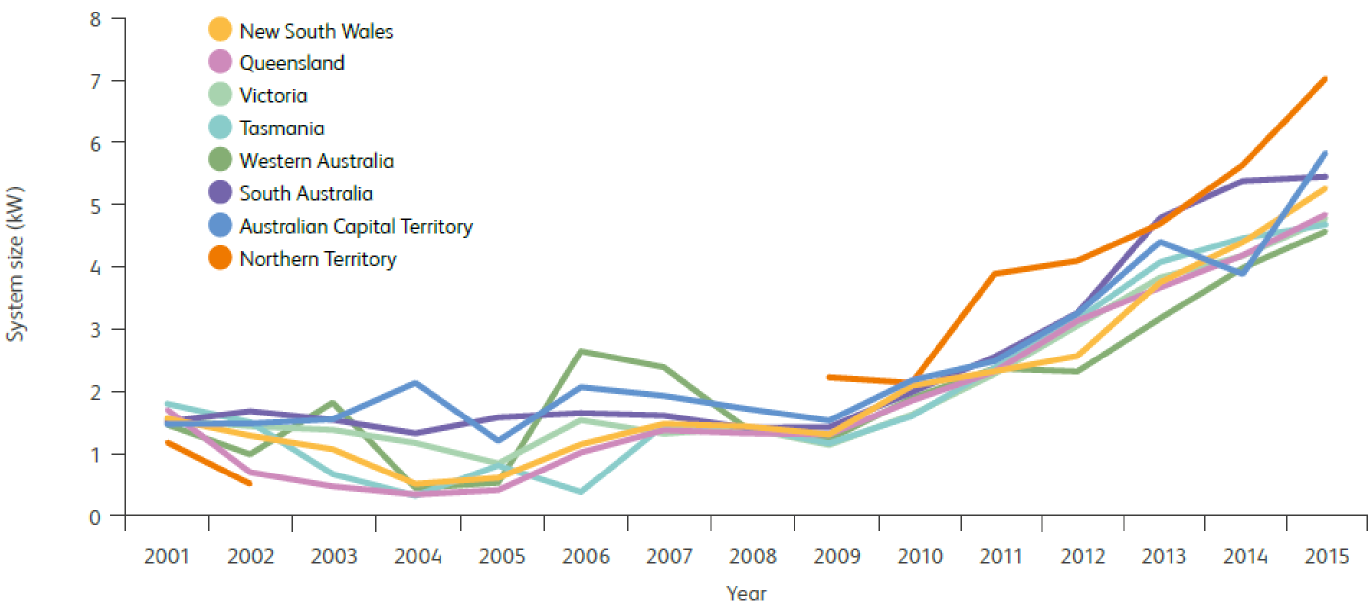

Figure 2-9 - State Average Solar PV System Size (kW) [24]

The renewable energy trend has allowed Queensland to generate 4% of its electricity from renewables, with two wind farms and 466,966 domestic solar systems [25]. Onat has highlighted in Table 2-1 below the advantages and disadvantages of PV systems [27].

Table 2-1- Advantages and Disadvantages of PV Systems [27]

<table>
<tr><th>Advantages of PV</th><th>Disadvantages of PV</th></tr>
<tr><td>Fuel source is vast and essentially infinite</td><td rowspan="2">Fuel source is diffuse (sunlight is relatively low-density energy)</td></tr>
<tr><td>No emissions, no combustion or radioactive fuel for disposal (does not contribute perceptibly to global climate change or pollution)</td></tr>
<tr><td>Low operating costs (no fuel)</td><td rowspan="3">Low conversion efficiency <40% for commercial applications</td></tr>
<tr><td>No moving parts</td></tr>
<tr><td>Ambient temperature operation</td></tr>
<tr><td>High reliability in modules (>20 years)</td><td rowspan="3">Poorer reliability of auxiliary (BOS) elements including storage</td></tr>
<tr><td>Modular (small or large increments)</td></tr>
<tr><td>Quick installation</td></tr>
<tr><td>Can be integrated into new or existing building structures</td><td rowspan="2">Initial investment sum</td></tr>
<tr><td>Can be installed at nearly any point of use</td></tr>
<tr><td>Daily output peak may match local demand</td><td rowspan="3">Lack of economical efficient energy storage</td></tr>
<tr><td>High public acceptance</td></tr>
<tr><td>Excellent safety record</td></tr>
</table>

2.3.4 Efficiency of PV

The photovoltaic cell is the technology which is rapidly improving. The first solar cells had less than 1% efficiency and in the 1950's the Si cells had around 6% efficiency [28]. Currently Si crystalline has 25.6% efficiency while the best solar cell is InGaP/GaAs/InGaAs with 37.9% efficiency [29]. The below Figure 2-10 shows the trending increase in efficiency for solar panels.

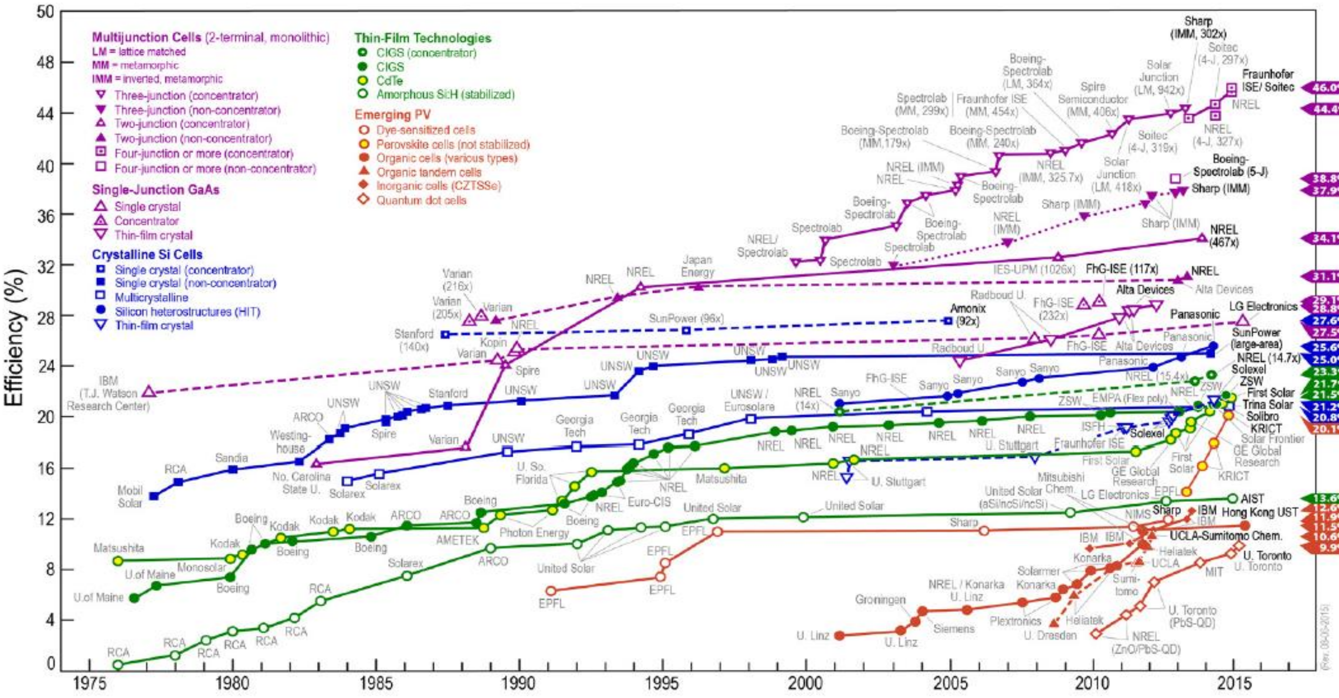

Figure 2-10 - Best Research-Cell Efficiencies, 1976-2015 [28]

While the efficiencies of PV are undoubtedly increasing with it is important to mention the detrimental performance of PV over its lifetime. Shamra wrote that PV experiences a continuous degradation due to aging [30]. A study by Meyer & Dyk reported that after an initial exposure of 130 sun hours, the performance of the CIS module degraded by more than 20%. That a-Si module degraded by about 60%, and the a-SiGe module degraded by approximately 13%. They mentioned that crystalline EFG-Si and mono-Si modules showed no degradation [31].

These percentages are quite ranging, while a study by Jordan & Kurtz in 2013 after an extensive study on relatively newer solar panels contested the findings in 2004 by Meyer & Dyk. Jordan & Kurtz stated the distribution is skewed toward high degradation rates with a mean of 0·8%/year and a median of 0·5%/year. They reported on the degradation rates on flat plate terrestrial modules recorded in literate from testing for the most recent four decades. The study spanned 2000 degradation rates and the data showed the median value of 0.5%/year [32].

In the most recent study for the trending increases of efficiency for PV technology conducted by Sampaio and Gonzalez in 2017 the Figure 2-11 below was produced [19].

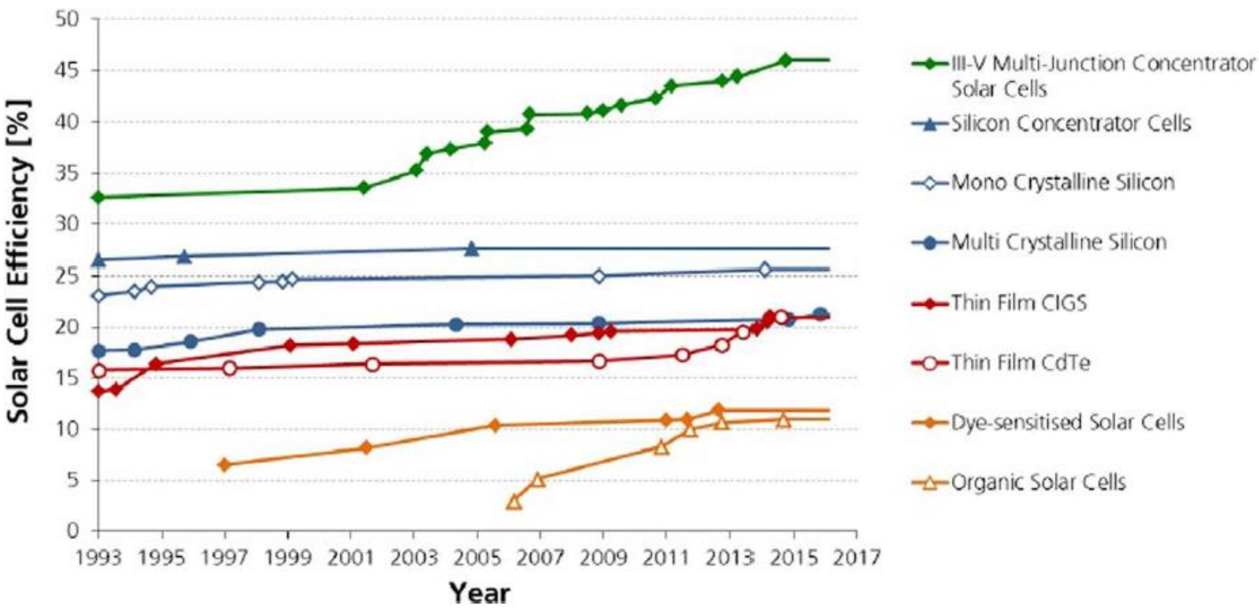

Figure 2-11 - Solar Cell efficiency [19]

2.3.5 Modelling of PV

As mentioned previously solar cells are PN junctions which can be reduced to an electrically equivalent solar cell model of a single diode, dependant current source and resistors as shown in the below Figure 2-12. The voltage drop over the diode depends on the type of material which is used to construct the solar cell. Silicone Crystalline cells have 0.74 V, Thin Film (GaAs) have 1.122 V and Silicone Amorphous have 0.896 V forward biasing drop [29].

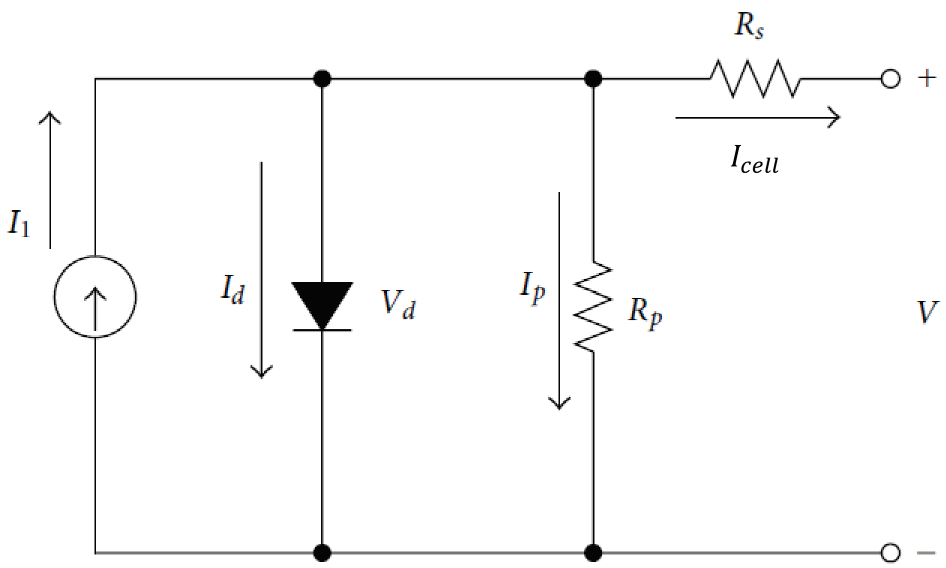

Figure 2-12 - Equivalent Circuit of a solar cell [28]

The incident energy in the form of photons from the sun are converted into photocurrent which is the current source I_l. The electrons in the valence band are given energy from the photos and "jump" up to the conduction band producing a current [33, 34].

The total current which flows out of the solar cell can be calculated by Kirchhoff's Current law at the top node: [35]

$$I_{cell} = I_l - I_d - I_p \tag{2-2}$$

Where:

- I_{cell} - is the current flowing out of the cell
- I_l - is the photocurrent source
- I_d - the diode current
- I_p - the current flowing through a parallel resistor caused by a flowed P-N junction

The current produced by the photocurrent source is given by the equation:

$$I_l = [I_{SC} + k_i(T_s - T)]\frac{S_i}{1000} \tag{2-3}$$

Where:

- I_l - is the photocurrent source
- I_{SC} - is the short circuit current at 1,000W/m^2 and 25 degrees Celsius
- T_s - is the surface temperature of the solar cell
- S_i - is the irradiation incident on the solar cell
- k_i - is the temperature modification coefficient for the short circuit current

In Baetens studies he utilised the formula below derived from Figure 2-12 for the instantaneous power produced by PV [33-35]:

$$P_{PV,ins} = I_{cell}V \tag{2-4}$$

$$I_{cell} = I_L - I_0\left[exp\left(\frac{V+I_{PV}R_S}{a_{ref}}\right) - 1\right] - \frac{V-I_{PV}R_S}{R_{sh}} \qquad \textbf{(2-5)}$$

Where:

- P_{PV} - is the instantaneous power produced by the cell
- I_{cell} - is the current produced by the cell
- V - is the voltage of the cell
- I_L - is the light generated current
- I_0 - is the reverse saturation current of the diode
- R_s - is the series resistance of the cells
- R_{sh} - is the shunt resistance of the cells
- a_{ref} - is the modified ideal factor for compensation of second-order effects depending on the cell

The above formula is for the calculation of instantaneous power. The sunlight which drives the independent photocurrent source is continually changing. The variable is the sunlight and it can be modelled using a probability density function (PDF) or measured and averaged. The average solar irradiance measurements are discussed later. Barrios acknowledges that the most common models are the Beta, Weibull, Log-normal and Gamma-Gamma distributions [36]. Instead Borowy in his calculations for average power used the Beta and Weibull functions with the formula [37]:

$$P_{PV,avg} = \int P(S) * f(S).dS \qquad \textbf{(2-6)}$$

Where:

- P_{PV} - is the average power produced over the time-period of integration
- f(S) - is the irradiance probability density function

While Borowy used the probability function to calculate the average power produced per period. Zahedi used the formula below to calculate the production of kilowatt hours (kWhrs) of energy produced for a solar system. This formula uses the calculated solar irradiance for a given region [38]. The peak sun-hour is an hour in which the sunlight intensity is 1,000 watts per square meter. This is converted from the Joules per day of solar irradiance to kilowatts and divided by the 1000 watts per square meter [27].

$$P_{PV,avg}(kW) = size(kW) * PSH * PR \qquad \textbf{(2-7)}$$

Where:

- P_{PV} - is the average power produced in kWhr
- $size$ - is the size of the system in kW
- PSH - are peak sun hours
- PR - is the production rating and is usually less than 1 due to manufacturers tolerances, dust and dirt and temperature

2.3.6 Effects of Shadows on PV

Solar cells are generally installed on rooftops and facades in the domestic environment. This type of solar cell mounting will generally become partially shaded at points during the day. The shading of one solar cell in a string becomes an issue as this cell can enter into a condition known as reverse bias and cause heating issues [33-35].

When a solar cell becomes shaded it stops being forward biased, stops producing current, it "turns off" and current stops flowing. This unbiased condition effectively produces an open circuit. This is normally not an issue but solar cells are serially connected into a string with each cells voltage being summed to produce the total voltage output of the string [39].

$$I_{substring} = I_{cell} \tag{2-8}$$
$$V_{substring} = N_s * V_{cell} \tag{2-9}$$

Where:

- N_s - is the nth-number of cells in series uniformly irradiated

Therefore, if we have a module comprised of 60 Silicone polycrystalline cells with an open circuit voltage of 0.6626 connected serially we would expect [29, 40][29, 40][29, 40][29, 40][29, 40][28, 36]:

$$V_{substring} = N_s * V_{cell}$$
$$V_{substring} = 60 * 0.6626$$
$$V_{substring} = 39.75$$

Referencing the datasheet for a standard 250W GEM Series Solar Module from Sapphire Solar with 60 cells of Polycrystalline Silicone the Open circuit voltage is 37.1 volts [38][36]. This is within three volts of what we expect and demonstrates the series connected system. There will be some losses due to connections. The voltage for the forward biasing of a silicone cell is shown for 33 samples in the below Figure 2-13. This shows the reverse breakdown voltage and at -20 volts the current is at 5 amps. This is approaching the maximum current of each cell [41].

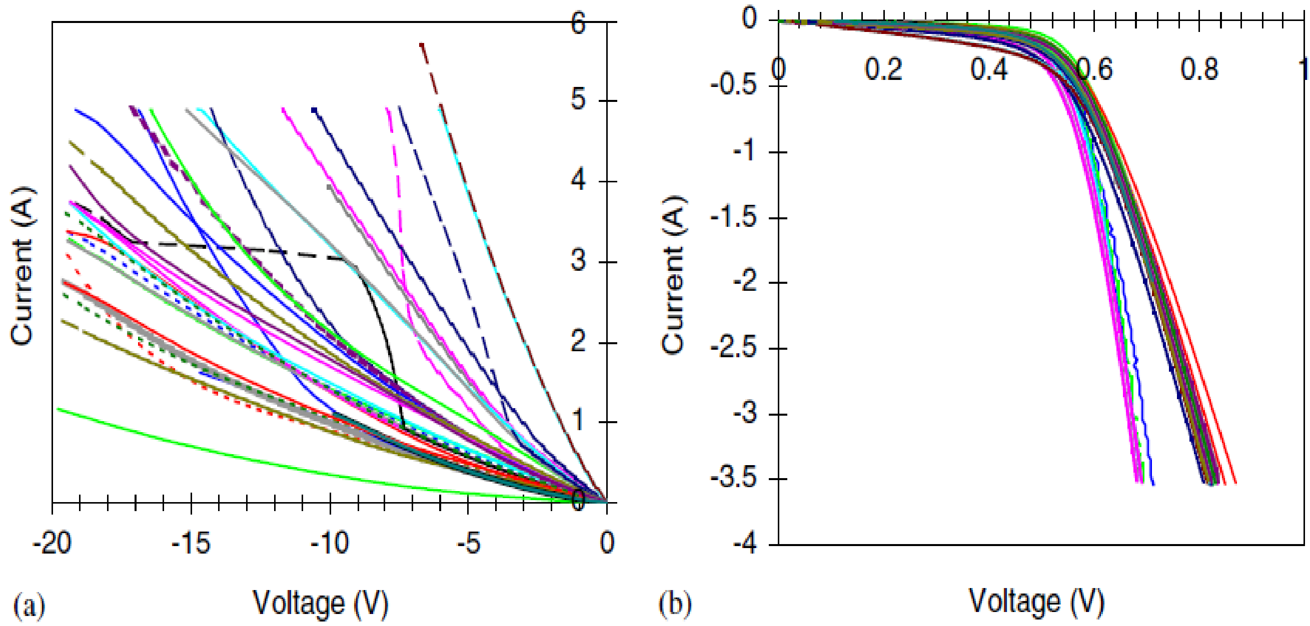

Figure 2-13 - I-V Characteristic for Silicone 33 cells tested without Irradiance (a) reverse bias and (b) forward bias, at 22 degrees Celsius [37]

This voltage is what can cause issues when some solar cells are not receiving irradiance, shaded or are faulty. If a solar cell becomes turned off the other solar cells continue to produce the voltage of the string minus that cell. This forces the cell into a conduction known as reverse bias, which dissipates power in the form of heat and creates a hot spot. Mohammod conducted extensive research on hot spot formation and demonstrated that if the power dissipated over the cell exceeds its maximum value it will permanently damage the cell and an open circuit will form. This open circuit in the series connected system stops all flow of current and the PV system will no longer function [34, 39, 42, 43]

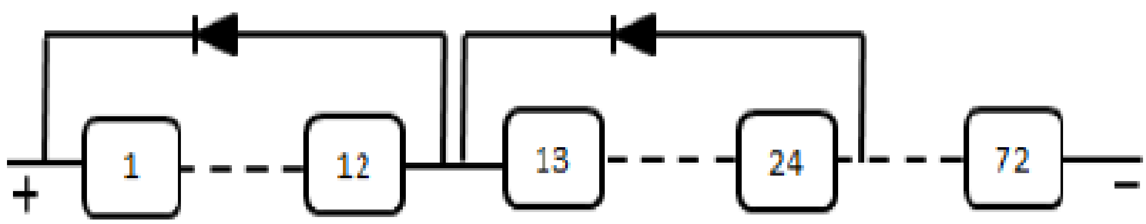

Figure 2-15 - Adding No-Overlapped bypass diodes [30]

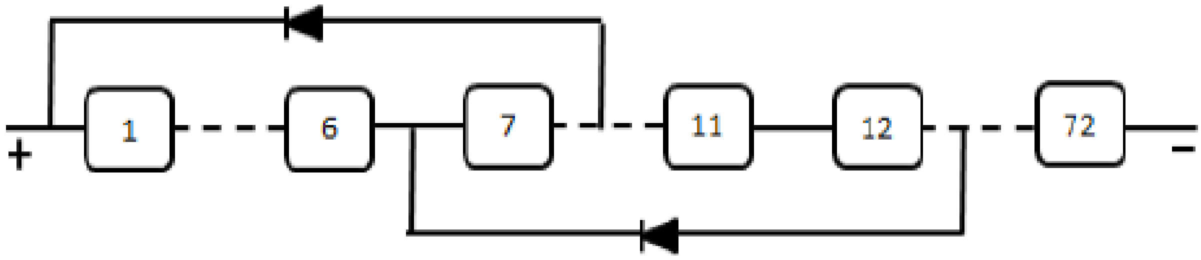

Figure 2-15 - Adding Overlapped bypass diodes [30]

To overcome the issue of solar cells operating in a condition of reverse bias there are different configurations of bypass diodes. There has been several studies by Mohammed, Duong and Silvestre on the correct configuration of bypass diodes [34, 42, 43]. Duong continues by saying that the configuration of the bypass diodes has an important influence on the possibility of a hot spot forming. Two common configurations are shown above in Figure 2-15 & Figure 2-15.

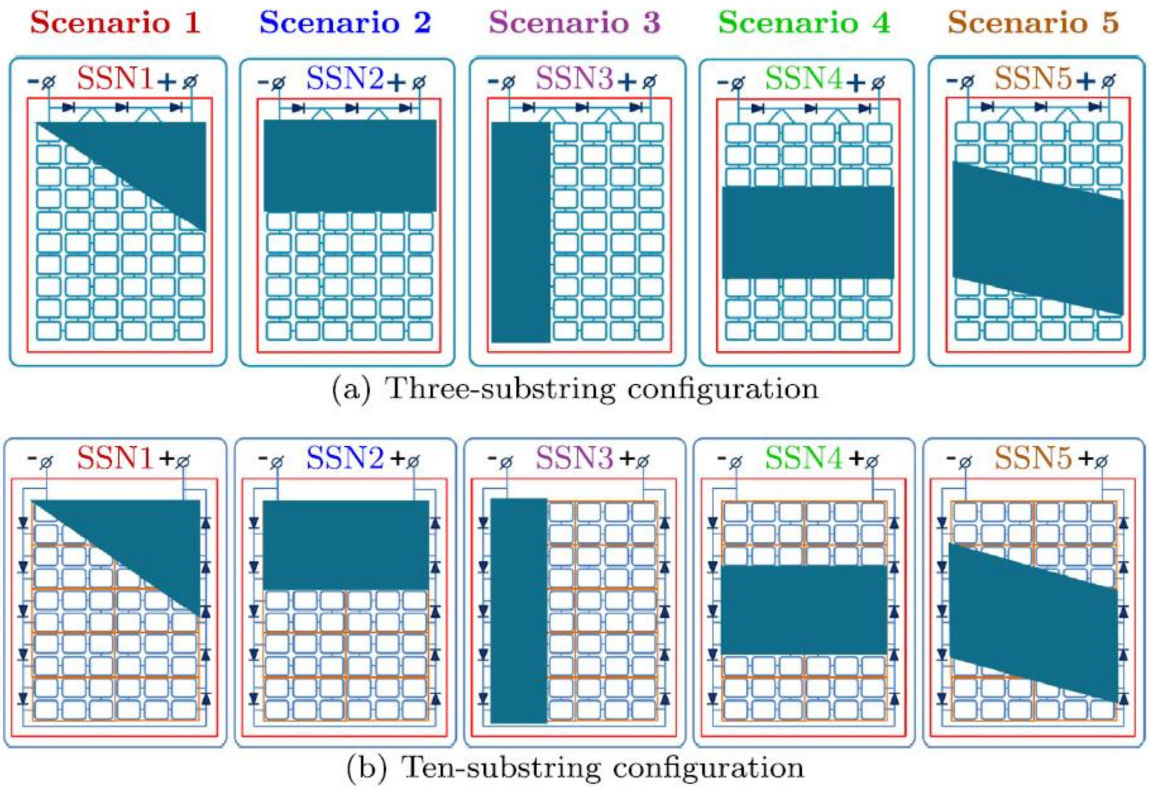

Figure 2-16 - Shading Scenarios used by Mai [38]

Studies conducted by both Silvestre and Mai validated that the configuration and shading location significantly affects the operation and performance of PV modules. They used similar methods, shading techniques of arrays and various scenarios also used by Mai, and are shown above in Figure 2-16. The research showed that the overlapped and not-overlapped configurations had their advantages and disadvantages for PV installation, and therefore, environmental factors must be taken into consideration.

