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A Comprehensive Methodology for Assessing the Quality of Solar Photovoltaic Systems

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A Comprehensive Methodology for Assessing the Quality of Solar Photovoltaic Systems

An Interactive Qualifying Project Final Report

Submitted to:
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Abstract

The goal of this project was to assist the Alternative Technology Association by providing an enhanced assessment methodology for solar photovoltaic systems, emphasizing the development of a quantifiable evaluation of reliability and performance. To realize this goal, we interviewed industry leaders, surveyed solar consumers, and researched factors affecting solar photovoltaic system quality. The project resulted in a more comprehensive assessment methodology to aid the ATA in providing consultations that examine the value of solar photovoltaic systems.

Executive Summary

This project focuses primarily on analyzing the quality of solar photovoltaic systems. Recently, Australia has become heavily reliant upon renewable energy resources such as solar and wind power. However, as the Australian solar market continues to grow rapidly, consumers are becoming more reliant on solar photovoltaic systems that have inherent failure mechanisms. For this reason, it is important to develop a quantitative methodology capable of comparing these systems and providing the public with products that will perform reliably, at a high level of efficiency for its expected life. An assessment of this nature will help to increase implementation of solar photovoltaic systems across Australia.

The Alternative Technology Association (ATA) supports widespread implementation of renewable technologies and provides advice to consumers and municipalities seeking to install them. Among these consultations, they provide assessments for municipalities participating in bulk buy programs. These bulk buy programs allow municipalities to implement renewable technologies at a more affordable cost. For these assessments, the ATA has an assessment methodology consisting of a decision-making matrix capable of comparing solar products based upon five categories: Price, Warranty, Quality, Company Experience, and Customer Service. While the matrix was helpful in pointing consumers in the right direction, some of the ranking