The interesting finding was that for a tropical climate the not-overlapped diode configuration was optimal [43]. In practice, not every cell can have a bypass diode as it is expensive so they are usually connected every 16 cells. Blocking diodes are added to the circuit to prevent reverse flows and serve a different purpose than bypass diodes as shown in the Figure 2-17 below. [44] [42] [45]

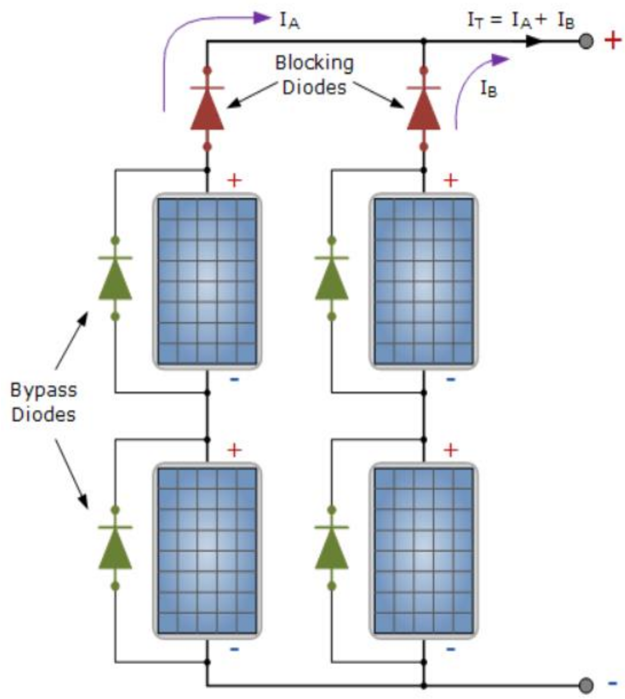

Figure 2-17 - Diagram of Bypass and Blocking diode functions [40]

2.3.7 Effects of Dust

Sun & Jiang found that the reduction of efficiency has a linear relationship with the dust deposition density, and the difference caused by cell types was not obvious. It was found that dust pollution had a significant impact on PV module output, corresponding to a reduction of PV output efficiency which grew from 0 to 26% [46]. This evaluation was validated by another study by Mani & Pillai who dust deposition loss of 5.86%, with the winter losses being 4–5% and 6–7% in summer [47]. These figures were significantly lower than the maximum of 26% from Sun & Jiang, but validated the reduction in PV output from dust deposition.

2.3.8 Costs of PV

The cost of a solar panel installation varies due to three primary factors: [48]

- System Size
  - Generally, a 1.5kW system will produce a third of some households demands. 3.0kW and 5.0kW systems are becoming more common.

- Installation Type and Labour
  - Depending on the type of roof and other factors the cost of installation may be increased. If it is a straight forward installation or if special frames must be installed, this can affect the cost. The system is expected to remain for approximately 25 years. Different companies charge different prices.

- Brand
  - The brand affects the price of system with the more established brands having correspondingly higher price. Generally, with warranty up to 25 years.

From the Australian Government website, it states the approximate cost of a solar system after the rebate and is shown in Table 2-2 below:

Table 2-2 - Approximate Cost of Solar Systems in QLD [42]

System Size	Price (AUD)
3kW	\$4,000 - \$6,000
5kW	\$5,000 - \$8,500
10kW	\$12,000 - \$16,000

It then goes on to state that an average 1.5kW system will generate approximately 6.3kW of electricity per day. The Australian Government uses the number 18kW for the average household although later in this paper it is re-establish 20kW. Using this number we arrive at a 1/3 reduction in electricity price for a household with irradiance equivalent to Brisbane, Australia. [48]

Life cycle costing of PV considers all the costs which will be occurred by an installation over the course of its life. The factors include salvage and maintenance costs. The maintenance costs of PV which also include the cleaning of each panel and inspection costs. These are approximately \$150.00 AUD for an inspection and ranges between \$10.00 - \$20.00 AUD per panel for cleaning. The fixed maintenance costs were summarized by Kumar & Tiwari as 10% of the investment cost [49].

As PV becomes ubiquitous around Australia the salvage value fluctuates and becomes rather difficult to determine in a volatile market. The criteria which McCabe used in a 2011 study identified pricing dependent on the strength of glass, amount of easily recycled aluminium, industry reduced average selling price (ASP). It was found that there were ranging values from \$0.04 to \$1.26 / watt [50].

2.3.9 Payback of PV

The advent of PV technology gives hope to sever the worlds dependence for its energy from fossil fuels. The obligations are outlined in the Kyoto protocol for the decrease of carbon dioxide and other gas emissions. While commenting on the lure of renewable technologies Rajoria raised the important factor of energy payback as a main criterion for comparison of energies. [51]

Knapp agrees with Rajoria and notes that the query translates into one key sense, do they represent a net gain. The net gain being do they produce more energy than it takes to produce them, or are the bigger economies just carbon swapping with poorer countries. A metric used by Fthenakis and other analysts is the Energy Payback Time (EPBT) for comparing sustainable technologies. [52] The EPBT is an equivalent for a financial payback and is defined as the time taken for a solar panel to produce the same amount of energy taken to originally manufacture it. It is a good indication for potential mitigation of carbon emissions summarises Alsema. [53] [54]

$$EPBT = \frac{(production\ energy\ requirements)}{(power\ rating)(insolation)} \tag{2-10}$$

Where:

- $production\ energy\ requirements$– the gross energy required to produce the product i.e. upstream process and raw materials i.e. silicon
- $power\ rating$– or efficiency is the rate at which the incoming sunlight is converted into electrical energy and includes system losses
- $insolation$– solar insolation or irradiance but also extends to installation style incorporating roof tilt, orientation, tracking, grid or standalone connection.

The first study on PV conducted by Hunt in 1976 yielded a EPBT of 11.6 years. Hay in 1981 arrived with 11.4 years for EPBT. For a multi-crystalline silicone PV rooftop system in 2005 the EPBT was calculated by Peharz at 3 years [52, 55]. Sampiao has validated the figures of 0.7 to 2 years for EPBT of PV subject to technology and location. Sampio provided the below **Figure 2-18** for EPBT decrease.

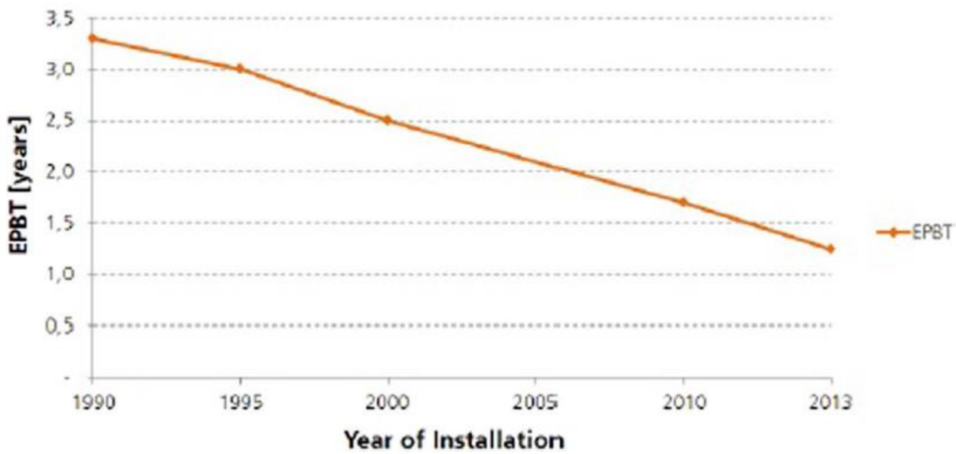

Figure 2-18 - Historical trend in times of Energy Return (EPBT) of photovoltaic modules of crystalline silicon [44]

2.4 Inverter System Technologies

An Inverter, Converter, Solar Inverter, or PV Inverter is an electrical device which converts DC input signal into a usable AC output signal. The inverter for a solar system converts the DC from the solar panels to AC, which can then be used in the residential household or fed into the commercial electrical grid. The solar inverter usually has additional unique functions when operating as a Distributed Energy Resource (DER) system with PV arrays such as maximum power point tracking (MPPT) and anti-islanding protection [56].

The inverter system in its most basic form can be organized as an astable vibrator circuit or another type of simple oscillator circuit. The principle invoked by the inverter is to create a magnetic field with the DC source. This current induces a voltage in another coil and when the DC source is switched in the opposite direction the induced voltage changes. This creates an oscillation or AC source when the action is repeated. There are three classifications for inverter systems [57]:

- Stand-alone Inverters – these inverters are used in isolated systems and convert from batteries charged by PV.
- Grid-tie Inverters – these inverters are in DER systems which are designed to match the phase of the supplier's sine wave and shut down upon loss of the network to prevent Islanding. They do not run when the network is out.
- Battery backup Inverters - these inverters are in DER systems which are designed to match the phase of the supplier's sine wave and do not shut down entirely upon loss of the network. When no network supply is detected they do not feed into the grid to prevent Islanding and can be switched to become an Emergency Power Supply (EPS) for small loads including lights and some power.

Solar Inverter Systems generally accommodate:

- Maximum Power Point Tracking (MPPT) – is a method utilised by PV inverters to maximise power. The source of power for the inverter is the sunlight and load for the inverter is the household. Through the course of the day both the source and load vary and to ensure the maximum power transfer the inverter must find the maximum efficiency for the system or the "maximum power point" [56].
- Anti-Islanding – is the action an inverter takes when it does not detect any network grid. The inverter is connected to the grid to match the phase it is producing with the network. In the event of a blackout there is no power so the inverter shuts down and does not feed power into the electricity grid. If a utility worker were to work on the grid during a black out and anti-islanding was not used he could potentially receive an electric shock. An Inverter with an EPS may still power a "microgrid" and feed selected circuits.

Park pointed out that the efficiency of each inverter is dependent on the efficiency curve for that particular inverter [22]. Konsen made the argument that the efficiency of inverters has improved since the mid-1990s from 90% up to 99% efficiency. This was due to new approaches such as MMPT algorithms and realisations, multilevel topologies, soft switching, output filter optimisation and silicon carbide semiconductors. [58]. It should be noted that a study by Carr placed the overall production ratio of the PV systems tested between 0.84 and 0.94 [59].

An Inverter system to be installed in Australia must comply with the Electrical Safety Act and Electrical Safety Regulations which include the Australian Standards for inverter systems AS4777. There are two parts for the grid connection of energy systems via inverters and Part 1 deals with installation requirements and the Part 2 deals with inverter requirements. The anti-islanding of inverters is specifically referenced stating that they shall incorporate passive forms of anti-islanding protection. [1] This protection is in the form of undervoltage, overvoltage, under-frequency and over-frequency is outlined in the Table 2-3 below [60].

Table 2-3 - Passive Anti-Islanding Set-point values [51]

Protective function	Protective function limit	Trip delay time	Maximum disconnection time
Undervoltage (V<)	180 V	1 s	2 s
Overvoltage 1 (V>)	260 V	1 s	2 s
Overvoltage 2 (V>>)	265 V	—	0.2 s
Under-frequency (F<)	47 Hz (Australia) 45 Hz (New Zealand)	1 s	2 s
Over-frequency (F>)	52 Hz	—	0.2 s

[1] The typical installation wiring for a grid tie inverter system as described in AS4777 is given in the appendices.

2.5 Battery Energy Storage (BES) Systems

2.5.1 BES Utility & Capital

The shift towards renewable energies is increasing and with it the demand to store this inexhaustible energy. The basis of energy storage is to keep energy produced at one period-of-time and use it later at another period-of-time. Battery banks are used as storage and to allow use of this energy when there is no sunlight. Battery storage technology has been improving and now there are Battery Energy Storage Substations which help to improve peak load times. Battery systems can be used for peak shaving, load shifting, backup power, demand response, microgrids, renewable power integration, frequency regulation and voltage control. The battery banks have traditionally been based on lead but have now moved to lithium technology [61].

BES systems are becoming popular in domestic applications for coupling with PV. The improving technology, decreasing cost for a system installation and governmental schemes are set to put BES systems into more common application. The BES system is technology which can offset the use of energy from whence it is created to when it is utilised as shown in the below Figure 2-19 [62].

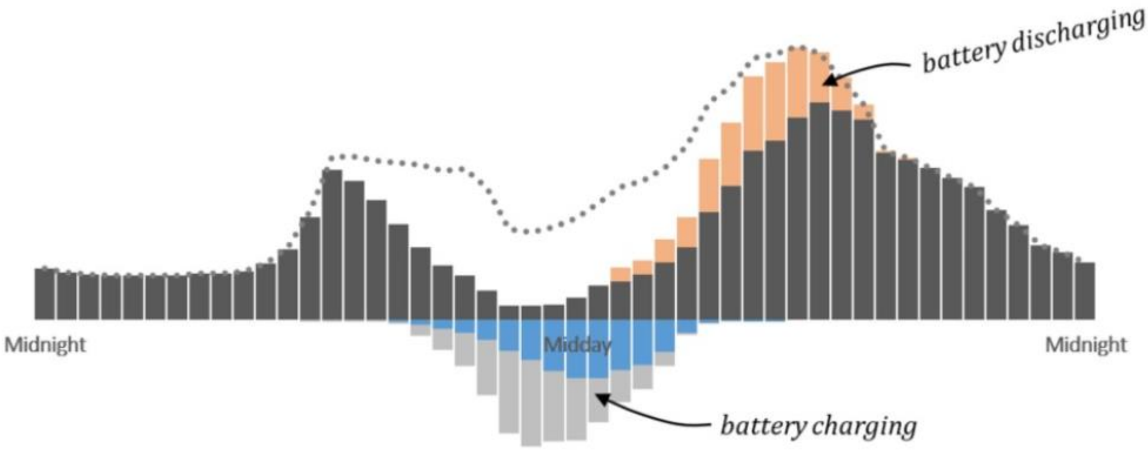

Figure 2-19 - Graphical view of potential offset with BES [53]

The two main solar batteries on the market for purchase in Australia are the LG Chem RESU, Redflow ZBM 2 and the Tesla Powerwall, which was released in 2015. These are Lithium-Ion and Zinc bromide batteries with 4-13.2kWhr ratings depending on the unit. The Powerwall 2 claims 89% round-trip efficiency, the ZBM 80% while the LG RESU claims 95% efficiency. The ZBM 2 promotes 100% capacity use. Rydh in a 2005 study concluded with values of 0.4-0.8 for overall battery efficiency; this seems to contradict the claims made by Telsa and LG but due to the decade in lapse in time it seems reasonable. [63] The retail price for a 10kWhr LG RESU is $9,700.00AUD, a 10kWhr ZBM2 is $10,600AUD and a 13.5kWhr Tesla Powerwall 2 is $8,750AUD. The typical cost of installation is between $1,150- $2900 AUD.

Battery Energy storage systems are costly, but with a government subsidy or rebate they become readily and economically viable. This is an acceptable proposition as the following 1st

July 2016, Adelaide in South Australia have in effect the 50% of the installed system cost up to a maximum of $5,000 for battery energy storage systems [64].

2.5.2 Modelling of BES

There are many variables which affect the performance of a battery and are discussed below. The Recharging time is important during the charging and discharging of a battery. If there is damage due to cell reversal or if a battery is stored during a completely discharged state it may be damaged. The depth of the discharge, humidity, temperature and the lifecycle in number of charge and discharge cycles are factors which affect the performance and life of a battery [65].

The battery life is greatest when the batteries are kept close to 100% of their capacity and after a deep or partial discharge are recharged quickly. [37] Optimal charging and discharging of a battery is dependent on the batteries characteristics and condition. The following is an explanation of battery nomenclature which affect its production and storage [66].

A PV system is not charging constantly but changes with solar irradiance and temperature. Shen summarized that calculation of the state of charge (SOC) of the battery is difficult and that the system can be assumed to completely (100%) discharge daily [66]. The energy stored on any day is given by the equation:

$$E_B(n) = E_B(n-1) * (1-\eta_s) + \left(E_{pv}(n) - \frac{E_L(n)}{\eta_{inv}}\right) * \eta_{batt} \tag{2-11}$$

Where:

- $E_B(n)$ – is the energy stored in the battery on nth day (present day)
- $E_B(n-1)$ – is the energy stored in the battery on nth-1 day (day before)
- η_s – is the daily battery self-discharge rate
- E_{pv} – is the energy generatred by the solar arry on the nth day
- η_{inv} – is the efficiency of the inverter
- η_{batt} – is the efficincy of the battery

On any nth day, the energy which can be stored in the battery is subject to the condition:

$$E_{B(min)} \leq E_B(n) \leq E_{B(max)} \tag{2-12}$$

Where:

- $E_{B(\mathrm{min})}$ – is the minimum energy level of the battery
- $E_{B(\mathrm{max})}$ – is the maximum energy level of the battery

The $E_{B(\mathrm{min})}$ is the minimum energy level the battery can achieve without affecting the specified battery life. This minimum level is the maximum depth of discharge (DOD). The

DOD is a measure of the percentage of battery which has been discharged compared to its total maximum capacity. A 80% discharge or DOD is considered a deep discharge [66].

$$E_{B(min)} = (1 - DOD_{max}) * C_{batt} \tag{2-13}$$

$$1 - DOD_{max} = SOC_{min} \tag{2-14}$$

Therefore,

$$E_{B(min)} = SOC_{min} * C_{batt} \tag{2-15}$$

Where:

- $C_{batt} * V_{rated} = E_{B(\max)}$ and is the energy capacity of the battery
- DOD_{max} – is the depth of discharge
- SOC_{min} – is the state of charge

The SOC is the state of charge of the battery and is a percentage expression which indicates a battery's remaining capacity over its total capacity. It is given by the formula[66, 67]:

$$SOC(n)\% = \frac{E_B(n)}{C_{batt} * V_{rated}} * 100 \tag{2-16}$$

The DOD of a battery is linked to the life of the battery. The lower the DOD then the lower the cost of the system and the shorter the battery life.

The difference in the battery technologies affect how they should be operated. The DOD can be shallow or deep and the higher the DOD the lower the cycle life and vice versa[68]. Batteries can suffer by an effect known as "memory" where the output is depressed over time and this fading is indicated by the State of Health (SOH) of the battery. The present full charged capacity of a battery is different from when the battery was new and subsequently declines over time. The following equation can be used to calculate the SOH of the battery[67]:

$$SOH\% = \frac{E_B(n)}{E_{rated}} * 100 \tag{2-17}$$

Where:

- E_{rated} – is the original rated capacity of the battery

2.6 North Queensland Solar Radiation

Solar PV systems derive their energy directly from the sun. The amount of sunlight hours and its intensity vary, therefore a measure of potential energy must be established. The Diffuse solar irradiance is a measure of the rate of incoming solar energy both directly and diffused on a horizontal plane at a point on the Earth's Surface. The device which measures diffuse solar irradiance is the pyranometer. Instruments to measure solar irradiance are complex and special procedures must be adhered to for calibration and measuring [69].

Australia is situated approximately in the middle of the tropic of Capricorn at 23.5 degrees latitude. It therefore experiences high degrees of solar irradiance which nominate it as a prime candidate for solar PV systems. The Australian Solar Irradiance is shown below in Figure 2-20 and was taken from the Bureau of Meteorology website [70].

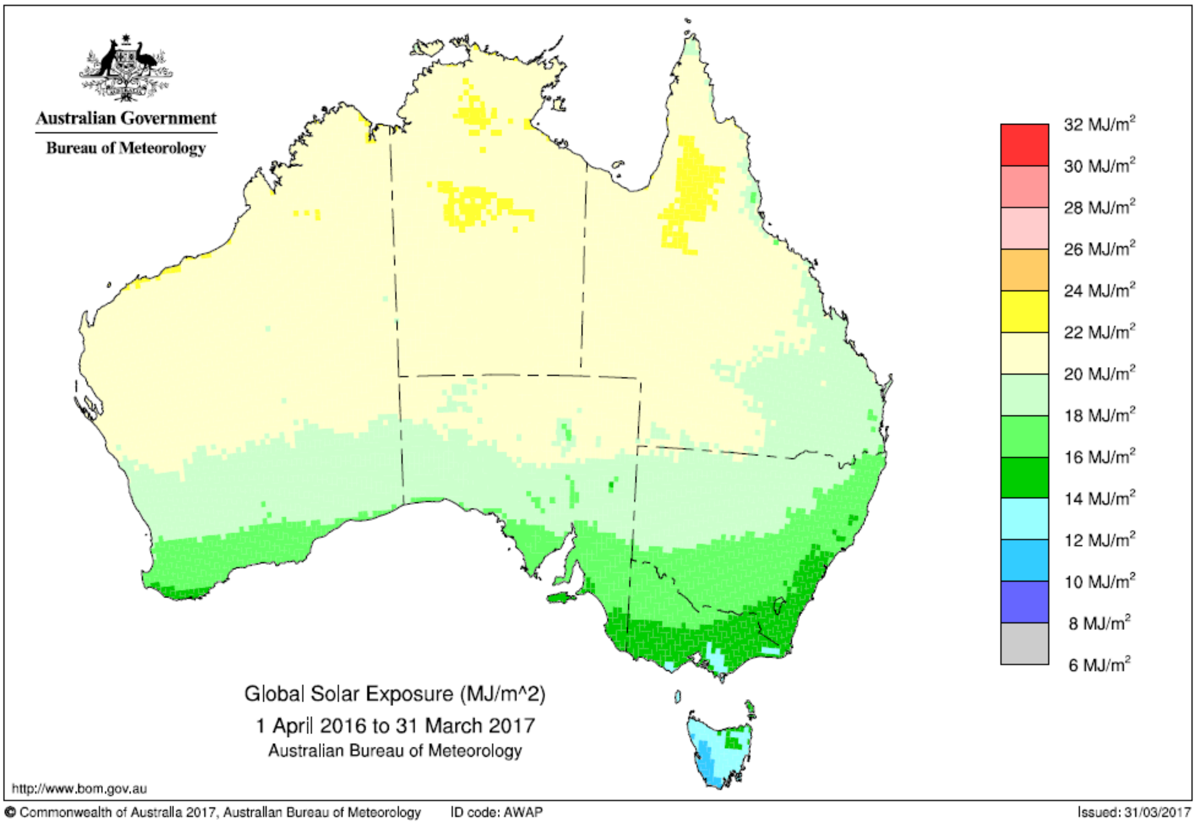

Figure 2-20 - Australian Solar Irradiance [61]

The Figure 2-20 above shows that Townsville experiences approximately 22MJ/m^2 of solar energy each year with approximately 300 days of sunlight [71]. Townsville experiences high levels of solar radiation throughout the year due to its high solar elevations and low total ozone columns [72]. This 22MJ/m^2 is a yearly figure and consequently from the tilt of the Earth's axis it varies as shown in the Figure 2-21 below. This total radiation figure was created in Turkey with a similar latitude to Townsville but in the Northern Hemisphere. It shows the relationship between month and amount of solar radiation and how it varies throughout the year.

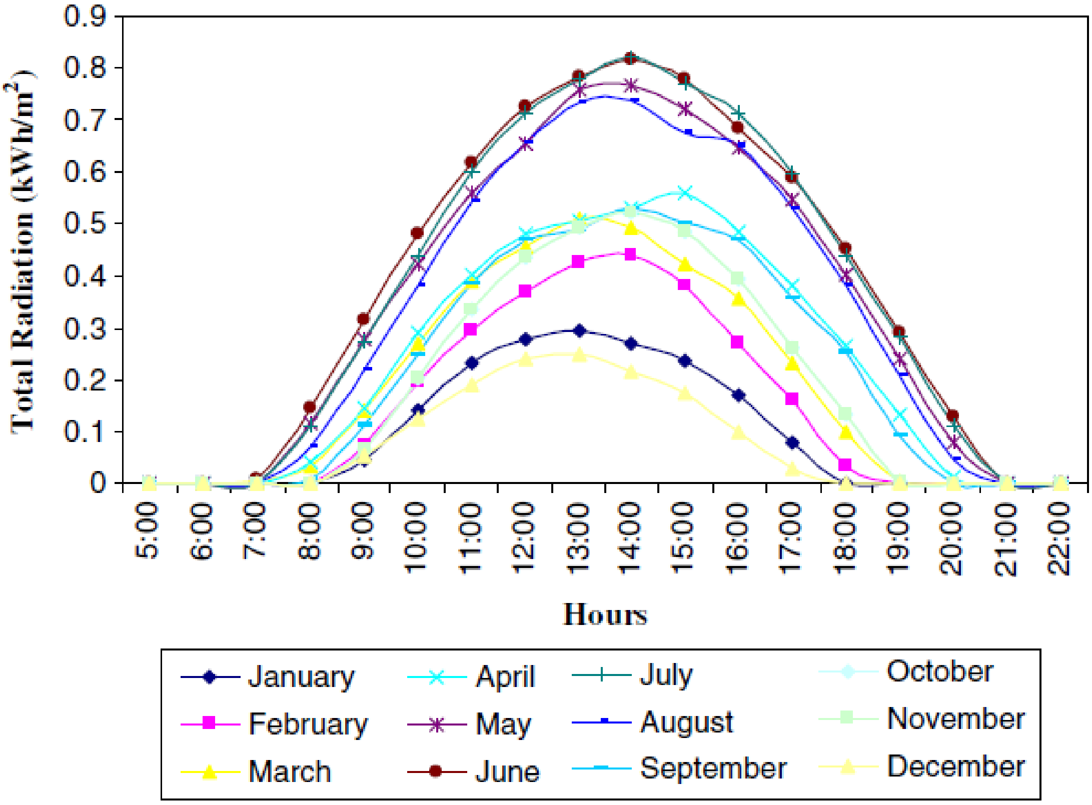

Figure 2-21 - Average hourly total solar radiation on horizontal surface (measured) [63]

2.6.1 PSH Conversion

The data which is given in Figure 2-20 is megajoules per meter squared. To convert megajoules per meters squared per day to peak sun hours the following conversions are used:

$$1\ Watt(sec) = \frac{1\ Joule}{1\ Second}$$

$$\left(1\ W = \frac{1\ J}{1\ sec} * \frac{60\ sec}{1\ min} * \frac{60\ min}{1\ hr} * \frac{24\ hr}{1\ day}\right) * 1000$$

$$1\ \mathrm{kW(day)} = \frac{8.64\ MJ}{1\ day}$$

$$\left(1\ W = \frac{1\ J}{1\ sec} * \frac{60\ sec}{1\ min} * \frac{60\ min}{1\ hr}\right) * 1000$$

$$1\ \mathrm{kW(hour)} = \frac{3.6\ MJ}{1\ hr}$$

$$0.277\ kW * 1\ hr = 1\ MJ$$

$$\boldsymbol{\frac{0.277\ kWhr}{1\ MJ} = 1} \tag{2-18}$$

$$\frac{20\ MJ}{1\ \mathrm{day}} * \frac{0.277\ kWhr}{1\ MJ} = 5.55\frac{kWhr}{day}$$

$$\frac{\frac{20\ MJ}{1\ m^2} * \frac{0.277\ kWhr}{1\ MJ}}{day} = 5.55\frac{\frac{kWhr}{m^2}}{day} = 5.55\ PSH$$

Therefore, a household in central Northern Territory receiving 20 MJ.m^2/day is equal to 5.55 peak sun hours (PSH) or solar irradiance.

2.7 Optimal Roof Tilt Angle & Orientation

Li and Liu conducted a study estimating the solar potentials of pitched roofs. The study demonstrated that the azimuthal angles and surface orientation affected solar yield. It was shown that north facing roofs received more annual solar radiation yields than south facing roofs in the southern hemisphere. The shadowing from erected objects showed significant effects on solar radiation yield. [9] The red shades in Figure 2-22 show higher amounts of solar radiation due to pitch and orientation.

Interestingly, in a study aimed at finding the optimal roof tilt angle for PV, the optimal angle for each month was found and the mean was taken. The study by Ulgen found in winter (December, January, and February) the tilt should be 55.7°, in spring (March, April, and May) 18.3°, in summer (June, July, and August) 4.3°, and in autumn (September, October, and November) 43°. Thus, the yearly average of these figures was 30.3° and this was the optimum fixed tilt for the year [73]. It should be noted here that the study was conducted in Izmir in Turkey with a latitude of 38.42°.

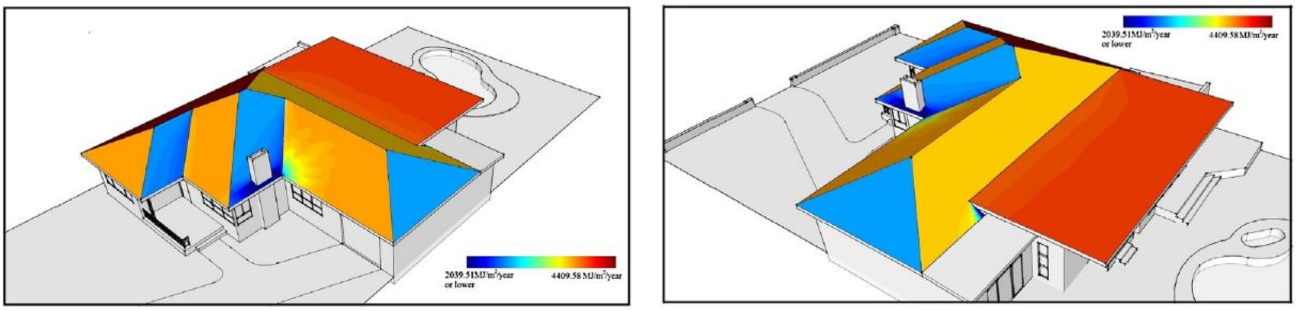

Figure 2-22 - 3D annual radiation map of pitched roof from south-eastern view (left) and north-eastern view (right) [9]

While this method seems reasonable the results of Cheng, Sanchez and Lee concluded that 98.5% of a system's performance with the optimal angle can be achieved using the latitude angle as a reference for the tilted panel in sites located in the Northern Hemisphere. They yielded results with a discrepancy factor of 1.67% in comparison with the data obtained from the computer simulation [74]. This seems to contradict the study by Ulgen, in asserting that the optimal tilt angle in Izmir should have been 30.3°. Perhaps this change of 8° is accountable for the 1.5% loss.

Demirkol, using the optimal roof tilt angles throughout the year and adjusting monthly, found gains in the amount of solar radiation were 1.1% and 3.9%, respectively. A daily average of 29.3% gain in total solar radiation resulted in an daily average of 34.6% gain in generated electricity [75].

As mentioned is it efficient to tilt the module at the angle towards the equator equivalent to the location but to gain another 25% - 35% the solar azimuth can be tracked during the day from east to west. Another 10% can be obtained by adjusting solar declination which is the lowering of the sun in the sky during winter [76]. Figure 4-2 shows the solar azimuth and solar declination of the sun during a day with reference to perpendicular angle (Note the declination is for the northern hemisphere).

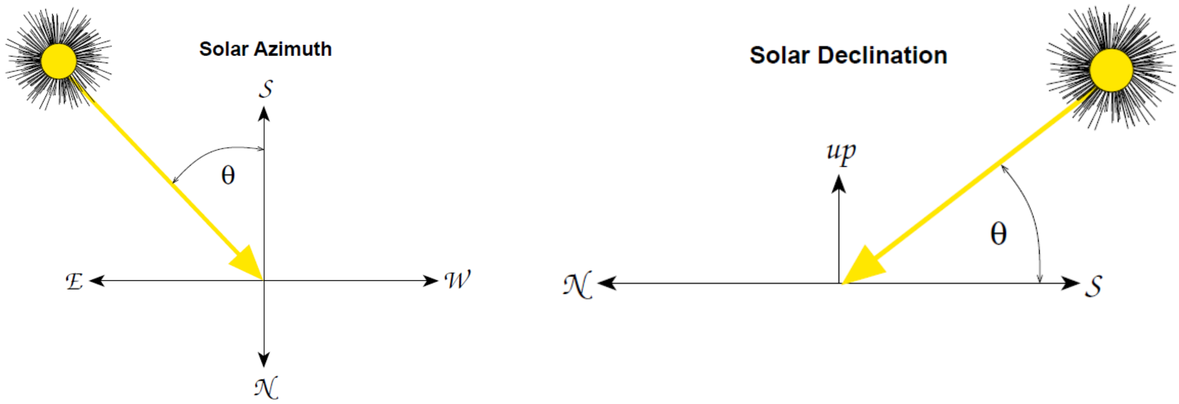

Figure 2-23 - Solar Azimuth (left) and Solar Declination (right)

Mondol studies of the effects on total insolation as functions of surface azimuth and tilt angles depicted are (Figure 2-24) shows the maximum annual total insolation is for a south-facing surface. The sun over the day spends equal time in the east and west which describes the symmetrical pattern over the azimuthal angles [77]. It is seen how a deviation in the azimuth angle either direction will not affect the output until 25 degrees. Note that his location was at 30 degrees latitude. Which is why the optimal tilt angle was 25 degrees and the efficiency of the PV decrease was it deviates from this value.

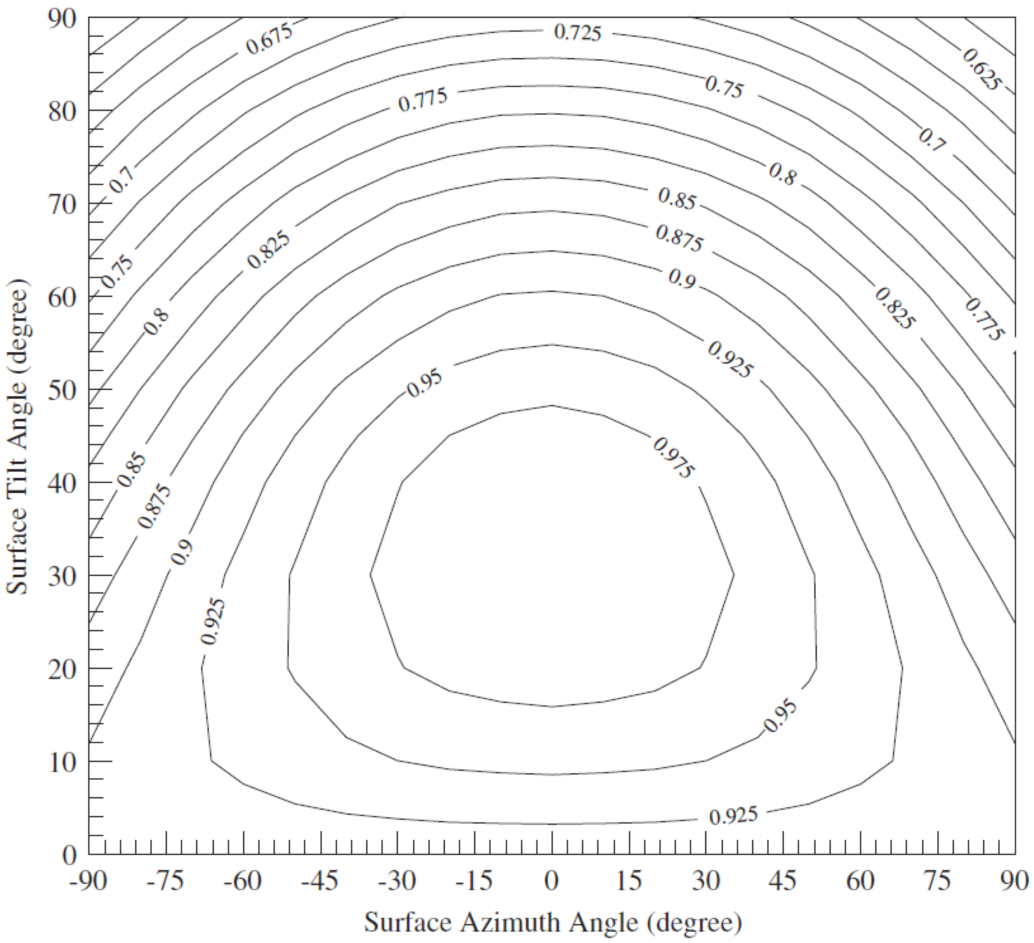

Figure 2-24 - Distribution of annual total insolation normalized with respect to the annual total maximum insolation

2.8 The Electricity Network (Grid)

The Electricity Network or Electricity Grid is a term used to refer to the network of transmission lines that connect generation to distribution of electricity. The basic operation of a grid consists of stepping the voltage up to a high voltage at the generation side and transmitting it over long distances though transmission lines. [25] There are smaller distribution grids that receive the stepped down voltage from a nearby substation and distribute it around for residential households and commercial businesses.

The Electricity grid colloquially refers to the grid of the state in which you are presently located, although there are four main grids in Australia. These being:

- WA*:* South West Interconnected System (SWIS)
- WA*:* North West Interconnected System (NWIS)
- NT*:* Darwin-Katherine Electricity Network (DKEN)
- QLD, NSW, ACT, VIC, SA, TAS*:* National Electricity Market (NEM)

The National Electricity Market (NEM) is the Australian wholesale electricity market which supplies Queensland, along with four other states and one territory. The NEM contains over 40,000 km of transmission lines and cables, making it one of the largest interconnected electricity markets in the world. It supplies approximately 200 terawatt hours of electricity to around 9 million customers annually. In 2014-15 $7.7 billion dollars (AUD) was traded on the NEM.

The Australian Electricity Rules including the Act and the Regulations are maintained by the Australian Energy Regulator which enforce the laws set out for the NEM. The Australian Energy Market Operator (AEMO) manages the NEM and provides critical planning, forecasting and power systems information, security advice, and services to stake holders [78].

The NEM supplies energy to Ergon Energy who are both a retailer and a distributor and play a relatively minor role in generation. Ergon Energy supplies electricity to Queensland with a service area of 97% including Townsville as shown in the Figure 2-25 right [79].

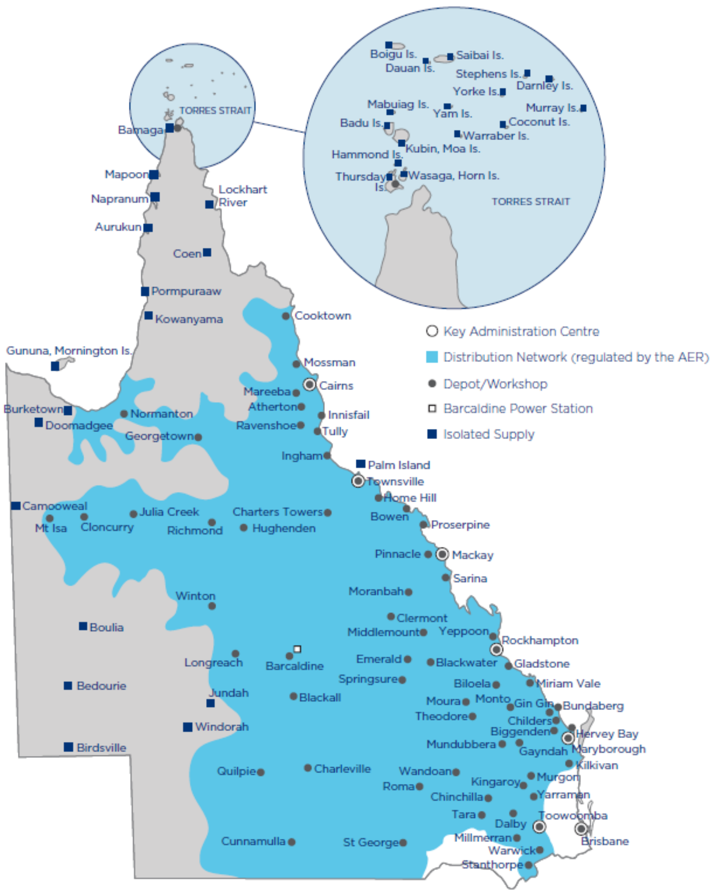

Figure 2-25 - Ergon Energy Service Area [65]

2.9 Load Profile

The term load profile in electrical engineering relates to the variation of the electrical load over time. The traditional load profile for a residential household sees a peak in the morning when people awaken to prepare breakfast. This then dips down during the day and after returning home from work and are preparing dinner, cleaning and using the lighting and air-conditioning the load increases again. This spike at the end of the day reduces as they go to bed and this profile repeats daily. This changes the profile depending on the age of any occupants and the age of any children.

There are many variables which can affect this general load profile such as temperature, living arrangement, holiday seasons and PV [80]. Richardson states that the electricity use in an individual domestic dwelling is highly dependent upon the activities of the occupants and their associated use of electrical appliances.

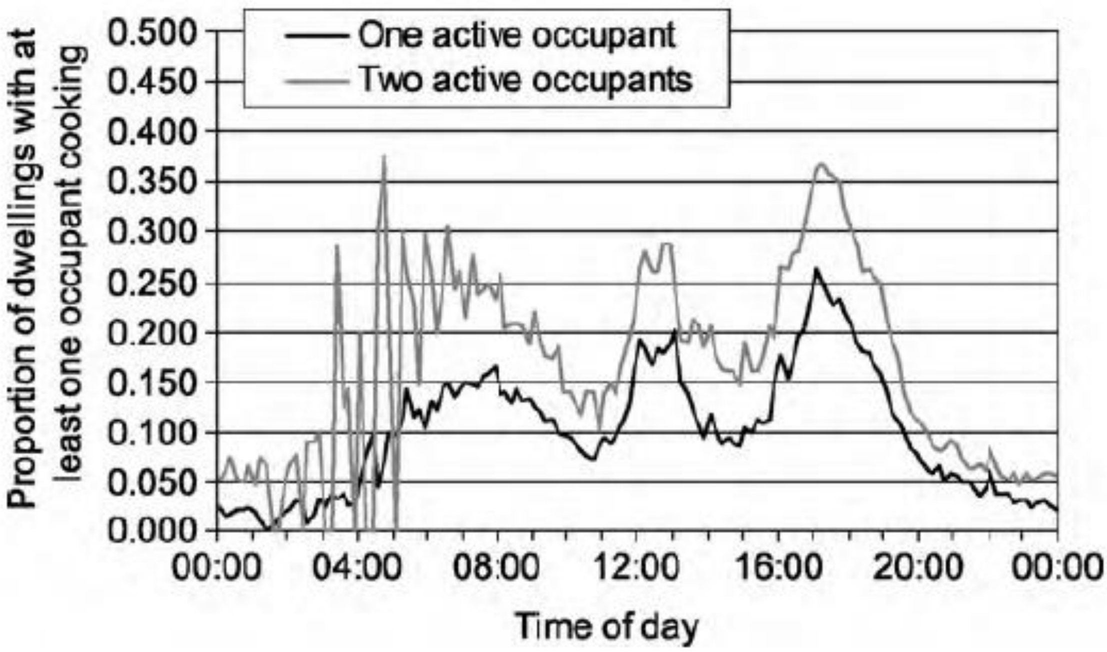

Figure 2-26 - Activity profiles for 'cooking", for one or two active occupants on a week day [66]

From the above Figure 2-26 it shows clearly the peaks and troughs in energy demand from the network. This is the traditional household that does not generate its own electricity. When residences produce, their own electricity, depending on the size of the system, it can potentially feed back into the grid.

The traditional peaks can strain the network and the unpredictability of the independent fed-ins produce more volatility. Hoffmann noted that fed-in energy from PV systems have the potential to disrupt the network and the networks ability to stabilize itself. The below Figure 2-27 is the typical load profile during the course of the day for an office building [81].

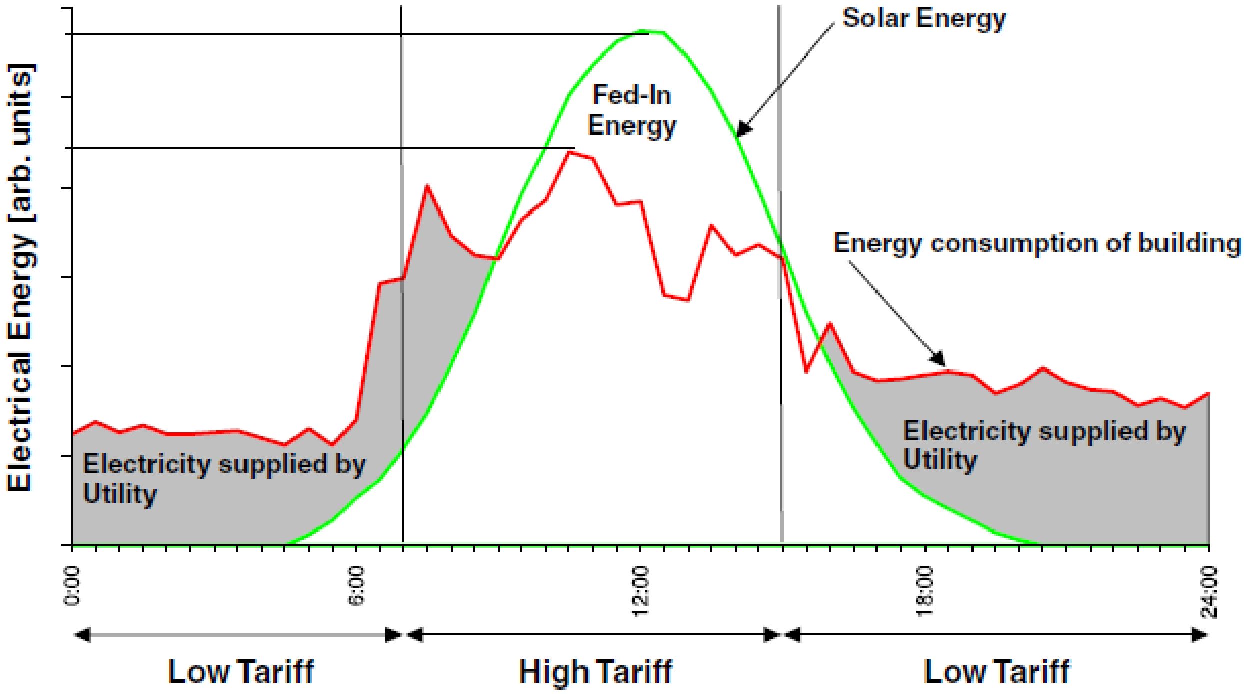

Figure 2-27 - 24hr Energy Profile [67]

The above figure shows a traditional load profile in red with the new daily solar production shown in green. Now with the advent of BES technology, there is a point where the amount of solar produced during the day can recharge batteries and this energy can be consumed overnight until the next recharge period. The only caveat with this is ensuring that there is adequate supply in the event of clouding for several days. The below Figure 2-28 shows the load profile for a house which is entirely stand alone. The red line shows solar output during the day, the green line is the output of the batteries while the blue line refers to the household consumption [82].

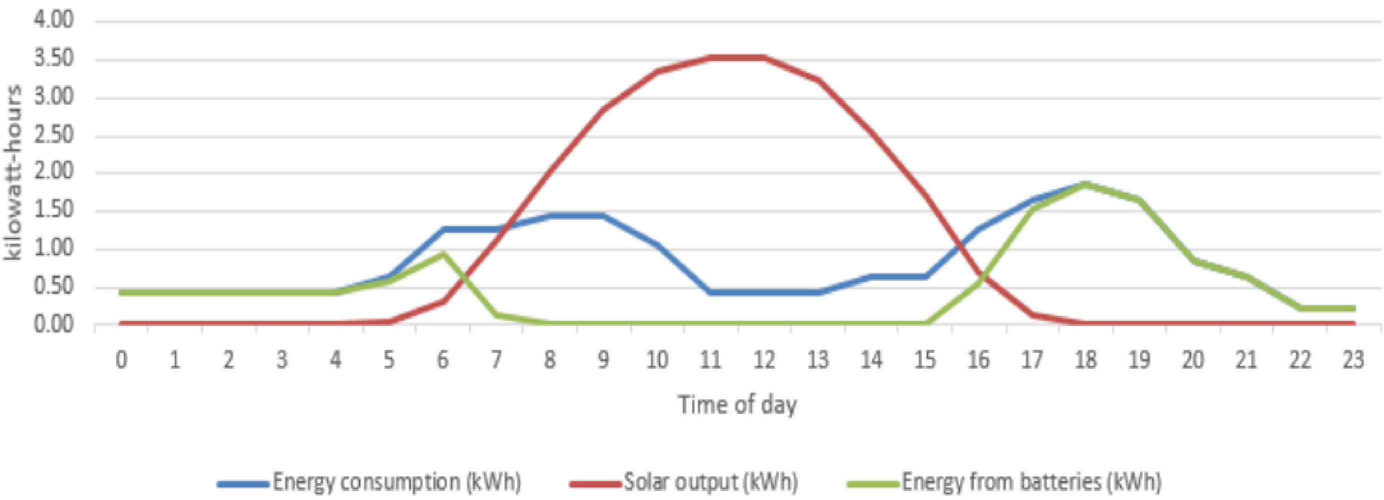

Figure 2-28 - Standalone Household Consumption Load Profile [68]

2.10 Network Demand Challenges

Ergon Energy is constantly monitoring this network to check if extra demand is needed or the load is reduced. The biggest change in this profile over time is the large drop in energy demand in the middle of the day. This is due to solar PV units exporting energy into the grid. The below Figure 2-29 is from Ergon Energy at the Dundowran Feeder in Hervey Bay (Qld) and illustrates how PV has affected the load profile [83]. It shows a reverse flow during the middle of the day at approximately 12:30pm in 2015.

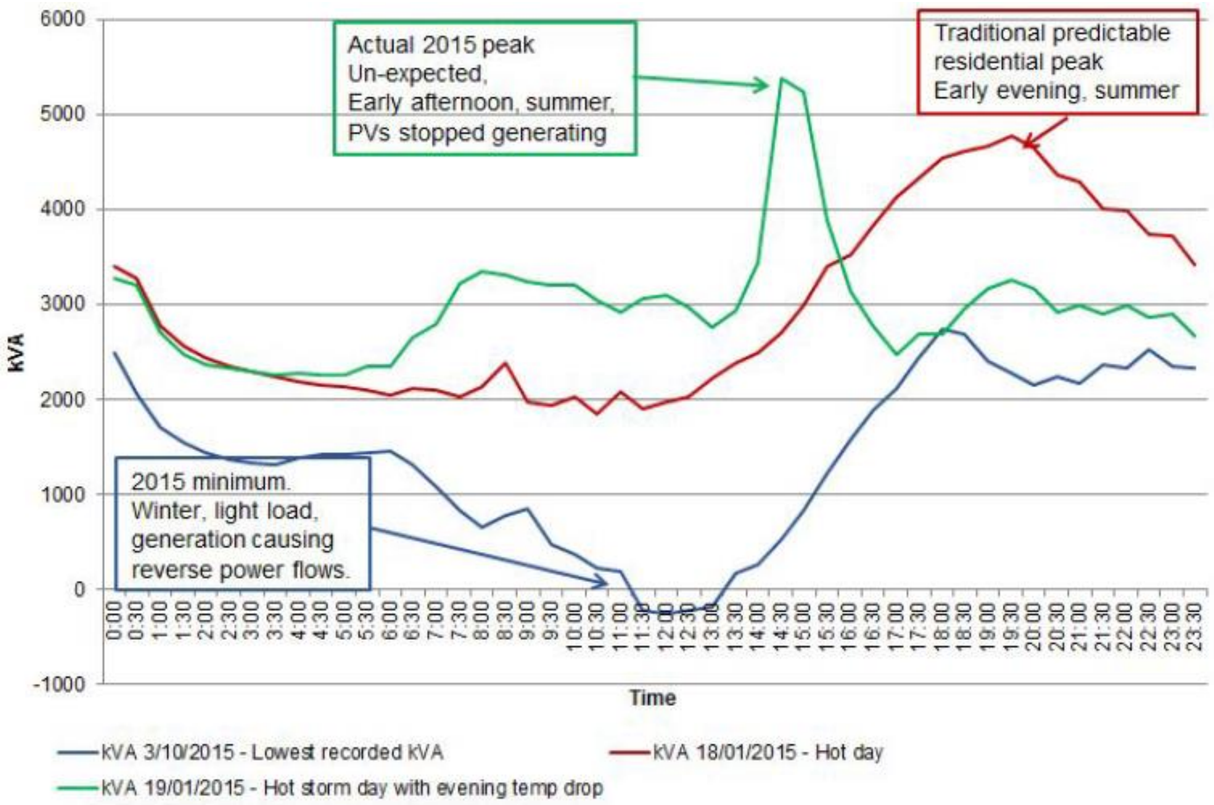

Figure 2-29 - Dundowran Feeder Load Profile [69]

The Planners at Ergon Energy need to identify issues with feeders and disruption which may occur with the grid. In the above Figure 2-29 the blue line shows this area has high solar PV utility which is meeting the energy requirements during the course of the day and is feeding electricity back into the substation. The red line shows the traditional load profile. The interesting phenomenon is that the green line has an unexpected peak in demand which cannot be met with PV technology and highlights the risks of cloud cover or storms. The sudden losses in power generation must be met and this demand can overload the feeder [83].

2.11 Tariffs and Rebate Change

An electricity meter is a device used by the Ergon Energy to accurately measure how much electricity is used through that line. A household may have more than one meter if they have several metering schemes. A metering rate is called a Tariff and there are different Tariff rates which usually vary according to availability of usage. The below Table 2-4 lists the different residential tariffs; tariff 11, tariff 31, tariff 33 and the solar fed-in tariff [84].

Table 2-4 - Electricity Pricing Information [70]

Tariff 11 Residential - 1 Jul to 30 Jun All usage. Anytime.	**Price (exc. GST)**	**Price (inc. GST)**
All usage	24.61 cents per kWh	27.071 cents per kWh
Daily supply charge	89.572 cents per day	98.5292 cents per day
Controlled load Tariff 31 Night rate (super economy)	**Price (exc. GST)**	**Price (inc. GST)**
All usage	14.423 cents per kWh	15.8653 cents per kWh
Daily supply charge	0.00 cents per day	0.00 cents per day
Tariff 33 Controlled supply (economy)		
All usage	19.96 cents per kWh	21.956 cents per kWh
Daily supply charge	0.00 cents per day	0.00 cents per day
Solar feed-in tariff options		
Solar feed-in tariff for regional Queensland. This amount is not subject to GST. (cents per kWh exported)	7.448	
44 c/kwh solar feed-in tariff. This is not available for new solar PV connections. This amount is not subject to GST. (cents per kWh exported)	44.00	

The Queensland Solar Rebate Scheme was an incentive introduced in 2008 for customers who applied before the 9th July 2012, and allowed a feed-in tariff rate of 44 cents per kWhr [85]. The scheme expired on the 1st July 2012 and for persons still receiving the tariff it is substantially higher than the current 7.448 cents/kWhr. The current feed in rate is less than one third for what is paid for the general usage Tariff 11 of 27.071 cents/kWhr. The low feed in tariff rate is beneficial to Ergon the electricity supplier as they are effectively purchasing the power at 7 cents and kWhr and selling it to the person next door for 27 cents/ kWhr. This is creating them 20 cents/kWhr just for maintenance of their network, when it needed to be maintained regardless for supply obligations. Ergon charge 90 cents per day for a person being connected to the grid regardless if electricity is consumed or delivered. [85]

Yao and Steemers heavily described the effects of daily residential electricity usage as it varies due to varying factors such as number of occupants and occupancy, cooling appliances, hours of lighting. Baetens addressed the same sources of energy consumption as Yao and Steemers but additionally included ventilation, space heating, pools, domestic hot water, floor area of the house, number of rooms, water inlet and outlet temperature, volume of water consumed, appliance energy consumption, seasons and weather [35, 86].

Ergon Energy, Queensland's Electricity supplier has written that there are a number of factors which affect electricity consumption, but climatic variance is no doubt the most important [87]. They further reinforced this by saying many Northern Districts have up to 73 per cent more electricity consumption in Summer compared to Winter and Autumn seasons. The Figure 2-30 below highlights the stark contrast in consumption between Winter and Summer months.

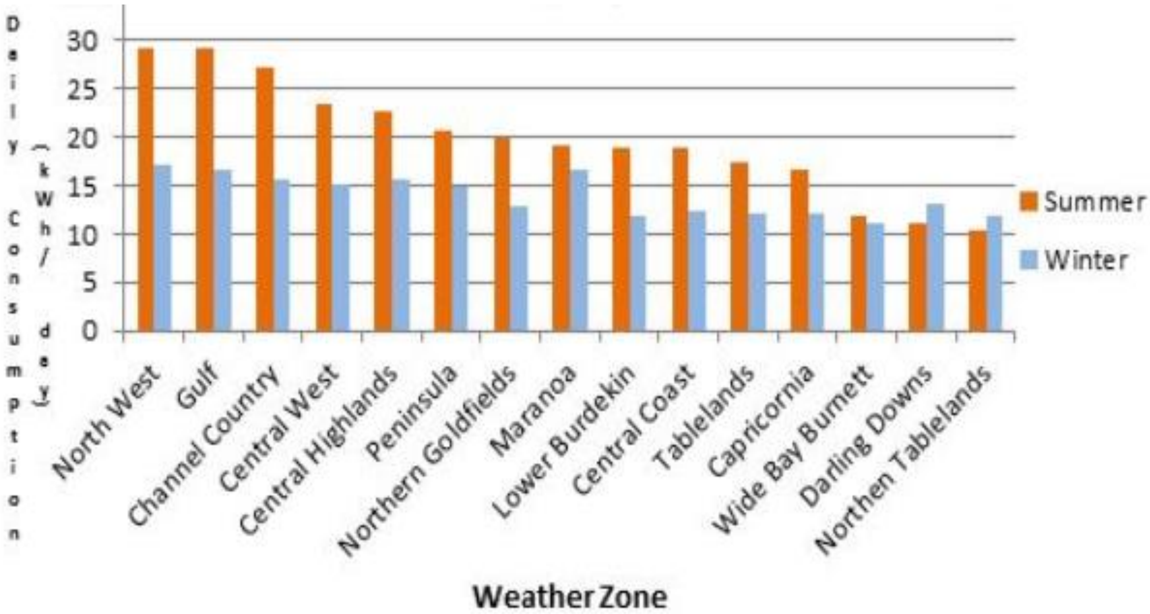

Figure 2-30 - Tariff 11 kWh/day - Summer Vs Winter [73]

The electricity bill for a residential property in Townsville with the post code 4814, with three occupants, no pool or gas connected main was studied. The billing for a year over the period of 15th of August 2015 to the 16th of August 2016 with Tariff 11 and 33 was averaged to a 21.01 kWhr per day with 2216kWhrs from February to May. This was in accordance with the Australian Government website "Energy Made Easy" that estimated 20 kWhr per day and 1804kWhr total in Summer for a household under those conditions with that postcode [88].

2.12 Economics of PV & BES System

Solar PV/BES technologies give consumers the ability to mitigate the cost of their electricity bills. Although the economics behind PV/BES installations are broad with many underlining variables which may affect the feasibility and returns. There are several models which are available to access and evaluate the performance of PV/BES systems [89, 90]. [27] The importance of modelling applications is due to the margin of variance between domestic households while maintaining a reasonable level of certainty in assessment. Each household varies in load, usage, model of PV/BES, tariff structure and rates [22]. The mains costs and savings can be divided in the associated section of the system. The main costs are listed below and illustrated in Figure 2-31:

- Solar Panels
- Inverter
- Battery
- Electricity tariff structure

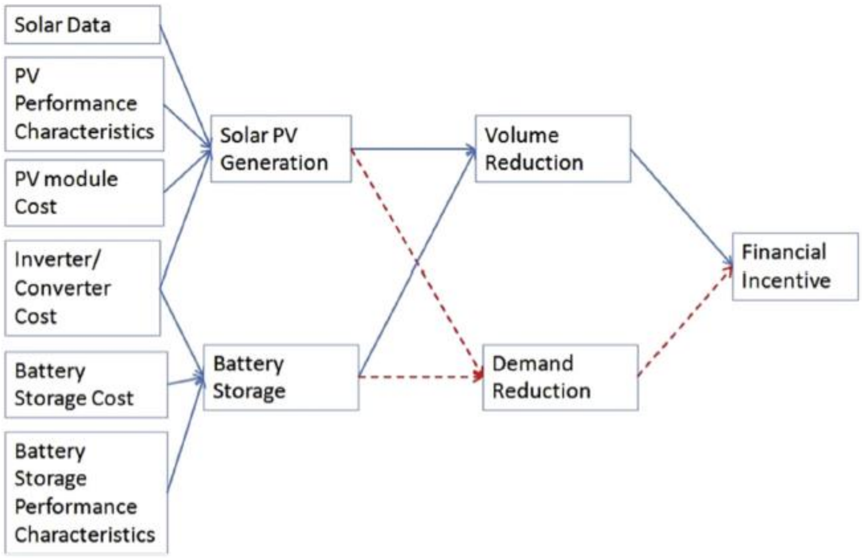

Figure 2-31 - System Variables and Saving Mechanisms [22]

The solar panels, inverter and battery all have their initial cost of capital and depending on the make and model have their associated efficiencies. The performance of the system will be affected by the region and solar irradiance. The performance is affected by the direction of the roof, the angle and if there is any partial shading during the day. The installation cost of the system will vary depending on the installation company and their associated varying rates. The electricity rates will affect the amount of savings as the power is offset from the cost of capital. The feed in tariff rate will directly affect the payback periods. If the government offers a rebate scheme for the installation of solar impacts payback periods. The time value of money must be mentioned as a cash lump sum payment against a financed scheme must be assessed for returns.

2.13 Market Software Competitors

There are software programs currently on the market which utilise past models and data sets to produce outputs which help to indicate to a potential consumer what savings or rate of returns on investments they can expect. They incorporate a Graphical User Interface (GUI) in which the user can enter data. There are currently several free programs which are available on the internet. They can be used to give indication to a potential customer the metrics for their installation and prospective returns.

These programs take input metrics in the form of cost over a billing period, post code, size of PV system, size of battery, tilt of roof, orientation of roof, energy supplier, tariff rates, operational pool or spa, if there are gas mains and when most of the electricity is consumed. Three of these programs will be analysed below and commented upon for user navigability, accessibility and aesthetic appeal:

2.13.1 Solar Power Calculator

https://solarcalculator.com.au/
This is the best of the three options. Offering a visually appealing graphical user interface with simple inputs. It gives the customer a graph and return on investment.

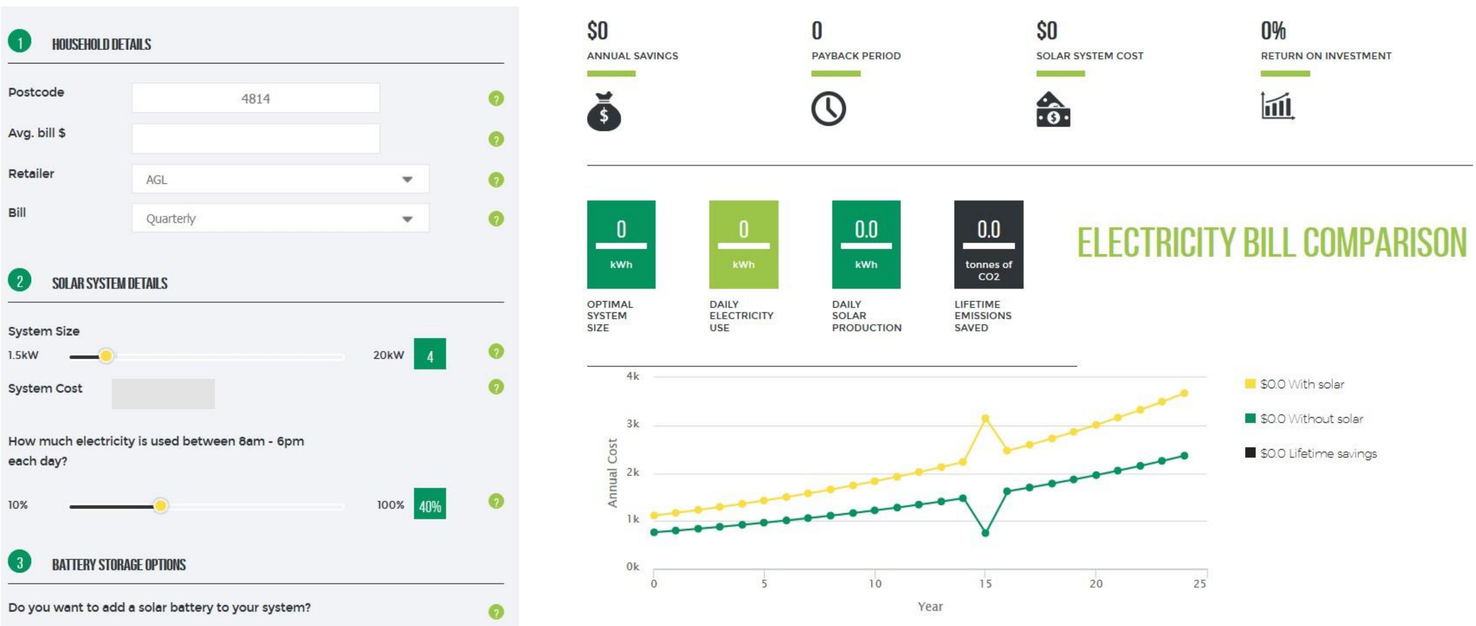

Figure 2-32 - Solar Power Calculate GUI

2.13.2 Solar Choice Solar & Battery Storage Sizing & Payback Calculator

https://www.solarchoice.net.au/blog/solar-pv-battery-storage-sizing-payback-calculator
This calculator is perhaps one of the least appealing interfaces but gives the customer easy inputs for the system type and size. It allows the customer to visualize the impacts of battery impacts.

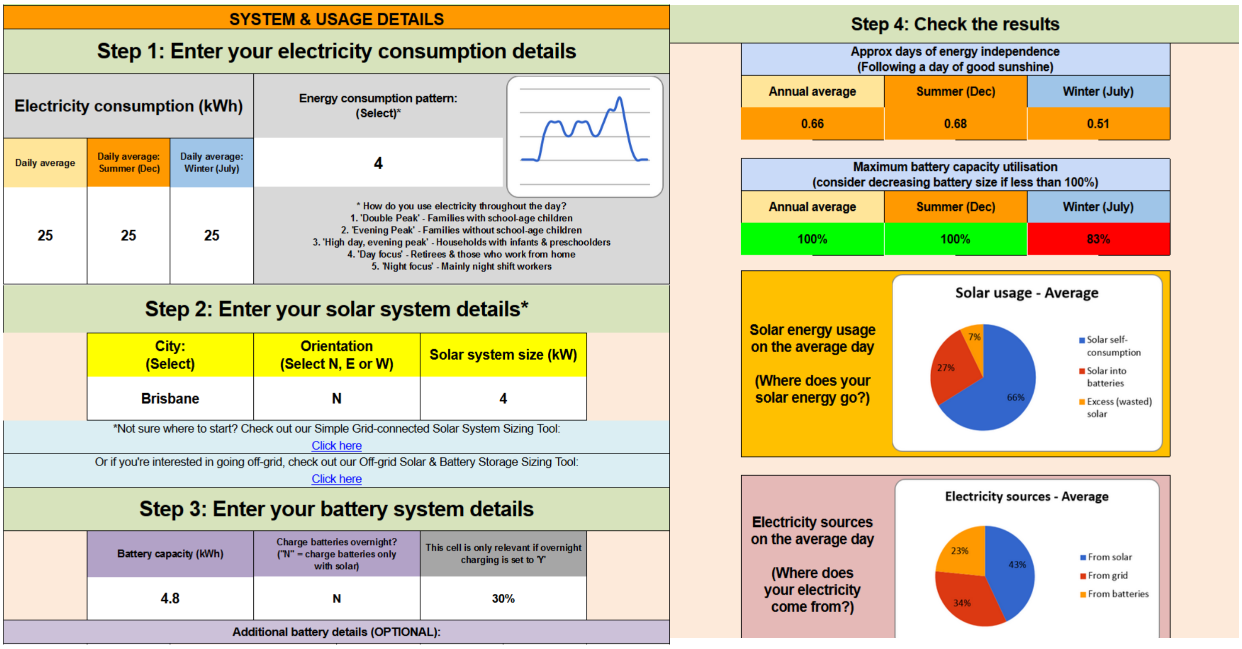

Figure 2-33 - Solar Choice GUI

2.13.3 Solar Savings Calculator

https://www.solarmarket.com.au/solar-savings-calculator/
This calculator has both simple and advanced options for the customer details. This feature allows a less experienced user to produce a reasonable estimate. The inputs are similar to the other previously analysed programs and has a good GUI.

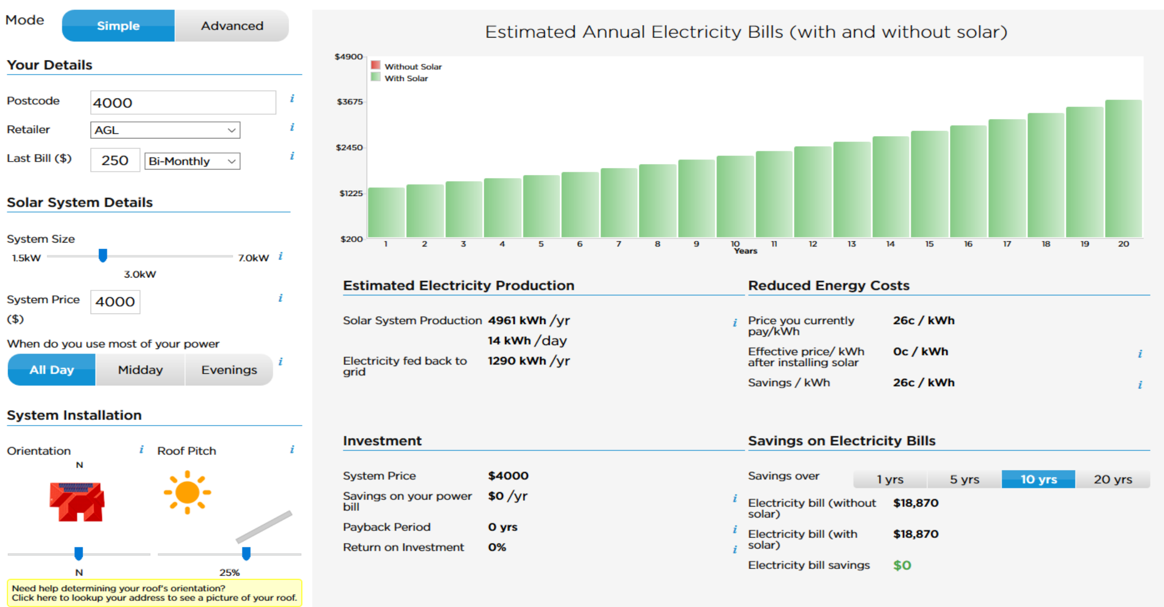

Figure 2-34 - Solar Savings GUI

2.13.4 Hybrid Optimisation Model for Multiple Energy Resources

The current market leader for modelling of renewable technology systems is a design tool called the Hybrid Optimisation Model for Multiple Energy Resources (HOMER) [91]. HOMER is a microgrid software developed by HOMER Energy and is currently the global standard for optimising microgrids. HOMER has been successfully implemented in the design and optimisation of military bases, grid connected campuses island communities and village power.

HOMER allows the comparison of thousands of possibilities to compare and access impacts of multiple variables such as wind speeds, fuel costs, solar irradiance and demand changes. There are heuristic techniques and algorithms embedded into the system which aids analysis. HOMER is a bulk processing tools which allows the simulation of a microgrid from time intervals of one minute for an entire year [92]. The interface for HOMER is shown below in Figure 2-35.

There are several modules which can be customised according to the simulation, these include:

- Biomass
- Hydro
- Combined Heat & Power
- Advanced Load
- Advanced Grid
- Hydrogen
- Advanced Storage
- Multi-Year
- MATLAB Link

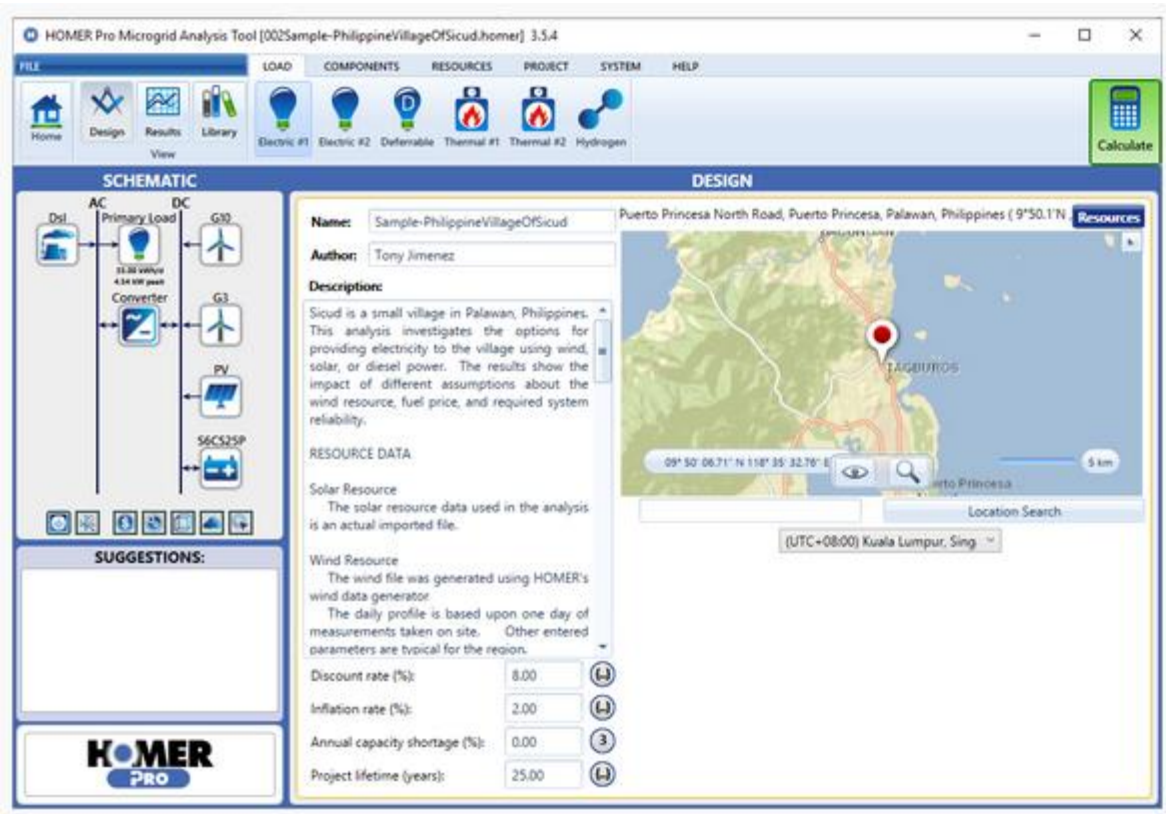

Figure 2-35 - HOMER GUI [77]

2.14 Summary of Findings

The literature reviewed in this document closely examines and analyses key issues, concepts, and technologies affecting the residential consumer, electricity network, and the electricity supplier. The key aspects of both current and future issues have been addressed with PV technologies, BES technologies, inverter systems, irradiance exposure, load profiles, tariff structures, network issues, shading effects, bypass diodes, energy payback, logistics and economics. The support that PV/BES hybrid systems can give to the electricity network to minimize strain and stabilize demand peaks, has enormous potential. The next question is what is the optimal size for reasonable stability with positive maximized economic return.

There is extensive literature covering the myriad of models which analyses different facets of solar PV installations and operation. Both Bernard and Li have modelled the amount of solar irradiance a roof will receive annually [9, 72]. While Jardini, Tonkoski, and Paatero have each conducted studies for the load profiles of domestic residential households and annual daily power consumptions [93-95]. Individually Faxas and Riahi made models for priority load control algorithms optimising energy management systems [89, 96]. The efficiencies of different types of solar cells were explored by Edalati [97]. There was limited information on the effects of orientation on PV production. No derating factors or formulas for degree change in orientation from north to decrease in PV production.

The efficiencies of both inverters systems and BES systems have been modelled by Kandatsu [98]. Zahedi submitted an interesting paper on the differing effects of different tariff schemes in Australia [99]. There has been extensive work with the life cycle assessment and economic analysis of low concentrating PV systems by De Feo and Petitio respectively [100].

The current market leaders for a user interface of solar power calculators were visited and commented upon over several metrics. There was not extensive coverage of optimised stages where a consumer could select certain levels of PV autonomy. The software for customers was difficult to access for checks and updates were disjointed. It appears that there was and continues to be a breakdown in the market for user friendly software and reliable feedback for potential PV customers. There was not an option in these programs for existing PV installation holders to upgrade or find an optimised operating point. Lappas says that there is an essential requirement for a simulation which functions under different locations, loads and financial circumstances. He goes on to state that there is no such model within an Australian context that provides a correctly represented characteristic applied to the commercial sale of electricity [22].

The disruptive voltage spikes that DER put to the grid during hours of peak production was shown to be an issue for the energy provider. The literature was not very supportive of adequate corrective measures to prevent or circumvent these reverse power flows. If there was an option or a rebate scheme for a level of battery capacity in a hybridized system which helped reduce peak demand and stabilized the grid from a DER level. Then this has the potential to become endorsed by Ergon and other suppliers and it may reach a governmental level with another rebate scheme for BES technology in QLD. There is a need for a platform to inform potential customers of the benefits of such an installation.

The potential for export of electricity of areas with higher solar insolation to areas which suffer high cloud cover or less solar radiation is becoming a probability. The feasibility study conducted by Blakers and Luther on the large-scale transmission of solar electricity to Southeast Asia from Australia found that it appears to be both technically and economically feasible over the next 40 years. They concluded by stating its possible for the Southeast Asian electricity system to be supported by up to one third by 2050; one third from Australian solar energy, one third from indigenous solar energy, and one third from conventional energy sources [101].

Despite the limited literature and access to programs for optimisation and upgrades this thesis will investigate the optimisation and deployment of sufficient models to size and optimise PV/BES systems. These models and program will be suitable for different residential households to provide maximum return on investments and minimize disruptive outputs to the grid. Three models will be created in a GUI for a MATLAB program each with varying levels of return and customer PV autonomy. There currently is no program which allows for dual array in varying directions as an input criterion. Furthermore, no programs currently have the option to allow for sub-circuit breakdown of various tariff structures. This appears to be a promising area with a high potential to create savings for customers at a domestic household level, as Lappas thought, the need exists as a major portion of electricity bills are due to peak demand times. This has the ability to help energy suppliers reduce peak demand to create a more stabilized and reliable electricity network for Australia [22].

3 METHODOLOGY

The aim of this chapter is to discuss the methodology and techniques which were employed to address the issues raised in the Literature Review. There was extensive research into the field of PV/BES technologies throughout the Literature Review to find the gaps in the existing body of knowledge, and where improvements and further research was necessary. This thesis calculated production and estimated costs for PV/BES installations with modelling program using GUI in MATLAB. This methodology depicts the development and criterion for the programs testability and was selected from several proposed methods. The layout was split into

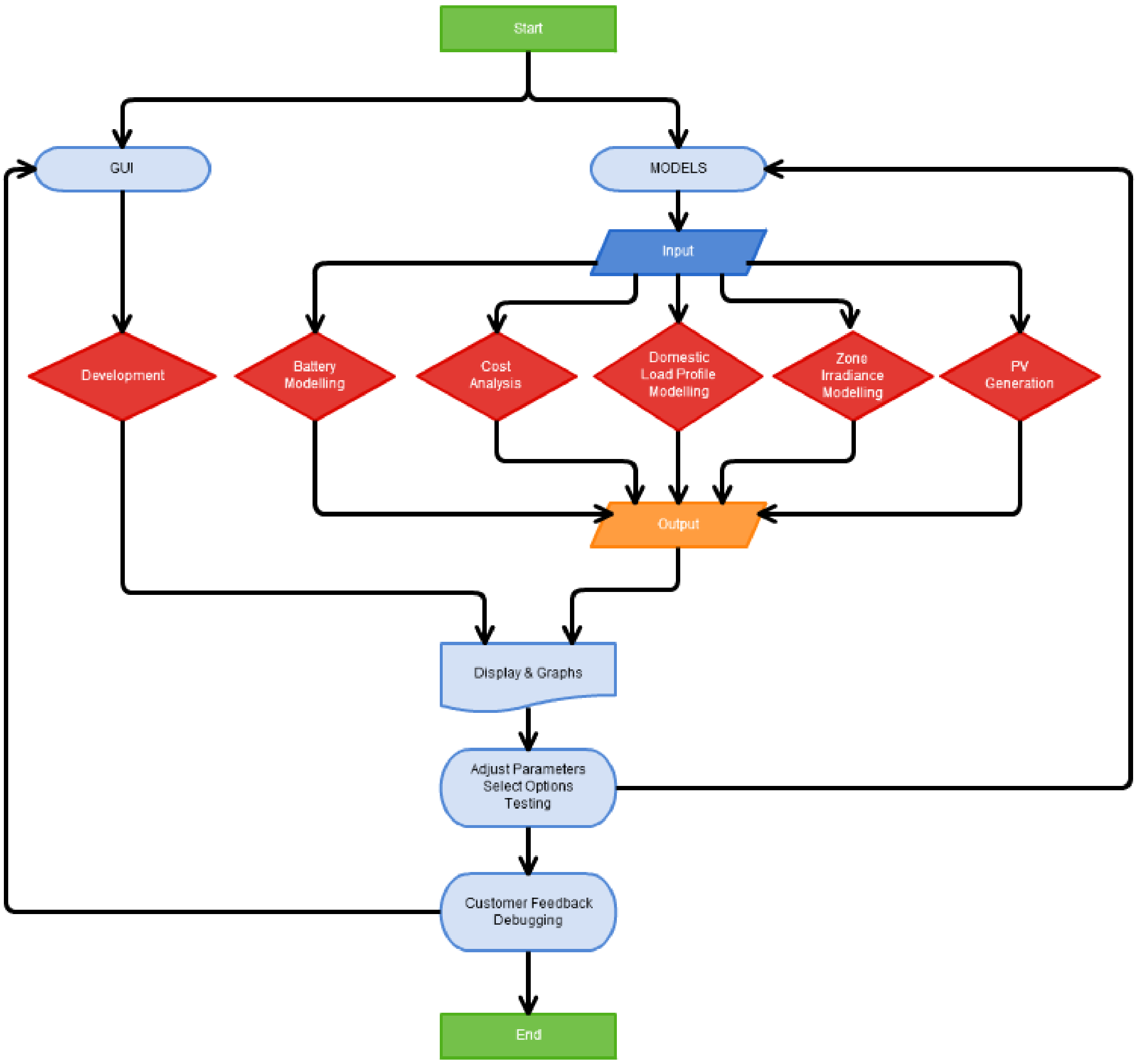

Figure 3-1 - Illustrated Scope of Works for Program Design

several different phases for ease of explanation and measurable progress milestones. The program was host to varying inputs for subsequent outputs while creating three graphs which will be addressed in greater detail in the proceeding chapter. One of the outputs for the program will be an economic assessment of the conditions with the corresponding economic climate.

The project will be modelled and verified where possible against existing pools of data and structures for analysis. Due to the capital cost of a PV installation, Battery and Inverter it was deemed economically unfeasible to purchase and to conduct physical tests to verify the results of the program. There were other factors which limited the possibility of physical trials such as time constraints, experience, electrical licenses/permits, premises for conducting experiments and test equipment. Future trials and tests for the program will be recommended in further research but is beyond the scope of this thesis. The substitution for simulations and comparative analysis was a reasonable trade off as there is minimal loss of accuracy and this technique has been utilised often and reduces external errors. The development of the program is illustrated in the above Figure 3-1. The illustrated Figure 3-1 shows how each section can be developed individually and incorporated into the finished working program.

3.1 Matrix Laboratory (MATLAB)

Matlab or (Matrix Laboratory) is a high-performance, multi-paradigm language environment which is currently in its fourth generation. Matlab was created by Mathworks and integrates computation, easy-to-use programming, matrix manipulations, graphing and plotting capabilities, interfaces and algorithms. Matlab can interface with other languages including C, C++, Java and Python. As of 2014 there are currently over 5 million users of Matlab.

Matlab also has the capabilities of:

- Scientific and engineering graphics
- Graphical user Interfaces
- Perform complex fast algorithms
- Prototyping, simulation and modelling
- Standard math and computation.

Given the capabilities, computational speed, modelling and simulation proficiencies, online technical blog, tutorials and support guides of Matlab, it was naturally selected as the program as which to conduct this thesis. Matlab will be used to realise the different phases of this paper and host the GUI for operation.

3.2 Graphical User Interface

The Graphical User Interface (GUI) was designed with an initial screen which to be visually appealing to entice users though aesthetics. The inputs were delivered on a prompt basis to the user which made it easily navigable. There was drop down boxes for options where available and auto corrects. If a value fell outside an allowable range then warnings would appear. Where possible there was scaling options. For the roof pitch, there was variable angle and for the orientation it was set to North.

3.3 Description of Functionality

The aim of this thesis was to develop a program to size and optimise PV/BES systems for different configurations of household demand, to maximize savings and disruptive outputs to the LV grid network. The cost of electricity for a domestic situation from a PV/BES system, up front capital expenditure and lifetime payback are to be modelled.

Three model screens were created in a GUI for a MATLAB program each with varying levels of return and customer PV autonomy. This appears to be a promising area with a high potential to create savings for customers at a domestic household level and help Ergon reduce peak demand to create a more stabilized and reliable electricity network for Australia.

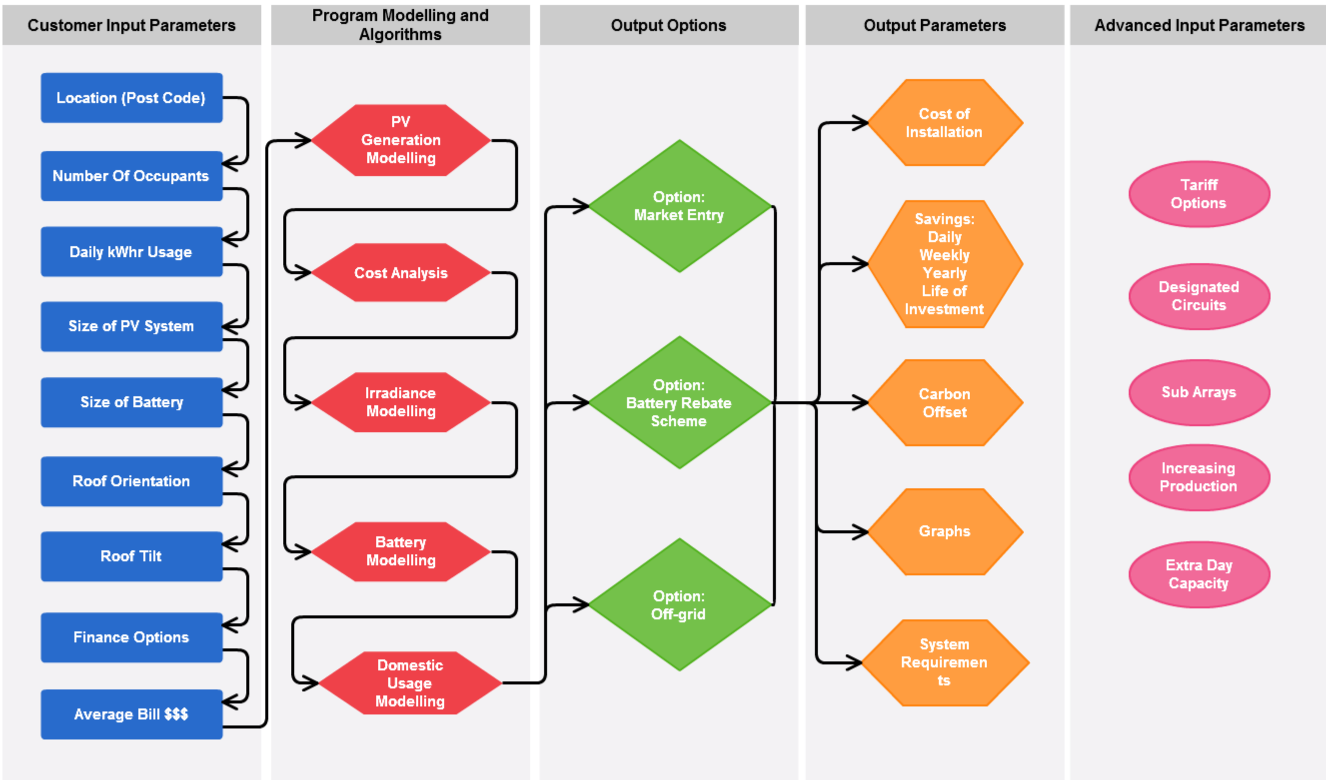

Figure 3-2 - Program Overview

3.4 Data Sourcing

The program collected raw data from several sources and it stored them in a source folder as a .mat file for access on processing. The data was manually entered into the containing files from the prospective websites. The postcode and geographical coordinates of cities around Australia was made available to the program though LatLong [102]. Latlong provided by the Latitude, Longitude and Postcode of a selected city.

The data for the average usage in households around Australia was found from the Australian Government [103]. This data was particularly useful as it contained daily average kWhr usage for households from one to four people. The data contained information for if gas or pool mains were connected. Not all the locations had data for gas connected main offsets.

The data for monthly averaged radiation incident on an equator-pointed tilted surface was found from NASA. NASA supplied data for PSH for differing angles of equator pointed surfaces [104]. The MathWorks help information was referenced during the coding process. To create the tab display the source doe "Multiple Tab GUI" by James Willmann was sourced and modified accordingly. [105]

3.5 User Parameters

3.5.1 Input Parameters

The input parameters are values which are entered into the program via the GUI. This allows an individualized assessment of every system to allow for unique differences. The input parameters will be sub-divided into a basic and advanced option. This allows for a browsing user to check possibilities readily and for an evaluating customer to make serious decisions and commitments.

The value which will be input first is the area post code. This allows for the program to check the average irradiance value. This has the second feature of checking tariff rates and the energy provider. The next input is the average daily kW or instead a quarterly bill kW/dollar can be input. This average would have been checked and if it is out of a certain tolerance an alarm will be displayed the user. The next input is for the solar array; what size and price. The next inputs are roof pitch and orientation. If there are two arrays, there is an option for two arrays with two orientations. Other inputs include if there is there any shading during the day and for how long. The next input is if battery storage is wanted; what size and cost.

The advanced input parameters are comprised of several different additional inputs and are described below. There is provision to allow for different tariff structures according to sub-circuit arrangement and peak demand. Other inputs include: annual bill inflation, feed in tariff kw from solar, opportunity cost and inverter replacement and battery replacement. There are different financing options such as solar loan, mortgage or upfront cash payment. The last inputs include the options for the maximum rate of return, or optimal grid stabilization for a battery rebate and for a standalone system.

3.5.2 Output Parameters

The output parameters will be indicative of what is selected on the input screen and will vary due to the available input values or availability. These will include graphs which indicate time to pay off and daily, monthly and yearly savings. The optimum point for each type of system will be displayed. The output parameters are explained in the following section.

3.6 Production Calculations

This section will focus on the calculation of the production values associated with each installation. The methods which will be used are the most common indicators to determine

3.6.1 Linear Tilt Approximation

The data from NASA held the values for PSH at different tilt angles. The program would access the source data and find the tilt values. Using the input value for the tilt angle it would find the next highest and lowest tilt angle. By taking a ratio between the highest and lowest of the different between the max and min it would multiply this by the PSH. This PSH was then used in the calculations and the data was indexed by columns while the state code used a switch statement which added to the row for referencing.

3.6.2 kW Production

The kilowatt production of the system was found using the equation from the Literature Review and the PSH which was indexed from NASA data. The production ratio was input from the user and the recommend values are stated in the Literature Review. The value of 0.85 was used in the GUI and will be justified later in the Discussion.

3.7 Risk Assessment

The risk assessment was completed as per the JCU procedure on the website. It is attached and all possible risks associated with the project we considered. The signed approved form is attached in the appendix.

3.8 Project Funding

The project is limited in its allowable budget and scope for the works of testing and were downgraded to comply with budget availabilities. The primary costs of the project are with licenses for the computer software. The Matlab Student Version was $115 AUD. Functions such as the “IRR” function were not included in the Matlab Student Version. The cost of the added tool box was $35 AUD.

3.9 Gantt Chart

The Gantt chart was created to give overview and scope for the works. Milestones were marked to ensure adequate progress was being achieved. The Gantt chart is attached in Appendix 1 and was reviewed throughout the project lifeline.

3.10 Economic Calculations

This section will focus on the methods to predict the financial outcomes associated with each installation. The methods which will be used are the most common indicators to determine profitability and are: Net Present Value (NPV), Life Cycle Cost (LCC), Annualized Life Cycle Cost (ALCC), Internal Rate of Return (IRR), Annual Payment (ANN-PMT), Electricity Price (EP) and Benefit to Cost Ratio (B/C) [90, 106]. Abdul summarized the merits and limitations of the economic tools below in Table 2-1.

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Table 3-1 *- Merits and Limitations of economic tools for calculation of LCC [76]*

Economic Tools	Merits	Limitations	Comments
Net Present Value (NPV)	Takes the time value of money into account. Generates the return equal to the market rate of interest [24, 25].	Not usable when the comparing alternatives have different life length. Not easy to interpret [23].	Most LCC models utilize the NPV method [23]. Not usable if the alternatives have different life length [24].
Simple Payback (SPB)	Easily calculated and interpreted [24].	Does not take inflation interest or cash flow into account.	Rough estimation if the investment is profitable [24].
Discount Payback Method (DPB)	Taking the time value of money [24].	Ignores all cash flow outside the payback period [24].	Only useful for screening but not decision making [24].
Equivalent Annual Cost (ECA)	Different alternatives with different life length can be compared [26].	Gives a mean value & doesn't specify the actual cost during each year of the LCC [26].	Comparing different alternatives with different life's length [26].
Internal Rate Of Return (IRR)	Results are presented in percent which gives an obvious interpretation [24].	Calculations need a trial and error procedure. Determined when the investments will generate an income [24].	Can only be used if the investments will generate an income [23].
Net Savings (NS)	Investment can be easily decided and [23].	Can be used if the investment generates an income [23].	Can be used to compare investment options, if the investment generates an income [23, 26].

3.10.1 Life Cycle Costing

The life cycle cost (LCC) is a sensible means for evaluating all the costs or total cost of a system over its associated lifetime and purchasing options. It is an important tool for ranking and selecting between alternative investments. It is a the sum of all the net present worth [27, 107, 108]. All types of projected costs such as maintenance, repair, operation, replacements and residual value are discounted to their present value for LCC of the project. The initial cost (C) of the system consists of the individual component prices such as PV panels, Inverter, batteries, electronic control and battery charger, the cost of civil work, installation. Operation and maintenance cost includes taxes, insurance, maintenance, recurring costs, etc.

$$LCC = \frac{(I_{pc}+ I_c+M_c+R_c+P_c)-R_v}{E} \tag{3-1}$$

Where:

- I_{pc} – is initial purchasing cost of equipment's
- I_c – is installation cost
- M_c – is operation and maintenance cost
- R_c – is replacement of system components cost
- P_c – is environment pollution mitigation and disposal cost of residues
- R_v – is salvage value of remaining materials
- E – is the energy produced by the system

The money for a project cannot always be paid upfront but is usually financed from a bank. The inflation and discount rates can affect a project as the value of the money is constantly changing. The inflation rate considers the depreciation of the money while the discount rate relates to the amount of interest that can be earned on the principal that is saved. The projected costs for an entire projects lifetime can be converted into a present worth value and evaluated. Using the below present worth factor [38]:

$$x = \frac{1+i}{1+d} \tag{3-2}$$

Where:

- x – is the present worth factor and is a dimensionless quantity
- i – is the inflation rate
- d – is the discount rate

We can now calculate the present worth for costs at the beginning of the year and a subsequent for costs at the end of the year. Costs at the end of the year are usually for maintenance and operation. There are two present worth factors which are used to help calculate the cost of a project. These are shown below [38]:

$$P_a = \frac{1-x^n}{1-x} \quad \textbf{(3-3)}$$

$$P_{a1} = XP_a \quad \textbf{(3-4)}$$

Where:

- n – is the lifetime of the project
- P_a – is cumulative present worth factor at the start of the year
- P_{a1} – is the present worth factor at the end of the year

Using the two factors for present worth we can calculate the entire Life Cycle Cost (LCC) for the project [38]:

$$LCC = \sum_{k=0}^{k=\infty} P_a C_n + \sum_{m=0}^{m=\infty} P_{a1} C_o \quad \textbf{(3-5)}$$

Where:

- C_n – is the expense occurred at the begginning of the year
- C_o – is the expense occurred at the end of the year

3.10.2 Annualized Life Cycle Cost

The Annualized Life Cycle Cost (ALCC) is useful for comparing two projects that do not have the same life span, making the LCC's incomparable; so, a comparison on an annualized basis is necessary. The ALCC would be assumed to be simply divided by the amount of years of the project. This is assuming an unchanging cost per year, which is not the case due to inflation and discount rates. Instead the ALCC is determined by:

$$ALCC = \frac{LCC}{P_a} \quad \textbf{(3-6)}$$

3.10.3 Annual Payment

If the money for a project is borrowed then the mortgage rate will affect the amount to be repaid. The rate at which the money is borrowed from the bank has a significant effect on the annual cost. For the calculation of the Annual Payment for a project the following formula will be used [38, 109]:

$$ANNPMT = LCC * j * \left[\frac{(1+j)^n}{(1+j)^n - 1}\right] \quad \textbf{(3-7)}$$

Where:

- $ANNPMT$– is the annual payment
- j – is the mortage rate set by the banking institution

The electricity price can be calculated from the ANNPMT and ALCC for a generating system. The calculation of the price for generation from a system is important to compare for viability of the project. To calculate the price of electricity two formulas will be use [38]:

$$Electricity\ Cost\ (ALCC)\$/kWhr = \frac{ALCC}{kWhr/year} \tag{3-8}$$

$$Electricity\ Cost\ (ANNPMT)\ \$/kWhr = \frac{ANNPMT}{kWhr/year} \tag{3-9}$$

Where:

- $kWhr/year$– is the power produced by the project per year in kilowatts

3.10.4 Present Value

The Present Value (PV) takes the present value of the money into consideration and is most accepted standard of assessment for financial investment [106].

$$P_v = \frac{F_n}{(1+d)^n} \tag{3-10}$$

Where:

- n – number of years
- P_v – Present value
- d – Discount rate
- F_n – is constant dollar cash flow

3.10.5 Net Present Value

The Net Present Value (NPV) takes the present value of the money into consideration and is an extension of PV value by adding up several years of cashflows [106].

$$NPV = -C_0 + \frac{C_1}{(1+d)^1} + \frac{C_2}{(1+d)^2} + \cdots + \frac{C_n}{(1+d)^n} \tag{3-11}$$

Where:

- n – number of years
- NPV– Net Present value

- d – Discount rate
- C_n – is dollar cashflow for the nth year

3.10.6 Internal Rate of Return

The Internal Rate of Return (IRR) is mathematically defined as the interest rate that allows the NPV to be equal to zero with a series of cashflows and is common economic tool for assessment. It is used for accepting or rejecting projects and is often viewed as a measure of efficiency [110].

$$0 = -NPV + \frac{C_1}{(1+IRR)^1} + \frac{C_2}{(1+IRR)^2} + \cdots + \frac{C_n}{(1+IRR)^n} \qquad \textbf{(3-12)}$$

Where:

- n – number of years
- NPV– Net Present value
- IRR – internal rate of return
- C_n – is dollar cashflow for the nth year

3.10.7 Return on Investment

The Return on Investment (ROI) is calculated as ratio of the earnings or profits of a project to the investment cost. There are different methods to calculate the profits of a project which are the total summed (Simple ROI) or the discounted present value (Discounted ROI). The Simple ROI does not take into the assumed future discount rates [110].

$$Simple\ (ROI) = \frac{Overall\ Financial\ Gain}{Total\ Investment\ Cost} \qquad \textbf{(3-13)}$$

3.10.8 Simple Payback Period

The Simple Payback Period (SPB) is determined by dividing the total investment cost by annual cashflow. The initial cashflow is extrapolated for every year. This fails to take into account the discount rate of money which is included in the Discounted Payback Period (DPB) [110].

$$Simple\ Payback\ Period = \frac{Total\ Investment}{Estimated\ Annual\ Net\ Cash\ Flow} \qquad \textbf{(3-14)}$$

4 MATLAB GUI PROGRAM

The previous section highlighted the important variables which were critical for the operation of a program to efficiently model the operation of a solar hybrid system. This section will outline an example calculation from the Solar Solution GUI and how it can be used to size a household. The program was coded into the Matlab workspace and the chosen option to have the information entered through a prompting system. This method was selected to allow the user sufficient time to source the correct information, for accurate simulations, and to facilitate smooth navigability.

The GUI was split into 5 different tabs which were Data Acquisition, Input Data, Estimated Production, Finance Options, and Display. This design was selected as it gave the user the ability to switch between options and created a user-friendly environment. The following section will explore the program and provide snapshots of how the user could input data.

4.1 Data Acquisition

The inputs were entered in the Data Acquisition phase using a prompted style option. Figure 1-1 shows the first screen upon entry to the GUI.

Figure 4-1 - Entry Screen to GUI prompt

Figure 4-2 shows the succession of prompting proceeding the user.

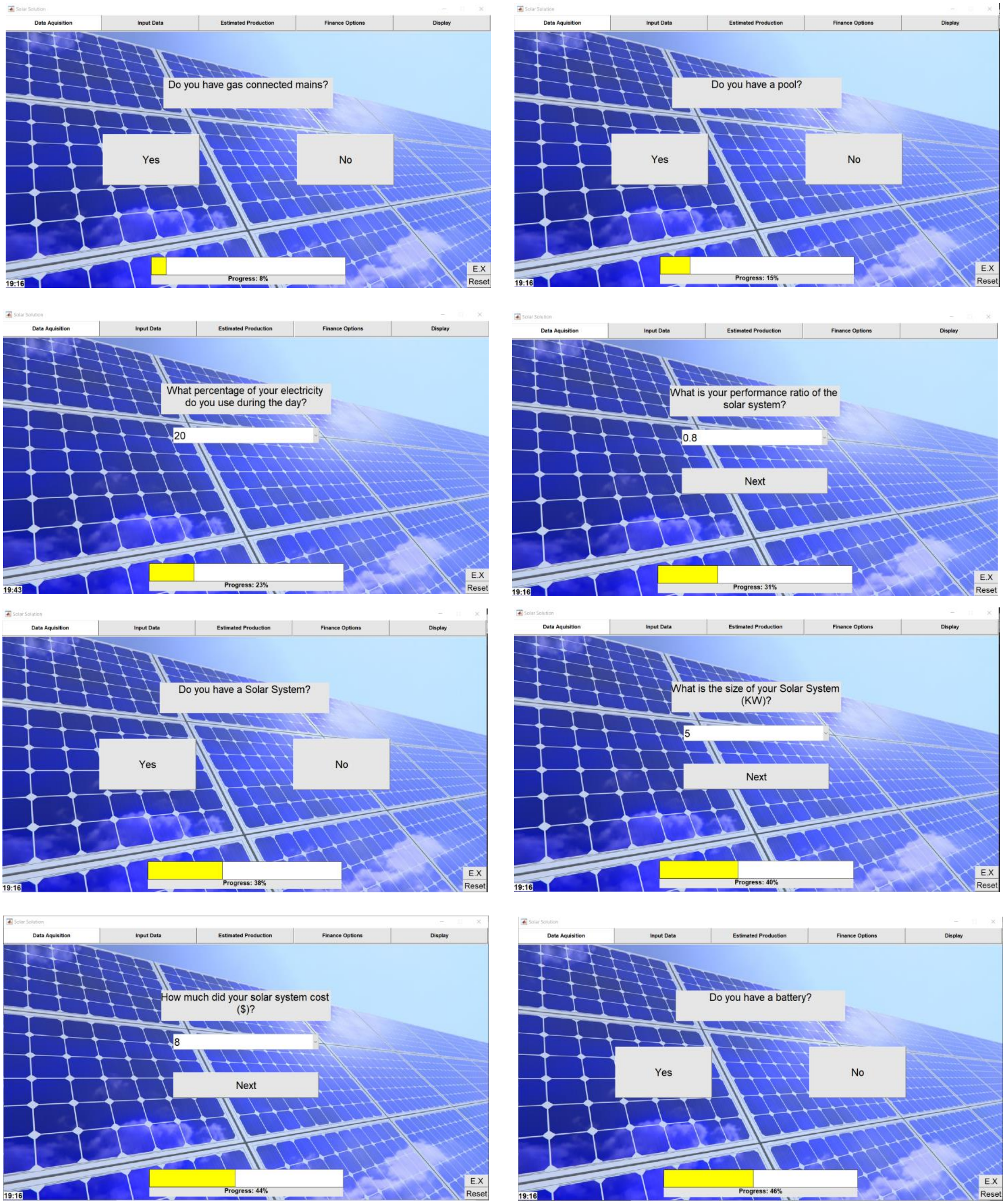

Figure 4-2 - Data Acquisition phase of GUI prompting

Figure 4-3 shows the succession of prompting proceeding the user (continued).

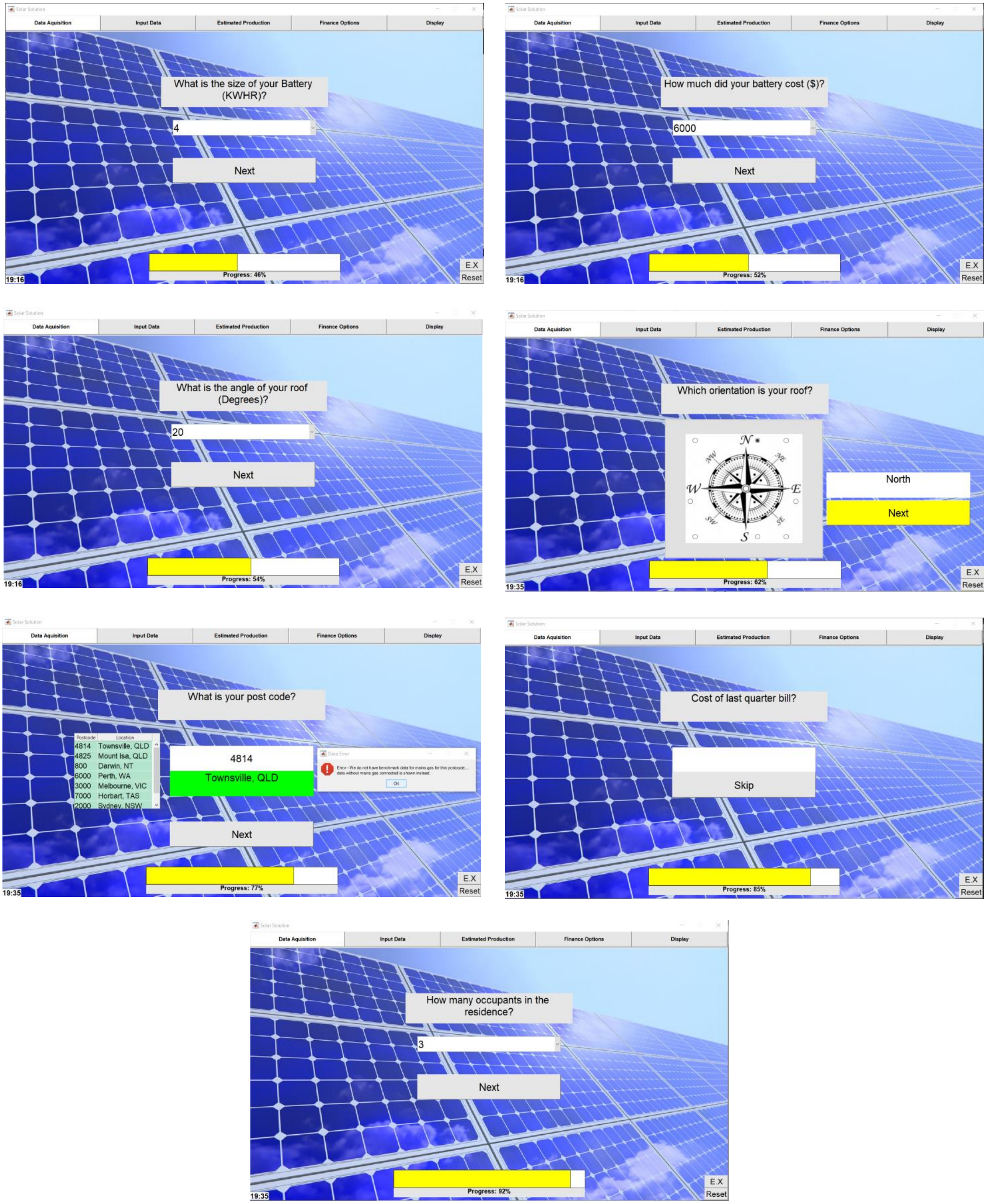

Figure 4-3 - Data Acquisition phase of GUI prompting

4.2 Input Data

The Input Data tab is automatically selected after the final prompt has been answered on the Data Acquisition tab. This displayed to the user all the information which has been entered and allowed verification before checking the results. This tab is shown in Figure 4-4.

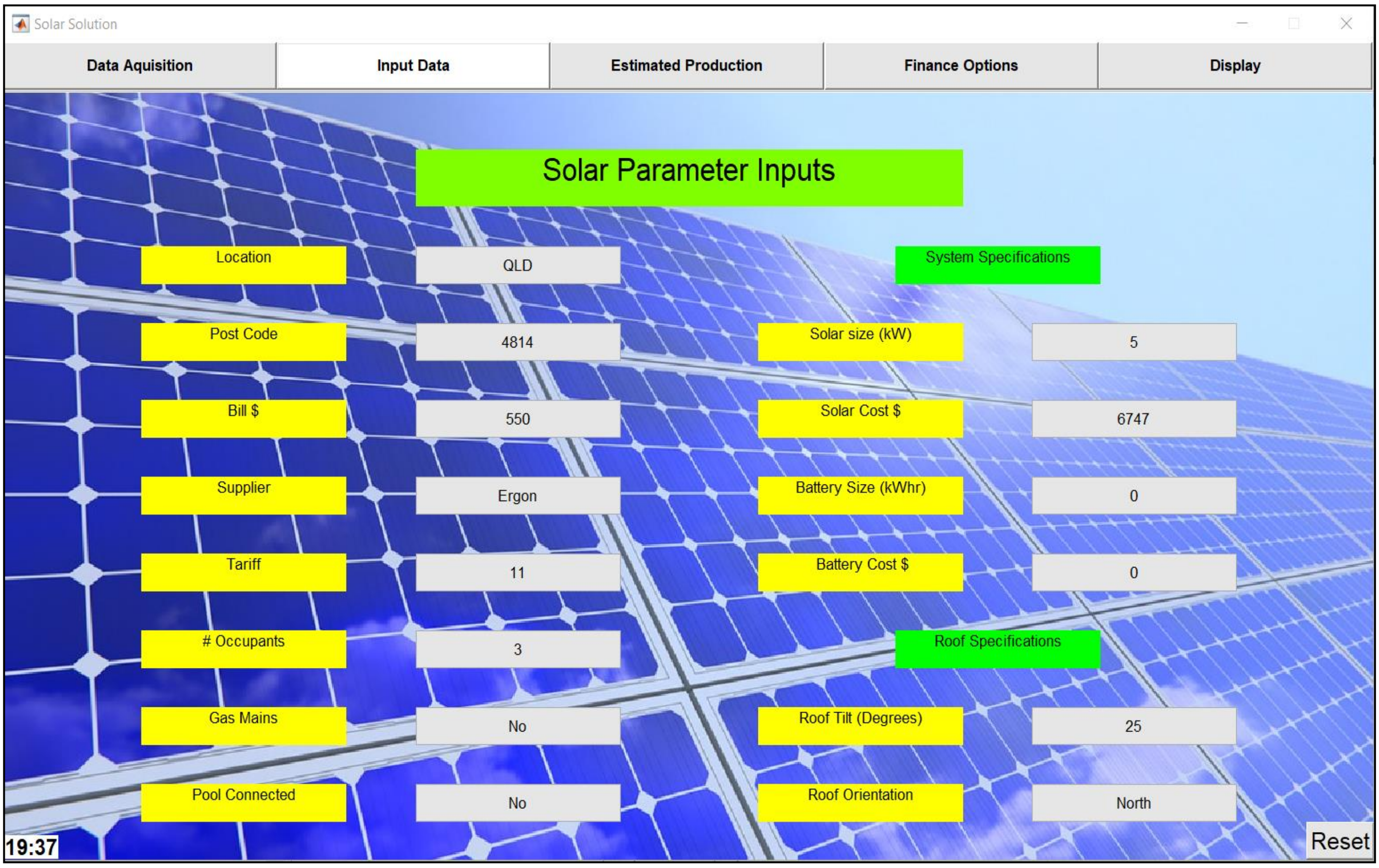

Figure 4-4 - Input Data tab

4.3 Estimated Production

The Estimated Production tab shows the estimated daily production for the solar system by the solar panels, the storage from the batteries and how much will be imported. The daily cost headings allow the user to compare how much they are spending per day on import and export and their actual savings for a day. This allows an easy comparison and effective savings. The Monthly Average kWhr Production graph shows how much they can expect their solar system to produce per day per month. This tab is shown in Figure 4-5.

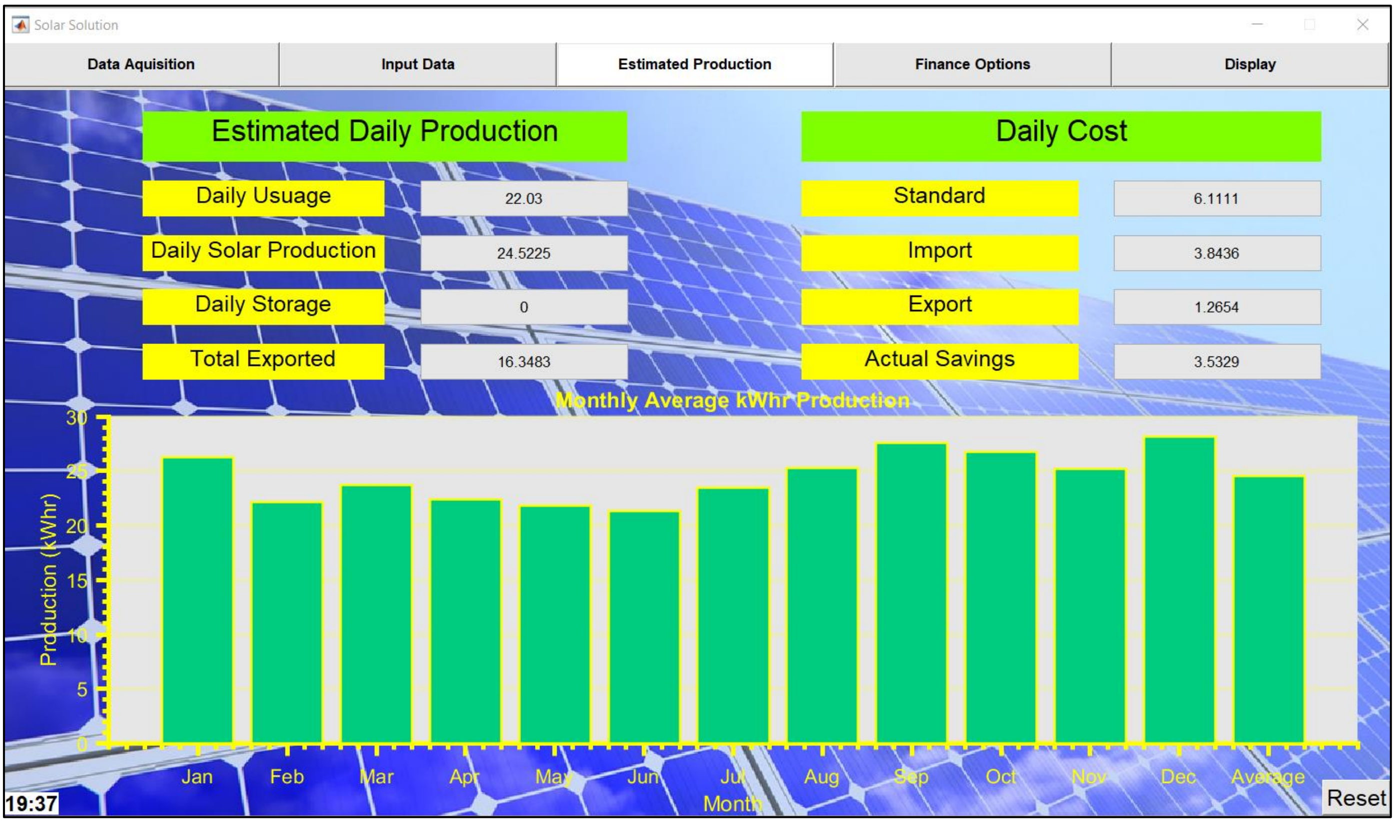

Figure 4-5 - Estimated Production tab

4.4 Finance Options

The Finance Options tab (Figure 4-6) displayed to the user their finance options based on Annualised Life Cycle Cost and Annual Payment calculations. There was an Internal Rate of Return calculation and Return on Investment calculation.

The expected savings heading displayed to the user easily readable expected savings for a month, year, 10-year and 20-year period. This heading also contained a payback period calculation and Net Present Value calculation.

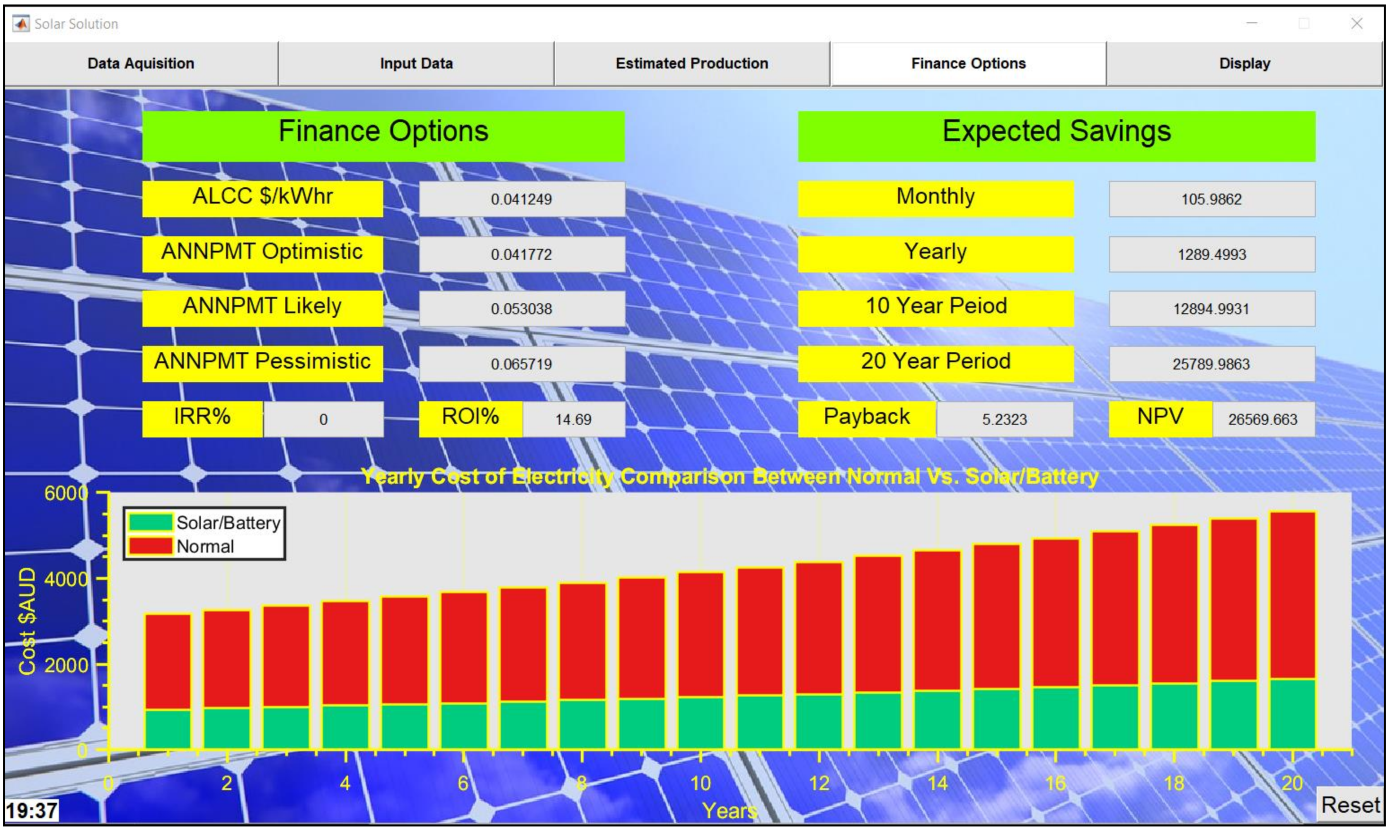

Figure 4-6 - Finance Options tab

4.5 Display

The Display tab (Figure 4-7) allowed the user to visualise what was occurring in their household. This tab had a solar panel, solar inverter, battery inverter, main panel, grid and home icon. Green coloured headings displayed how what was created, stored or exported. The red coloured headings showed import and usage.

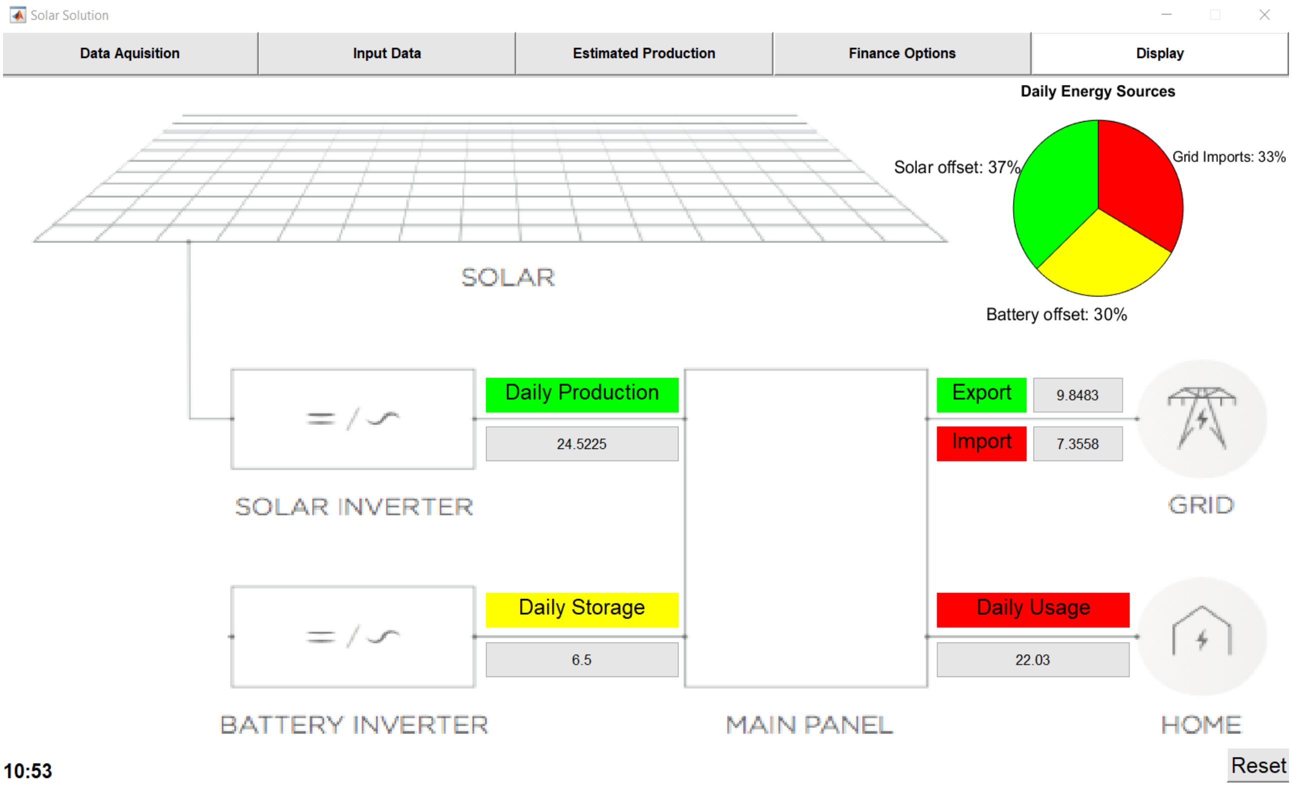

Figure 4-7 - Display tab

4.6 Additional Features

There were several features which were added to the program for aesthetics and to facilitate rapid operation. Firstly, a clock feature was added to the South-West corner. Secondly, a reset button was added to the South-East corner giving the user the ability to reset if any incorrect information was inadvertently entered. Thirdly, error message dialogues were included which gave extra information, errors or warnings when entering information or if it was not available.

Two graphs were included, one to depict expected daily production per month for the solar system, and the second was to show the calculated saving per year for the installed solar system over a 20-year period. These two graphs were visual aids to help relay the possible savings to the user. A progress bar was added to the design to all the user to gauge progression while entering the input information. When the GUI was loading a “loading bar” was added to give indication on the time to completion of the calculations.

5 RESULTS

The Solar Solution Matlab GUI was tested by selecting three different locations, Darwin, NT, Townsville, QLD and Hobart, TAS and analysing the outputs from the program. Several parameters were kept constant to analyse the desired figures. The stars in Figure 5-1 illustrate the locations which were selected for testing.

Figure 5-1 - Locations selected for analysis (Gold star denotes location)

These locations were selected due to their diversity in location around Australia and variance in latitude which are specified in Table 5-1. The equator tilted panels is equal the latitude of the location to provide maximum solar irradiance. The GPS locations were specified in from the source LatLong [102].

Table 5-1 - Locations Selected

Specifications	**Location**		
City	Townsville	Darwin	Hobart
Post Code	4814	800	7000
Latitude	-19.259	-12.463	-42.882138
Longitude	146.817	130.846	147.327195
Equator Titled Panels	-19	-12	-42

5.1 Constant Parameters

To successfully test the program several parameters were kept constant to order to provide a basis to examine the output from the program at the prospective locations. The inputs which were kept constant are listed in Table 5-2.

Table 5-2 - Constant Parameters

Constant Variables	Value
Gas Mains Connected	No
Pool Connection	No
Electricity Load Profile	30%
Performance Ratio	0.85
Solar Size	5 kW
Solar Cost	7000 AUD
Battery Size	10 kWhr
Battery Cost	9700 AUD
Roof Tilt	Equator tilted
Roof Orientation	North
Bill Entry	No
Number of Occupants	3

5.2 Output Production Figures

The output production figures were retrieved from the program and are shown in Table 5-3 for each prospective location.

Table 5-3 - Output Production Figures

City	Townsville	Darwin	Hobart
Daily Usage (kWhr)	19.2	18.5	27.2
Daily Production (kWhr)	24.6925	26.945	17.7225
Daily Storage (kWhr)	10	10	10
Total Exported (kWhr)	6.4617	7.9633	1.815
Daily Cost – Standard ($AUD)	5.3261	5.1319	7.5453
Daily Cost – Import ($AUD)	0.2688	-0.1336	3.1325
Daily Cost – Export ($AUD)	0.5001	0.6164	0.1405
Daily Cost - Actual Savings ($AUD)	5.5574	5.8819	4.5532
Energy Sources Analysis - Solar Offset	42.9%	47.3%	21.7%
Energy Sources Analysis - Battery Offset	52.1%	52.7%	36.8%
Energy Sources Analysis - Grid Imports	5.1%	0.0%	41.5%

5.3 Output Finance Figures

The output finance figures were retrieved from the program and are shown in Table 5-4 for each prospective location

Table 5-4 - Output Finance Figures

City	Townsville	Darwin	Hobart
Annualized Life Cycle Cost ($/kWhr)	0.1603	0.1469	0.2233
Annual Payment - Optimistic ($/kWhr)	0.1623	0.1488	0.2262
Annual Payment - Likely ($/kWhr)	0.2061	0.1889	0.2872
Annual Payment - Pessimistic ($/kWhr)	0.2554	0.234	0.3558
Internal Rate of Return	4.5967	5.3334	2.132
Return on Investment	-1.8406	-1.261	-3.6341
Expected Savings – Monthly ($AUD)	166.721	176.4563	136.5966
Expected Savings – Yearly ($AUD)	2028.4	2146.9	1661.9
Expected Savings - 10 Year Period ($AUD)	20284	21469	16619
Expected Savings - 20 Year Period ($AUD)	40569	42938	33239
Payback Period (years)	13.0149	12.2969	15.8852
Net Present Value ($AUD)	16682	19742	7212.1

5.4 Monthly kWhr Production Graphs

The average monthly kWhr per day expected production for each location is shown in Figure 5-2, Figure 5-3 and Figure 5-4.

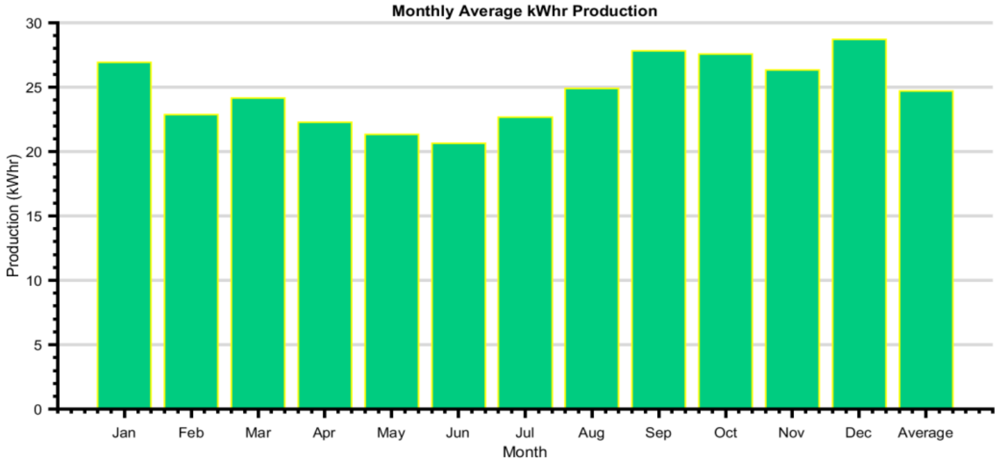

Figure 5-2 - Monthly kWhr Production - Townsville

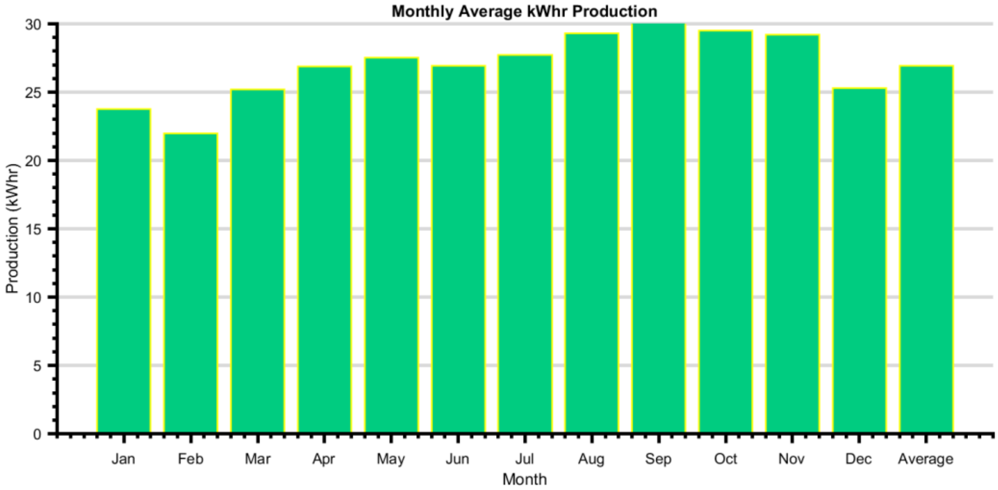

Figure 5-3 - Monthly kWhr Production - Darwin

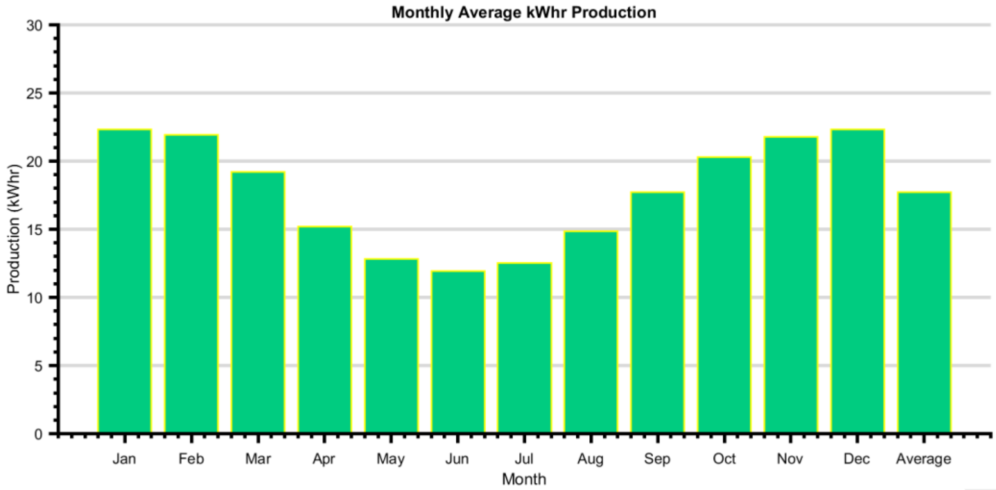

Figure 5-4 - Monthly kWhr Production - Hobart

5.5 Yearly Saving Plots

The yearly cost of electricity for installations with PV/BES and without are shown for each location in Figure 5-6 ,Figure 5-5 and Figure 5-7.

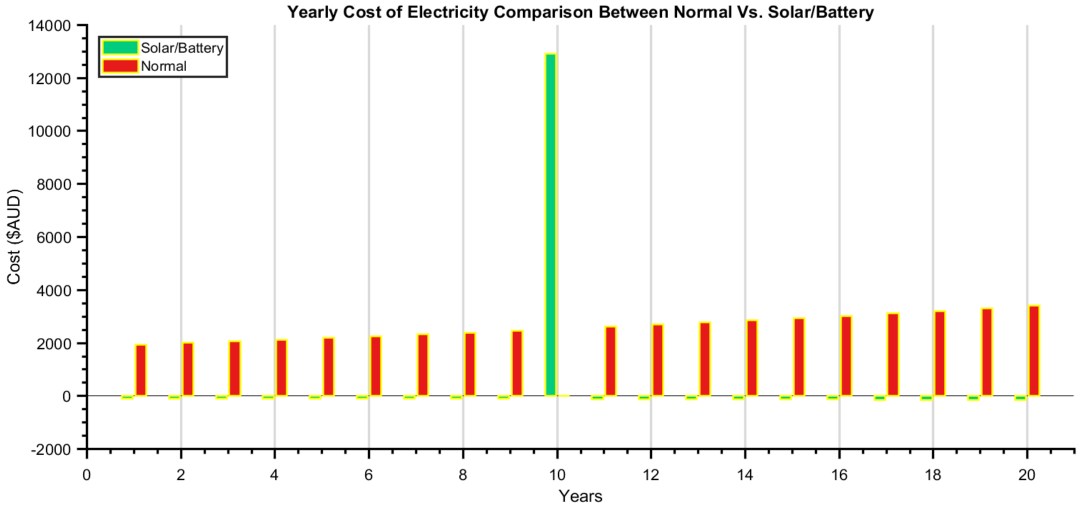

Figure 5-6 - Yearly Savings with Solar Vs. Normal - Rate Townsville

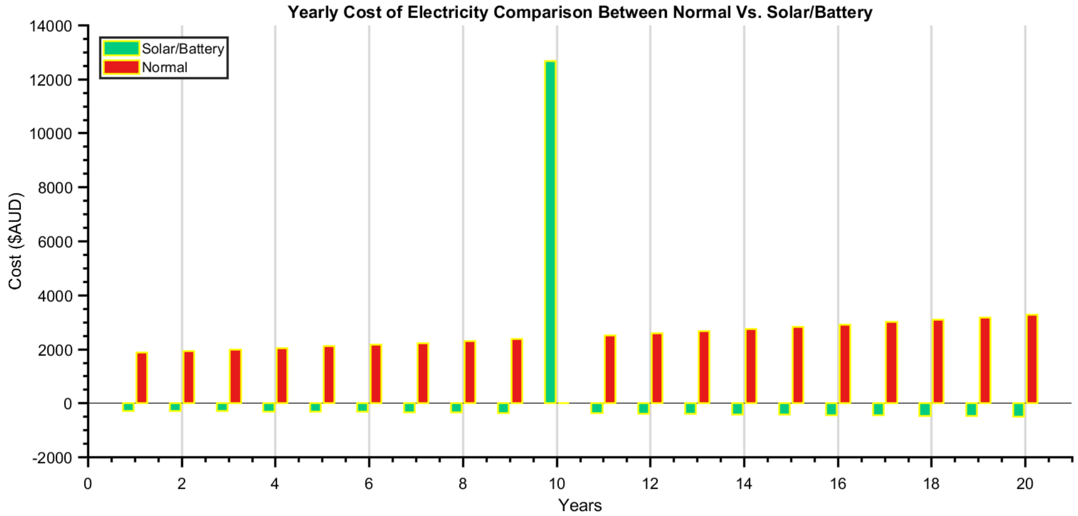

Figure 5-5 - Yearly Savings with Solar Vs. Normal Rate - Darwin

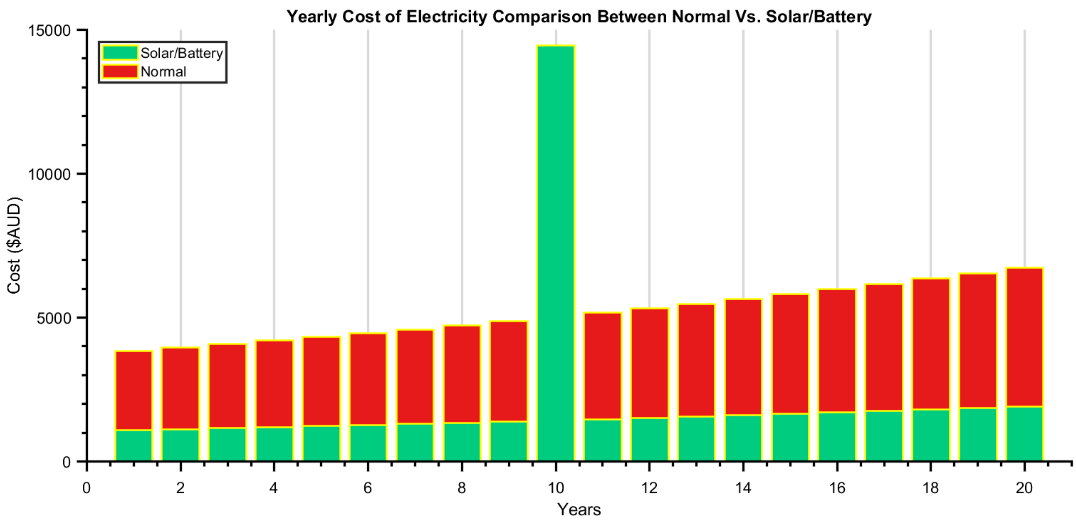

Figure 5-7 - Yearly Savings with Solar Vs. Normal Rate - Tasmania

5.6 Daily Energy Sources Charts

The daily energy sources for each location are shown in Figure 5-8, Figure 5-9 and Figure 5-10.

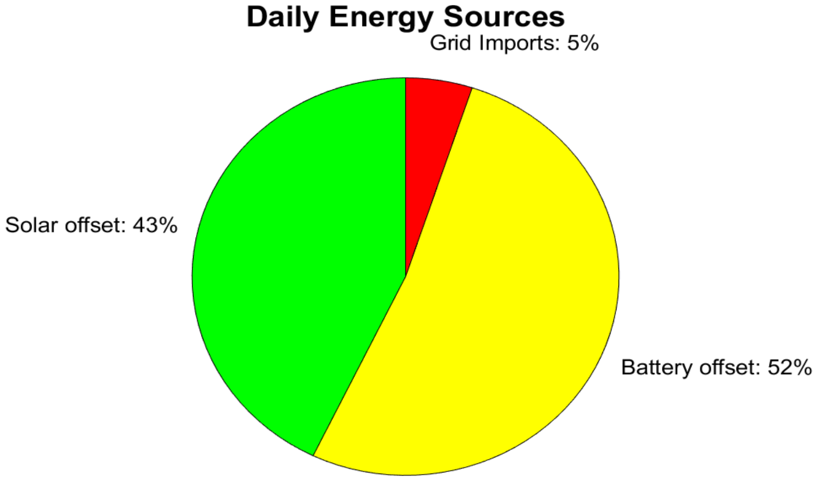

Figure 5-8 - Household Energy Sources Pie Chart -Townsville

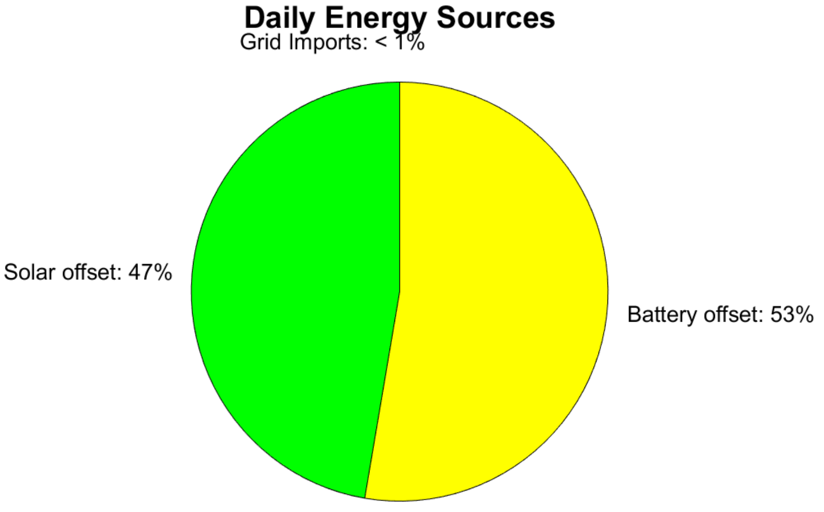

Figure 5-9 - Household Energy Sources Pie Chart Darwin

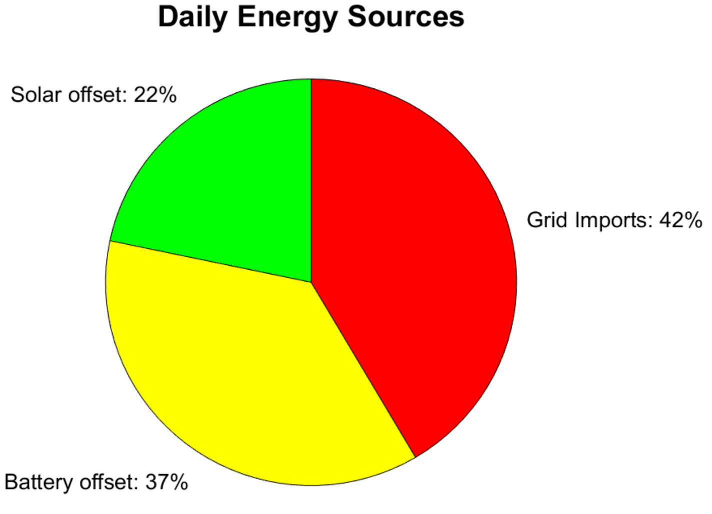

Figure 5-10 - Household Energy Sources Pie Chart Hobart

6 DISCUSSION

The Solar Solution GUI has the ability to handle many scenarios while incorporating robust error checking properties. The results and following discussion only consider the situation for a residential household at three different locations without gas mains or pool connection. In reality, the Solar Solution has the capacity to facilitate results for non-battery applications, non-solar applications and with the inclusion of the former and later combined, and excluded. The provision for different lifespan projects and financial calculations is possible but was not utilised.

6.1 Effects of Selected Location & Constant Parameters

The locations which were selected for analysis around Australia were: Townsville, Queensland, Darwin, Northern Territory and Hobart, Tasmania, and are shown in Table 5-1. These locations were selected due to their variance in latitude from the equator. Darwin has a latitude of -12 degrees from the equator, Townsville -19 degrees and Hobart -42 degrees from the equator. The varying latitudes were expected to give a decreasing value of production the higher the degree -- and validate the program. The postcode for each location was entered into the program as Townsville, 4814, Darwin 0800 and Hobart, 7000.

The decision to excluded a gas mains connection and pool connection was done to increase the accuracy of the calculations. This was due to the availability of information and benchmark data by the Australian Government to accurately compare gas and pool daily usage figures. The electricity load profile was set at 30% of daily usage during the day, to identify how much electricity would be used in the household after production. The performance ratio was assigned the value of 0.85 for the simulations, as was stated in the literature review, and is an accurate depiction of the overall efficiency of a PV/BES system.

The solar size and cost of 5kW and $7000 AUD were based off average values for combined cost and install, as stated in the Table 2-2 in the literature review; therefore, the brand and style were not relevant. The battery size and cost of a 10kWhr and $9700 AUD were based on the LG Chem RESU, with a cost price of $8222.50 and installation ranging from $1000-$2000 AUD. The numeric value of $9700 AUD was deemed acceptable for both cost and installation price of battery. The roof orientation was set in a north facing direction and the roof tilt was given the latitude value of the respective location i.e. Townsville was set at 19 degrees roof tilt due to the latitude location of -19 degrees.

The monetary value of the bill input was set at zero in order to allow the program to calculate the average usage from the post code entry and the internal imported database. The number of people was set at three for an arbitrary value which allowed the correct indexing of the Australian Government data. This indexing cross-referenced the tariff and solar feed in rates. These values were maintained consistent and prices varied due to demand, supply, population, environment, access, and time. In order to create a suitable simulation, the tariff rate of 27.74 c/kWhr and solar feed in rate of 7.448 c/kWhr were assigned. These rates are similar to the tariff rate of 27.071 c/kWhr and solar feed in rate of 7.74 c/kWhr hour assigned by Ergon Energy as seen in Table 2-4.

6.2 Energy Production Feasibility Calculations

The following section will discuss the output production figures shown in Table 5-3. The daily usage in kWhr which was output from the simulations for Townsville, Darwin and Hobart was 19.2, 18.5, and 27.2 respectively. Ranking these from lowest to highest corresponds with Darwin, Townsville and Hobart, which shows corollary with increasing degrees of latitude at -12, -19 and -42 – this aligns with what we would expect for usage. This higher usage at the higher latitudes is an effect of heating from ambient inside atmosphere and water.

The Peak Sun Hours (PSH) were calculated from data supplied by NASA for monthly averaged radiation incident on an equator-pointed tilted surface (kWh/m^2/day) and are shown in Appendix 7. The amount of solar irradiance the Earth receives was outlined in the literature review; Using the conversion formula (2-18) to PSH, it was expected that higher concentrations would appear at lower latitudes. This was confirmed by the Daily Production (kWhr) values: 24.6925 for Townsville, 26.945 for Darwin, and 17.7725 for Hobart.

The angle of the solar panels was set at their prospective latitudes for maximum solar irradiance at each location. The values validate the fact that lower latitudes receive the most solar irradiance/PSH. The daily production values were calculated using the formula (2-17) in the literature review with the size of the solar system at 5 kW and with a performance ratio of 0.85. The change per month for Townsville, Darwin and Hobart is shown in Figure 5-2, Figure 5-3, and Figure 5-4. From these graphs, the clear change throughout the year across all three is obvious. The production peaks over the sunny summer season months and then dips in production over the winter season months. This dip is caused due to the tilt of the Earth as it orbits the sun.

Figure 5-4 for Hobart displays the best example of the trend hypothesised, with a clear increase and decrease through from the solstice-equinox-solstice-equinox; this progression is here quite apparent. The Townsville production graph (Figure 5-2) shows a dip during the winter season but has lower than expected production months for November and March. This nonuniformity is again observed in the production graph (Figure 5-3) of Darwin for the months of February and December.

The daily storage was calculated from the size of the battery and was considered fully charged at the end of the day by either solar production and imports, or both. In all three locations, the charge of the battery was 10 kWhr and equalled the size of the battery.

The total exported in kWhr was the net result of the kilowatts produced daily minus the kWhrs used in the household and the daily storage. The kilowatts produced daily and daily storage have been mentioned above while the kWhrs used from the solar during the day was a percentage of what was produced. This percentage was a constant parameter and was set to 30%. Therefore, the total exported in kWhr for each Townsville, Darwin and Hobart was, 6.4617, 7.9633 and 1.815.

It can be seen that the location Darwin has 7.9633 kWhr of exports while Hobart only has 1.815 kWhr. This is due to Darwin having more peak sun hours, and consequently, higher production of 26.945 kWhr to Hobart's 17.7225 kWhr. This means that a larger amount produced minus the battery and 30% internal usage will yield a larger surplus of energy to be exported to the grid.

All the monetary values stated in this discussion are based in Australian Dollars (AUD) and the indication for currency will be omitted henceforth. The “Daily Cost – Standard” for each location was based on the tariff rate of 27.071 c/kWhr which was multiplied by the daily usage of kilowatts for each location. Townsville was $5.3261, Darwin was $5.1319, and Hobart was $7.5453, which corresponded to the higher import of kWhrs paying the most -- due to cost being associated with rate multiplied by the amount of kWhrs used. These daily values represent the normal cost of electricity for the customer without solar or battery offset.

The “Daily Cost – Standard” is the benchmark for cost of electricity at each representative location and was utilised for the calculation of “Daily Cost – Actual Savings”. The “Daily Imported” was found by subtracting the daily storage and how much solar was used in the residence from the average usage. The “Daily Cost – Imported” was created by multiplying the amount of kWhrs imported by the import tariff rate stipulated. The “Daily Cost – Export” was created by multiplying the amount of kWhrs exported by the stipulated solar feed in rate.

The result of the PV/BES system was having the household supplied or partially supplied electricity at a new rate. The actual savings were calculated from subtracting the cost of imports from the standard rate and adding the cost of exports. The actual savings for each location was $5.5574, $5.8819 and $4.5532 for Townsville, Darwin and Hobart. The saving value for Hobart was $4.55 per day off the household electricity cost. This was increased when examining Townsville at $5.55 and Darwin at $5.88.

Despite these figures, it was noted that the standard cost of electricity for Darwin was $5.13 and the amount of savings from the installation of a PV/BES system was $5.88. These figures are apparently incorrect, yet it must be taken into account that the PV/BES system supply the entire households electricity needs. The surplus of this electricity is then sold back to the grid; thus, this electricity is earning money. Hence, there is a gain larger than the cost price of electricity for this region. The same effect was observed in Townsville with a cost price of $5.32, while the actual savings were $5.55.

Figure 5-8, Figure 5-9 and Figure 5-10 show the pie charts in relation to each location. The solar offset percentage (green) for Townsville, Darwin and Hobart is 42.9%, 47.3% and 21.7% respectively. The battery offset percentage (yellow) for Townsville, Darwin and Hobart is 52.1%, 52.7% and 36.8% respectively. The grid imports percentage (red) for Townsville, Darwin and Hobart is 5.1%, 0% and 41.5% respectively. It is noted that Darwin does not import any electricity from the grid with 0.00% grid imports.

It is affirmed that this 0.00% grid importation of electricity is due to the high solar electricity production which covers the household usage, battery recharging and exports to the grid. This production covers the household as seen in the load profiles in [2.8] from between 6:00am to 6:00pm. The average kilowatt usage in Darwin for this type of residence is such that outside of the solar production period the 10 kWhr of the battery is sufficient to supply.

Moreover, the values of 42.9% and 47.3% for solar offset in the locations of Townsville and Darwin are approximately the 30% of the load profile which was established earlier. The offset at these two locations are in the forties, while Hobart at 21.7% is lower as a consequence of two reasons. Firstly, the higher daily kWhr usage for a domestic residence; Secondly, the lower PSH and subsequent decreased solar production.

6.3 Economic Payback Potential

The following section will discuss and analyse the output financial figures shown in Table 5-4 for each location. All the monetary values stated below are based in Australian Dollars (AUD) and the indication for currency will be omitted henceforth.

The Annualized Life Cycle Cost ($/kWhr) was calculated using the Life Cycle Cost (LCC) outlined in the methodology (Section 3.7) and the formula (3-6). The ALCC is a means to compare two projects that do not have the same lifespan, making the LCC's incomparable; so, a comparison on an annualized basis is necessary. The ALCC was used instead of the LCC to compare these projects, as the provision for different lifespans of projects was incorporated into the program; hence, the ALCC was selected as output from the program. The ALCC in these instances incorporated a battery replacement at 10 years which was fused into the LCC.

The Annual Payment (ANNPMT) was selected as an output for financial analysis and incorporated three different mortgage rates of 1%, 3.5% and 6%. The ANNPMT was calculated using the formula (3.7) and each rate. The rates were split into optimistic (1%), likely (3.5%) and pessimistic (6%) to give a broad analysis of potential payment schemes and mortgage climates, as these significantly affect the cost of electricity.

The ANNPMT and ALCC were calculated on a $/kWhr basis over their lifetimes using the formula (3-6, 3-7) outlined in the literature review for the generating systems. The ALCC for Townsville, Darwin and Hobart was $0.1603, $0.1469 and $0.2233 respectively. The optimistic ANNPMT for Townsville, Darwin and Hobart $0.1623, $0.1488 and $0.2262. The likely ANNPMT for Townsville, Darwin and Hobart $0.2061, $0.1889and $0.2872. The pessimistic ANNPMT for Townsville, Darwin and Hobart $0.2554, $0.234and $0.3558.

Considering that Queensland's energy provider (Ergon Energy) charges $0.27071/kWhr, it sets the benchmark for the cost of electricity comparisons in Queensland. Using this as a reference, it disqualifies the likely and pessimistic values for ANNPMT in Hobart, which are above at $0.27071 at $0.2872 and $0.3558.

The ALCC cost price of electricity is for money that is not financed from a bank i.e. cash or savings; it is an economically viable production strategy for the locations, as they are all below $0.23, which is $0.04/kWhr below the benchmark of $0.27071. The ALCC cost price in Darwin is $0.1469 which is approximately half the cost of the benchmark cost of electricity.

Economic Option	Average
Annualized Life Cycle Cost ($/kWhr)	0.1768
Annual Payment - Optimistic ($/kWhr)	0.1791
Annual Payment - Likely ($/kWhr)	0.2274
Annual Payment - Pessimistic ($/kWhr)	0.2817

Table 5-4 shows the average for each location in ALCC, and ANNPMT with optimistic, likely and pessimistic mortgage rates. The average ALCC $0.1768/kWhr while the average ANNPMT for an optimistic mortgage rate is $0.1791/kWhr; this is a difference of 0.013 cents/kWhr. Under these economic conditions, it is apparent that the difference in cost of electricity is minimal between ALCC and ANNPMT options, and both are applicable and below the national benchmark cost.

Results from Table 5-3 show that as the mortgage rate increases the cost of electricity increases in a ANNPMT option. The average for ANNPMT option with a likely rate is $0.2274/kWhr and a pessimistic rate is $0. 0.2817/kWhr. The likely ANNPMT is still below the benchmark but the pessimistic ANNMT rate is $0. 0.01099/kWhr over.

The expected savings or Net Savings (NS) were calculated using the daily savings figure and extrapolated to one month, year, 10 years and 20 years by a linear expansion, e.g. daily savings multiplied by 30 for a month, 365 for a year, etc. These values were not adjusted for inflation or discount rate, they are linear extrapolations for analysis. These values represent what would be saved from a normal bill without PV/BES system installed. They incorporate the net gain from the cost of electricity offset by the PV/BES system. These values do not take into account the cost of the investment or replacement costs.

The Expected Savings – Monthly for Townsville, Darwin and Hobart was $166.721, $176.4563 and $136.5966; the Expected Savings – Yearly was $2,028.4, $21,46.9 and $1,661.9; the Expected Savings – 10 Year Period was $20,284, $21,469 and $16,619; and the Expected Savings – 20 Year Period was $40,569, $42,938 and $33,239. These figures seem high, as for Townsville after a 20-year period the expected savings are $40,569, which appears optimistic and will be discussed in-depth in the next section.

The Figure 5-5, Figure 5-6, and Figure 5-7 in the results show the plots of the yearly savings for Townsville, Darwin and Hobart. All three figures show how the cost of electricity is going to rise through inflation and this trend is clearly depicted (red). Figure 5-5 & Figure 5-6 have increasing negative values (green) for the cost of PV/BES – this indicates savings to the customer. This is due to the exportation and the solar feed in rates which a shown as a negative value and cash inflow. Figure 5-7 shows the green PV/BES cost with the red overlapping it, which indicates the cost of the supply of the household with and without the system.

Simple Payback (SPB) Period is the length of time required for an investment to recover its initial outlay in terms of profits or savings. This was calculated from the equation 3-14 in the literature review, which was the cost of the investment divided by the cashflow for one year. Townsville, Darwin and Hobart each had 13.0149, 12.2969, and 15.8852-year payback periods respectively. Hobart was the longest payback period due to the lower latitude causing poor production while coupled with higher daily kWhr usage -- which increased imports and subsequently costs.

Whilst the potential savings of a project are critical, it is important to consider the value in the present sum of money, in contrast to some future value it will have when it has been invested at compound interest; this is usually the difference between cash inflows and outflows all discounted from the future. This was why the cost of the project was depicted in the Net Present Value (NPV), to give a monetary value of the present worth. The NPV of Townsville, Darwin and Hobart was $16,682.00, $19,742.00, and $7,212.10 correspondingly. This clearly identifies

Darwin as having the highest present-day worth; while Hobart was less than 50% of both Townsville's and Darwin's NPVs.

Measuring the profitability was important for budgeting the capital in potential investments for possible clients, which is why the Internal Rate of Return (IRR) was incorporated into the Solar Solution. The syntax and function to solve for IRR in Matlab code is "Return = irr(CashFlow)". This function is not included in most Matlab versions, so it was coded manually, but the upshot is the compatibility across all editions. The formula which was coded was outlined in the methodology formula 3-12. In brief, the IRR is the discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero.

Through simulations the program yielded for Townsville, Darwin and Hobart an IRR of 4.5967%, 5.3334%, and 2.132%. Remembering that the IRR is often defined as the theoretical discount rate at which the NPV of a cash flow stream becomes zero, and that the discount rate assumed in this paper was 4%, the values from 2.1-5.3% are realistic. This is within +/- 2% of the assumed value, and validates the supposition.

The discounted Return on Investment (ROI) is another common tool for evaluating the efficiency of investments, and Townsville, Darwin and Hobart had ROI's of -1.8406%, -1.261%, and -3.6341% respectively. All the ROI's are negative values with the most negative value corresponding to Hobart. These values were negative due to three factors; firstly, the assumed discount rate of 4%; secondly, the assumed inflation rate of 3%; thirdly, the assumed cost of the batteries and other components. The decision to use the discounted ROI, and not Simple ROI and the accumulation of the net savings (NS), was due to deciding the time value of money was crucial for accuracy. The change in value of money is important and by not accounting for potential shifts can lead to disingenuous data and results. If a Simple ROI approach was undertaken, then the values would have been positive.

6.4 Assumptions

As mentioned previously in the 6.3 Economic Payback Potential section, the values for the discount rate, mortgage rates and inflation rate were assumed. The inflation rate was set to 3%, the mortgage rate was 1%, 3.5% and 6%, and the discount rate was 4%.

Performance and efficiencies were described in the literature review with the batteries between 80-95% efficiency, PV panels ranging from 25.6-37.9%, and inverters between 90-99% efficiency. Thus, with the loss in cabling and assuming some degradation a system efficiency of 85% is practical.

Lifetime expectancy for the solar system was set at 20 years for the simulations but the program could be changed to 25 years. This assumption was derived from 2.3.8 Costs of PV from the literature review which stated that systems generally last 25 years. 20 years was deemed an acceptable assumption as the batteries were only guaranteed for 20 years, and thus, this incorporated an offset for PV operating degradation which was not included.

The tariff rate was arbitrarily assigned the value of 27.74 c/kWhr as this was similar to Ergon Energy's tariff 11 rate of 27.071 c/ kWhr. The solar feed in rate was similarly based off Ergon

Energy's 7.448 c/kWhr at 7.774 c/kWhr. This rate was assumed to not change over the 20-year period which is not likely the case. This was why a small increase was combined into the rates.

The assumption of the battery being replaced at 10 years was founded in the data sheet for the Telsa Powerwall 2 and the 10-year guarantee. This gives the customer a guarantee of 20 years for the assumed cost price of the batteries. The cost of the second battery was not discounted, inflated or trended for the tenth year, but instead assumed to be equal to the cost of the initial battery. This assumption was used in the ALCC. The decreasing cost of a battery was assumed to offset the inflation rate. The battery was assumed to be fully charge to its capacity at the end of each day.

Equal cash inflows for the calculation of the Simple Payback (SPB) period were assumed. The cash flows were not adjusted due to the difficulty in assuming the change in price of electricity rates, inflation, discount and future costs. Thus, the SPB was selected to minimize necessary assumptions and potential margins of error.

Whilst calculating the LCC for the project, several assumptions and trade-offs were made. The salvage cost of the PV/BES system were assumed to be equal to the degradation costs for the system; as the viability of the salvage of PV systems is not well established. The maintenance costs of PV and the battery were assumed to be equal to the recyclability costs. Figures for the salvage costs and recyclability costs are hard to estimate, which is why the trade-offs were opted over unreliable data. The degradation of the PV/BES system was factored into the unadjusted cost of the second battery, as a precautionary measure.

6.5 Limitations in Matlab GUI Modelling

The Solar Solution GUI has several limitations which could not be circumvented due to access restrictions, data, time and resource constraints. These limitations will be highlighted in the following section.

The data which was used from NASA [104] for the PSH is not an updating resource. The data is static and saved in a.mat file. If the data were updated then the GUI would not have access and lose accuracy. A solution would be to have the GUI continually updating periodically. This solution would be applicable to the daily usage data from the Australian Government [88]. This data is subject to the same static nature as the NASA data; a similar solution would be recommended.

The data from the Australian Government [88] did not benchmark data for gas mains in many locations. This is not an issue with the Solar Solution GUI but access to reliable data for gas connected residential households around Australia was non-existent. Access to the most recent data for irradiance, prices, efficiencies and sizes may be an issue and will affect the outcomes associated with the program.

Accuracy is important for all estimations and by using a set tariff rate for each location it was affected. By tailoring the input data to each location, energy supplier and tariff, an enhanced estimation would be effected. This set tariff rate would allow the amount entered in the bill entry prompt to accurately back calculate the average usage.

Although tailoring each location for the energy provider would render estimations improved, the reality is that the program only works with flat-rate tariffs. If all rates could be used for time of use, block tariffs and fixed daily ‘supply charges’ or electricity retailer discounts (e.g. ‘pay on time’ and ‘direct debit’ discounts) then the program would have a reduced margin of error.

Load profiling of households is a method to predict the expenditure of electricity during the day. The program currently only judges the electricity used daily by the amount entered by the user. If several scenarios were predicated for e.g. peak at night, peak at morning, double peak or constant then perhaps the accuracy could be improved.

Despite this study only using a northern orientation for each location, the program did not possess the ability to use arrays with differing orientations. This was partly due to the data supplied from NASA, which was north-orientated. The literature review (Section 2.3) examined the lack of information for differing orientations and their effects on PV performance.

Dual arrays were capable of being entered into the program, but as mentioned above the ability to have different orientations was not possible; if two arrays were installed in a household then the total combined kilowattage would be used for the sizing, e.g. two 2.5 kW arrays would be combined to a 5kW system. This is only a true approximation if they were both orientated true north.

A linear approximation was used to calculate the PSH from the NASA data for households with differing roof tilt angles. This approximation may not be entirely valid as it is mapping a degree based value to a linear value. Although not entirely correct, the net result of error would be negligible as the optimum tilt angles are recorded in the NASA data.

6.6 Solar Solution Comparison Table

Table 6-1 is a comparison of the Solar Solution to other solar sizing software which is currently on the market. The table displays the Solar Solution GUI (blue), the Solar Choice (green), the Solar Power Calculator (red) and the Solar Savings (orange). The left column lists allowable inputs to the programs and the ticks indicate if the program has the capacity to facilitate the input parameter.

Table 6-1 - Solar Solution GUI Comparison

FEATURES	The Solar Solution	Solar Choice	Solar Power Calculator	Solar Savings
Allowable Inputs				
Prompted Entry	✓	✗	✗	✗
Gas Mains Connected	✓	✓	✗	✗
Pool Connection	✓	✓	✗	✗
Electricity Load Profile	✓	✓	✓	✓
Performance Ratio	✓	✓	✗	✓
Solar Size	✓	✓	✓	✓
Solar Cost	✓	✓	✓	✓
Battery Size	✓	✓	✓	✗
Battery Cost	✓	✓	✓	✗
Roof Tilt	✓	✓	✓	✓
Roof Orientation	✓	✓	✓	✓
Post Code Entry	✓	✓	✓	✓
Bill Entry	✓	✓	✓	✓
Number of Occupants	✓	✗	✗	✗

7 CONCLUSION

The optimisation and estimation of solar photovoltaic and storage for domestic use was investigated in this thesis; through the creation of a GUI in the program Matlab and proceeding analysis of output data through extensive simulation. It has successfully created a modelling program both for production and economic output from PV/BES systems. The economic analysis included life cycle costing and cost of electricity, to provide a readily comparable figure. Whilst solar calculation programs have been created previously, no program hosts the features which are utilised in the Solar Solution GUI.

The primary focus of this work was on creating a model which compiles recent data, existing theories, trends, and methods, and incorporating them into a syntax in the modelling workspace of Matlab. To achieve this objective, it was necessary to analyse every variable which affects PV/BES systems. In so far, it was necessary to set certain parameters at values deemed reasonable in accordance with the literature. Thus, the Solar Solution GUI with its features and parameters was tested and analysed by the selection of several locations with varying latitudes throughout Australia. The selected sites of assessment were Townsville, Darwin, and Hobart.

1) Based on the results from the output data of the program, it was shown that due to the lower latitudes receiving higher PSH, the kWhr production per day for a given PV system was increased.
2) It was found that data for domestic residential households for kWhr usage, namely gas connected configurations was not sufficient.
3) Households with combined installation of PV/BES in each location produced a reduced cost of electricity per kWhr in respect to the Australian benchmark cost.
4) A Darwin residence supplied with the sizing specified in this document of PV/BES was found to be self-supportive -- without the importation of electricity from the grid.
5) The annual payment costs of a PV/BES system were found to be economically feasible in the mortgage climate rates of optimistic and likely, while the pessimistic figures were viable in most situations with a lower latitude.
6) All simple payback periods were within the lifetime of the projects and net savings were substantial compared to investment cost.
7) Discounted return on investment yields were calculated at negative integer values, due to the methodology used in assuming a higher discount rate against lower inflation rates.
8) Whilst syntax and programming capability in the Matlab workspace allows mathematical freedom, it was found aesthetics and time consumption was a disadvantage of using this style of program.

Excitement for the economic and production capabilities of PV/BES technologies is rapidly growing throughout Australia. This paper has validated the potential for export and self-production capacity for locations of low latitudes in Australia and the ability of the Matlab program to size PV/BES installations. The transmission of solar electricity from lower latitudes in Australia is both technically and economically feasible over the next 40 years using PV/BES systems.

8 RECOMMENDATIONS

There is a great opportunity to further expand on the results of this thesis. The current program and modelling can be refined and expanded in both scope and resource. Limitations and assumptions of the program were mentioned in the proceeding sections. Hitherto, if further research were to be conducted on solar photovoltaic and storage for domestic use and principally, the simulation and estimation of cost and production; the following recommendations should be considered:

- Further testing and debugging of the program should be performed for all scenarios for every combination to try and find issues which can be rectified.
- Different orientations should be allowed as input parameters both for a primary, primary-auxiliary combo, or dual combination of arrays.
- Studies on salvage, maintenance and recycle costs in Queensland need to be established.
- Benchmark data for households throughout Australia are not well known and needs to be accrued.
- Carbon offset calculations and indication.
- Creation of three modes or options for the user is recommended to be included in the program:
    - Market Entry – Maximum Return

      The Market Entry option is effectively an enticer or market entry for persons whose sole incentive is an investment with maximized returns. This will evaluate the cheapest installation costs and equipment.

    - Incentivised Grid Stabilization Scheme

      The second option is the grid stabilization scheme which will be proposed to energy suppliers and a governmental level for prospective budget or backing. The underlying goal of this recommendation is to provide a sound basis for a proposal to the government and energy suppliers for funding. This is an acceptable proposition as of the 1st of July, 2016, Adelaide in South Australia already have in effect a rebate of 50% of the installed system cost up to a maximum of $5,000 for BES systems [64].

    - Three Day – Standalone Grid Autonomy

      The third option will be for the user to completely disconnect from the electricity network. This is for people who wish to become completely electrically independent and operate on renewable energies. This option will be most costly due to current technological limitations, but a shift has commenced towards standalone systems. There are currently many rural and remote small low power operations which are entirely run on renewable energy. The days of autonomy for each installation should be displayed.

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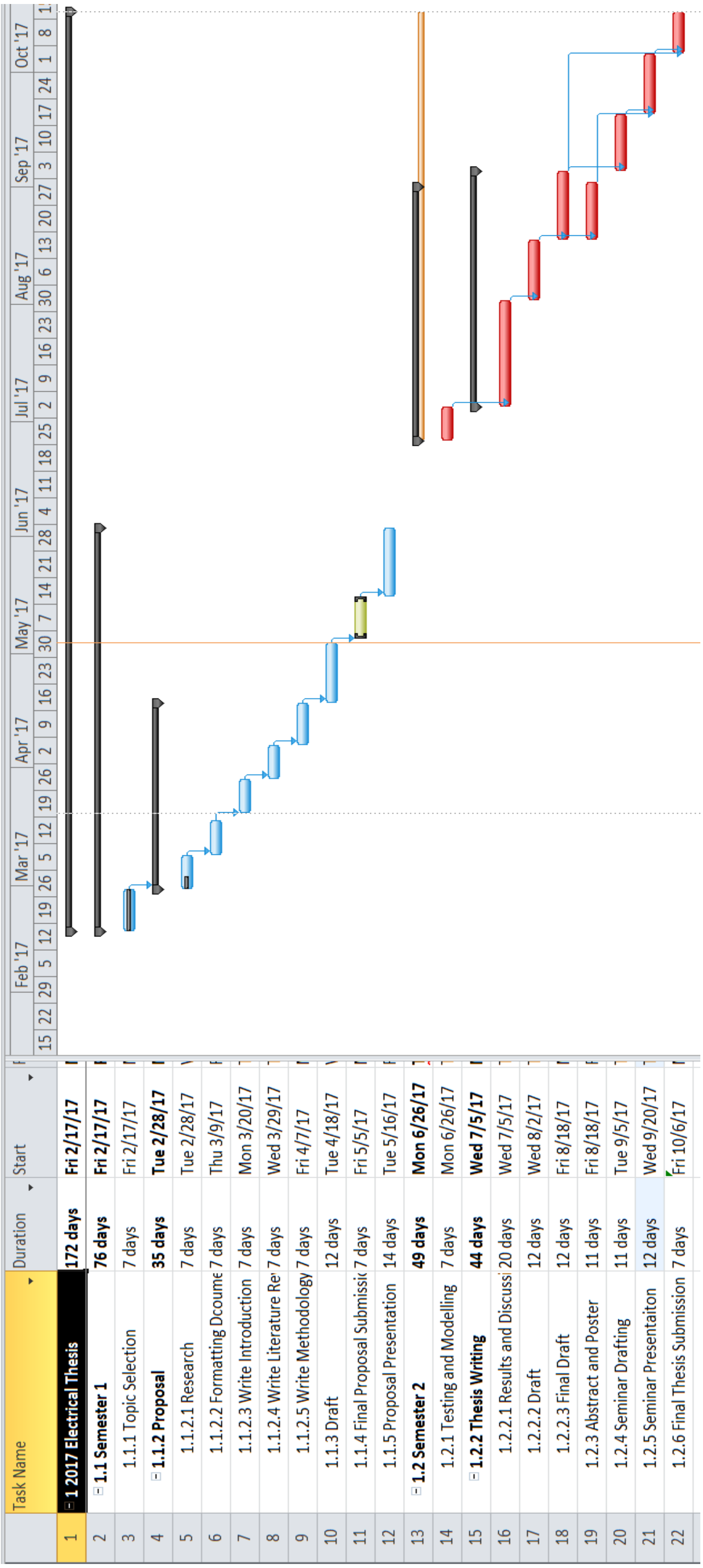
10 APPENDICES

APPENDIX 1 – PROGRESS GANTT CHART



Appendix 2 – Risk Assessment

NUMBER	RISK DESCRIPTION	TREND	INHERENT	CURRENT	RESIDUAL
501	EG4011 - Thesis - Clinton Elliott - Solar Energy		Not Assessed	Medium	Low

RISK OWNER	RISK IDENTIFIED ON	LAST REVIEWED ON	NEXT SCHEDULED REVIEW
EG4011 Thesis Students	18/04/2017	18/04/2017	18/10/2017

RISK CONSEQUENCE	RISK FACTOR(S)	EXISTING CONTROL(S)	PROPOSED CONTROL(S)	OWNER	DUE DATE
	On campus after hours	**Control:** Let administration know what I am working after hours. **Control:** Have them call every 30 minutes to check if I am ok.	**Control:** Report suspicious activity	Ahmad Zahedi	20/04/2017
	Working with electrical appliances 230v mains electricity printers computers	**Control:** Correct guards Test and tagged	**Control:** Isolate power if unsure	Ahmad Zahedi	20/04/2017
	low periods of sitting at desk eye strain carpal tunnel back strain	**Control:** Correct setup workstation regular breaks stretching	**Control:** Adjust workstation see Medial specialist if any real concerns	Ahmad Zahedi	20/04/2017
	Air condition removing moisture Periods without water consumption can cause headaches	**Control:** Hydration Panadol Adjust temperature	**Control:** Set up a timer, to consume water	Ahmad Zahedi	20/04/2017

APPENDIX 3 – RISK ASSESSMENT (APPROVAL)

Risk Assessment [Ref Number: 567]

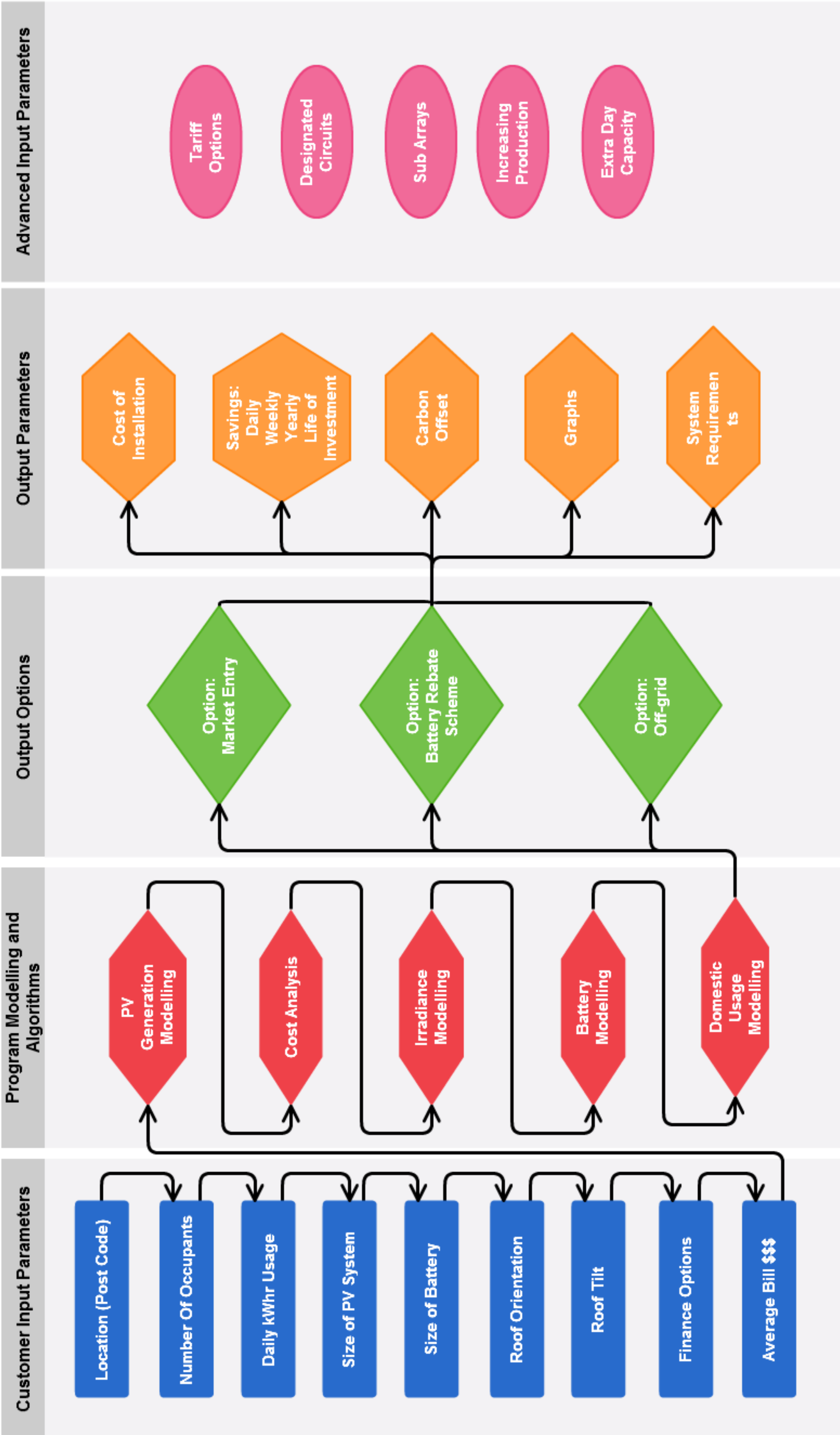
Date Printed: Friday, 5 May 2017

Risk Assessment Approval

Description of Role	Signature	Date	Contact Number
Operator			
Supervisor AHMAD Zahedi		5/5/2017	16907
John Renehan Safety Advisor		5/5/17	14459
Head of Discipline	J D GINGER	8/5/17	X4420

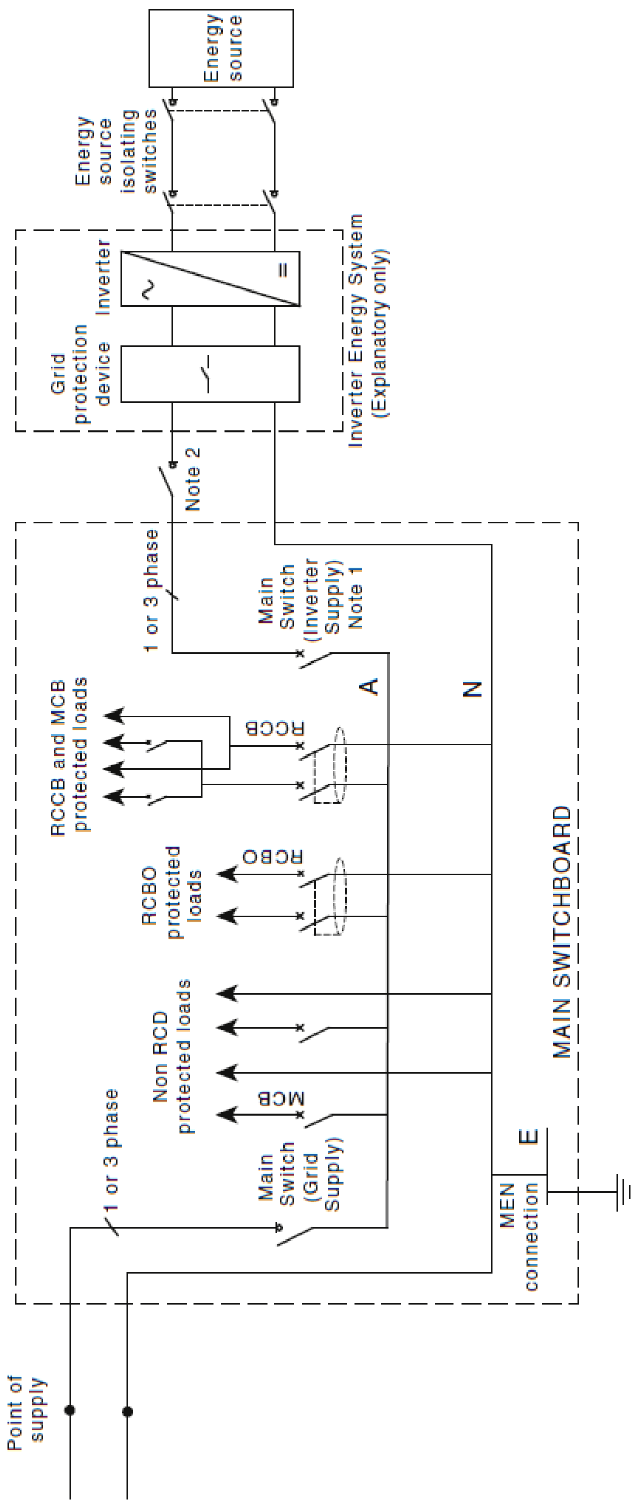
THIS FORM IS TO BE DISPLAYED IN THE IMMEDIATE VICINITY OF THE EXPERIMENT BEING UNDERTAKEN

APPENDIX 4 – PROGRAM OVERVIEW



APPENDIX 5 – TYPICAL INSTALLATION WIRING OF INVERTER

AS/NZS 4777.1:2016 12



Notes

1 For the main switch (inverter supply) and cable protection requirements refer Clause 3.4.

2 For isolating switch requirements refer Clause 3.4.3.

3 Earth connections other than the main earth conductor and earth electrode are not shown.

FIGURE 1 TYPICAL INSTALLATION OF AN INVERTER ENERGY SYSTEM TO A MAIN SWITCHBOARD

APPENDIX 6 – PROJECT CODE & TITLE

ProjectCode
AZ2

Title:	SolarPhotovoltaicand storage fordomesticuse

Description

Solar photovoltaic (PV) electricity is receiving a significant attention. This is mainly because of its ability to directly convert sun energy into electricity. One of the weaknesses of solar PV electricity is that it can rarely provide immediate response to the changing load. Recently, an important attention has been turned to the use of an energy storage technology. Combing with storage makes solar PV system more attractive. Smart battery management can create a more effective way of electricity into the power grid. At domestic level a battery of an electric vehicle can provide such a system.

The objectives of this project is to design, optimize the size, and calculate the cost of electricity from a PV/Storage for domestic application.

APPENDIX 7 – NASA PEAK SUN HOUR DATA

Townsville	Tilt 0	0	6.35	5.56	5.56	4.79	4.27	4	4.39	5.13	6.18	6.59	6.62	6.71	5.51
	Tilt 4	4	6.39	5.55	5.62	4.92	4.46	4.21	4.62	5.32	6.3	6.61	6.57	6.76	5.61
	Tilt 19	19	6.33	5.38	5.68	5.24	5.02	4.86	5.34	5.86	6.54	6.49	6.2	6.76	5.81
	Tilt 34	34	5.97	4.96	5.45	5.29	5.31	5.24	5.77	6.08	6.43	6.02	5.53	6.42	5.71
	Tilt 90	90	2.55	1.94	2.57	3.26	3.92	4.08	4.5	4.08	3.28	2.17	1.76	2.82	3.09
Mount Isa	Tilt 0	0	6.84	6.3	6.11	5.56	4.83	4.32	4.54	5.46	6.11	6.57	6.88	6.96	5.87
	Tilt 5	4	6.88	6.3	6.21	5.79	5.16	4.65	4.86	5.75	6.27	6.6	6.82	7.02	6.02
	Tilt 20	19	6.79	6.1	6.3	6.25	5.93	5.45	5.63	6.4	6.52	6.48	6.39	6.98	6.27
	Tilt 35	34	6.36	5.6	6.06	6.38	6.37	5.94	6.08	6.69	6.42	6.03	5.64	6.58	6.19
	Tilt 90	90	2.59	2.07	2.86	4.01	4.88	4.78	4.73	4.61	3.38	2.28	1.84	2.81	3.41
Darwin	Tilt 0	0	5.52	5.2	5.9	5.99	5.82	5.55	5.76	6.36	6.87	7.07	6.79	5.84	6.06
	Tilt 12	12	5.59	5.17	5.93	6.32	6.47	6.34	6.52	6.9	7.06	6.94	6.87	5.95	6.34
	Tilt 27	27	5.43	4.92	5.71	6.44	6.96	6.99	7.12	7.21	6.96	6.44	6.65	5.82	6.4
	Tilt 90	90	2.43	1.94	2.23	3.46	4.75	5.29	5.16	4.3	2.9	1.72	2.6	2.65	3.29
	Tilt space	95	2.43	1.94	2.23	3.46	4.75	5.29	5.16	4.3	2.9	1.72	2.6	2.65	3.29
Perth	Tilt 0	0	8.41	7.49	5.93	4.34	3.09	2.62	2.82	3.62	5.04	6.41	7.71	8.45	5.49
	Tilt 16	16	8.18	7.62	6.43	5.07	3.82	3.37	3.56	4.3	5.59	6.67	7.59	8.14	5.85
	Tilt 31	31	7.51	7.31	6.54	5.46	4.3	3.89	4.06	4.7	5.8	6.54	7.06	7.39	5.87
	Tilt 46	46	6.47	6.61	6.29	5.56	4.53	4.19	4.33	4.84	5.7	6.07	6.17	6.28	5.58
	Tilt 90	90	2.46	3.09	3.76	4.13	3.78	3.69	3.72	3.75	3.75	3.1	2.55	2.3	3.34
Melbourne	Tilt 0	0	6.31	5.81	4.53	3.26	2.27	1.84	2.03	2.7	3.67	4.77	5.68	6.17	4.08
	Tilt 22	22	6.17	5.98	5.03	4.02	3.06	2.63	2.83	3.42	4.18	5.01	5.61	5.97	4.48
	Tilt 37	37	5.71	5.72	5.07	4.27	3.41	3.01	3.19	3.69	4.27	4.87	5.25	5.48	4.49
	Tilt 52	52	4.99	5.19	4.84	4.31	3.57	3.21	3.38	3.77	4.15	4.5	4.64	4.76	4.27
	Tilt 90	90	2.61	2.99	3.26	3.39	3.11	2.92	3.02	3.08	2.98	2.75	2.55	2.48	2.93
Hobart	Tilt 0	0	5.78	5.18	3.92	2.61	1.8	1.46	1.62	2.33	3.39	4.62	5.52	6	3.68

	Tilt 27	27	5.68	5.4	4.51	3.39	2.71	2.44	2.59	3.23	4.08	4.94	5.49	5.72	4.18
	Tilt 42	42	5.25	5.16	4.52	3.58	3.02	2.81	2.95	3.5	4.17	4.78	5.12	5.25	4.17
	Tilt 57	57	4.59	4.67	4.31	3.59	3.16	3.02	3.13	3.58	4.06	4.4	4.51	4.54	3.96
	Tilt 90	90	2.73	3	3.12	2.95	2.85	2.85	2.9	3.07	3.1	2.94	2.74	2.69	2.91
Sydney	Tilt 0	0	5.91	5.25	4.48	3.56	2.73	2.49	2.68	3.49	4.6	5.41	5.88	6.24	4.39
	Tilt 18	18	5.78	5.32	4.82	4.16	3.46	3.37	3.54	4.28	5.15	5.63	5.8	6.04	4.78
	Tilt 33	33	5.38	5.11	4.84	4.42	3.87	3.89	4.04	4.68	5.32	5.5	5.43	5.57	4.84
	Tilt 48	48	4.73	4.66	4.62	4.45	4.07	4.2	4.31	4.82	5.21	5.1	4.82	4.85	4.65
	Tilt 90	90	2.34	2.55	2.93	3.35	3.43	3.77	3.77	3.82	3.54	2.83	2.4	2.31	3.09
Brisbane	Tilt 0	0	6.19	5.39	4.95	3.98	3.23	3.02	3.22	4.04	5.12	5.52	6.07	6.35	4.75
	Tilt 12	12	6.06	5.41	5.15	4.34	3.71	3.59	3.78	4.56	5.47	5.62	5.98	6.18	4.99
	Tilt 27	27	5.65	5.22	5.19	4.6	4.12	4.13	4.29	4.99	5.65	5.5	5.61	5.71	5.05
	Tilt 42	42	4.98	4.78	4.96	4.63	4.32	4.43	4.57	5.15	5.54	5.11	4.99	4.97	4.87
	Tilt 90	90	2.09	2.28	2.81	3.22	3.41	3.75	3.76	3.84	3.38	2.49	2.13	2.04	2.94

APPENDIX 8 – AUS GOV ENERGY CONSUMPTION DATA

City	Post Code	# People	Pool	Gas	KWhr/day	Annual	Tariff #	Tariff Rate	Solar Rate
Townsville	4814	4	0	0	24.6	8979	11	0.27071	0.07448
	4814	4	0	1	24.6	8979	11	0.27071	0.07448
	4814	4	1	0	32.5	11862.5	11	0.27071	0.07448
	4814	4	1	1	32.5	11862.5	11	0.27071	0.07448
	4814	3	0	0	19.2	7008	11	0.27071	0.07448
	4814	3	0	1	19.2	7008	11	0.27071	0.07448
	4814	3	1	0	27	9855	11	0.27071	0.07448
	4814	3	1	1	27	9855	11	0.27071	0.07448
	4814	2	0	0	16.8	6132	11	0.27071	0.07448
	4814	2	0	1	16.8	6132	11	0.27071	0.07448
	4814	2	1	0	24.6	8979	11	0.27071	0.07448
	4814	2	1	1	24.6	8979	11	0.27071	0.07448
	4814	1	0	0	10.8	3942	11	0.27071	0.07448
	4814	1	0	1	10.8	3942	11	0.27071	0.07448
	4814	1	1	0	18.7	6825.5	11	0.27071	0.07448
	4814	1	1	1	18.7	6825.5	11	0.27071	0.07448
Mount Isa	4825	4	0	0	25.2	9198	11	0.27071	0.07448
	4825	4	0	1	25.2	9198	11	0.27071	0.07448
	4825	4	1	0	33.3	12154.5	11	0.27071	0.07448
	4825	4	1	1	33.3	12154.5	11	0.27071	0.07448
	4825	3	0	0	19.6	7154	11	0.27071	0.07448
	4825	3	0	1	19.6	7154	11	0.27071	0.07448
	4825	3	1	0	27.7	10110.5	11	0.27071	0.07448
	4825	3	1	1	27.7	10110.5	11	0.27071	0.07448
	4825	2	0	0	17.2	6278	11	0.27071	0.07448
	4825	2	0	1	17.2	6278	11	0.27071	0.07448
	4825	2	1	0	25.2	9198	11	0.27071	0.07448
	4825	2	1	1	25.2	9198	11	0.27071	0.07448
	4825	1	0	0	11.1	4051.5	11	0.27071	0.07448
	4825	1	0	1	11.1	4051.5	11	0.27071	0.07448
	4825	1	1	0	19.1	6971.5	11	0.27071	0.07448
	4825	1	1	1	19.1	6971.5	11	0.27071	0.07448
Darwin	800	4	0	0	20.5	7482.5	11	0.27071	0.07448
	800	4	0	1	20.5	7482.5	11	0.27071	0.07448
	800	4	1	0	26.6	9709	11	0.27071	0.07448
	800	4	1	1	26.6	9709	11	0.27071	0.07448
	800	3	0	0	18.5	6752.5	11	0.27071	0.07448
	800	3	0	1	18.5	6752.5	11	0.27071	0.07448
	800	3	1	0	24.6	8979	11	0.27071	0.07448
	800	3	1	1	24.6	8979	11	0.27071	0.07448

	800	2	0	0	18.6	6789	11	0.27071	0.07448
	800	2	0	1	18.6	6789	11	0.27071	0.07448
	800	2	1	0	24.7	9015.5	11	0.27071	0.07448
	800	2	1	1	24.7	9015.5	11	0.27071	0.07448
	800	1	0	0	9.6	3504	11	0.27071	0.07448
	800	1	0	1	9.6	3504	11	0.27071	0.07448
	800	1	1	0	15.8	5767	11	0.27071	0.07448
	800	1	1	1	15.8	5767	11	0.27071	0.07448
Perth	6000	4	0	0	20	7300	11	0.27071	0.07448
	6000	4	0	1	20	7300	11	0.27071	0.07448
	6000	4	1	0	20	7300	11	0.27071	0.07448
	6000	4	1	1	20	7300	11	0.27071	0.07448
	6000	3	0	0	17	6205	11	0.27071	0.07448
	6000	3	0	1	17	6205	11	0.27071	0.07448
	6000	3	1	0	17	6205	11	0.27071	0.07448
* No pool	6000	3	1	1	17	6205	11	0.27071	0.07448
	6000	2	0	0	14.1	5146.5	11	0.27071	0.07448
	6000	2	0	1	14.1	5146.5	11	0.27071	0.07448
	6000	2	1	0	14.1	5146.5	11	0.27071	0.07448
	6000	2	1	1	14.1	5146.5	11	0.27071	0.07448
	6000	1	0	0	11.2	4088	11	0.27071	0.07448
	6000	1	0	1	11.2	4088	11	0.27071	0.07448
	6000	1	1	0	11.2	4088	11	0.27071	0.07448
	6000	1	1	1	11.2	4088	11	0.27071	0.07448
Melbourne	3000	4	0	0	14.6	11789.5	11	0.27071	0.07448
	3000	4	0	1	13.7	5767	11	0.27071	0.07448
	3000	4	1	0	22.8	21097	11	0.27071	0.07448
	3000	4	1	1	21.9	15074.5	11	0.27071	0.07448
	3000	3	0	0	19.2	9928	11	0.27071	0.07448
	3000	3	0	1	11.1	8066.5	11	0.27071	0.07448
	3000	3	1	0	27.4	19272	11	0.27071	0.07448
	3000	3	1	1	19.4	17410.5	11	0.27071	0.07448
	3000	2	0	0	15.3	8541	11	0.27071	0.07448
	3000	2	0	1	10.6	3869	11	0.27071	0.07448
	3000	2	1	0	23.5	17885	11	0.27071	0.07448
	3000	2	1	1	18.8	13176.5	11	0.27071	0.07448
	3000	1	0	0	11.6	6168.5	11	0.27071	0.07448
	3000	1	0	1	7.4	1861.5	11	0.27071	0.07448
	3000	1	1	0	19.8	15512.5	11	0.27071	0.07448
	3000	1	1	1	15.6	11169	11	0.27071	0.07448
Horbart	7000	4	0	0	32.3	7336.5	11	0.27071	0.07448
	7000	4	0	1	15.8	5329	11	0.27071	0.07448
	7000	4	1	0	57.8	10001	11	0.27071	0.07448
	7000	4	1	1	41.3	7993.5	11	0.27071	0.07448
	7000	3	0	0	27.2	6935	11	0.27071	0.07448
	7000	3	0	1	22.1	5037	11	0.27071	0.07448

	7000	3	1	0	52.8	9599.5	11	0.27071	0.07448
	7000	3	1	1	47.7	7701.5	11	0.27071	0.07448
	7000	2	0	0	23.4	5621	11	0.27071	0.07448
	7000	2	0	1	10.6	4161	11	0.27071	0.07448
	7000	2	1	0	49	8285.5	11	0.27071	0.07448
	7000	2	1	1	36.1	6862	11	0.27071	0.07448
	7000	1	0	0	16.9	3285	11	0.27071	0.07448
	7000	1	0	1	5.1	2993	11	0.27071	0.07448
	7000	1	1	0	42.5	5949.5	11	0.27071	0.07448
	7000	1	1	1	30.6	5694	11	0.27071	0.07448
Sydney	2000	4	0	0	20.1	7336.5	11	0.27071	0.07448
	2000	4	0	1	14.6	5329	11	0.27071	0.07448
	2000	4	1	0	27.4	10001	11	0.27071	0.07448
	2000	4	1	1	21.9	7993.5	11	0.27071	0.07448
	2000	3	0	0	19	6935	11	0.27071	0.07448
	2000	3	0	1	13.8	5037	11	0.27071	0.07448
	2000	3	1	0	26.3	9599.5	11	0.27071	0.07448
	2000	3	1	1	21.1	7701.5	11	0.27071	0.07448
	2000	2	0	0	15.4	5621	11	0.27071	0.07448
	2000	2	0	1	11.4	4161	11	0.27071	0.07448
	2000	2	1	0	22.7	8285.5	11	0.27071	0.07448
	2000	2	1	1	18.8	6862	11	0.27071	0.07448
	2000	1	0	0	9	3285	11	0.27071	0.07448
	2000	1	0	1	8.2	5694	11	0.27071	0.07448
	2000	1	1	0	16.3	5949.5	11	0.27071	0.07448
	2000	1	1	1	15.6	5694	11	0.27071	0.07448
Brisbane	4000	4	0	0	19.1	6971.5	11	0.27071	0.07448
	4000	4	0	1	19.8	7227	11	0.27071	0.07448
	4000	4	1	0	25	9125	11	0.27071	0.07448
	4000	4	1	1	25.7	9380.5	11	0.27071	0.07448
	4000	3	0	0	15.1	5511.5	11	0.27071	0.07448
	4000	3	0	1	14	5110	11	0.27071	0.07448
	4000	3	1	0	21	7665	11	0.27071	0.07448
	4000	3	1	1	19.9	7263.5	11	0.27071	0.07448
	4000	2	0	0	13.5	4927.5	11	0.27071	0.07448
	4000	2	0	1	10.4	3796	11	0.27071	0.07448
	4000	2	1	0	19.4	7081	11	0.27071	0.07448
	4000	2	1	1	16.3	5949.5	11	0.27071	0.07448
	4000	1	0	0	8.7	3175.5	11	0.27071	0.07448
	4000	1	0	1	5.4	1971	11	0.27071	0.07448
	4000	1	1	0	14.6	5329	11	0.27071	0.07448
	4000	1	1	1	11.4	4161	11	0.27071	0.07448

APPENDIX 9 – MATLAB SOURCE CODE

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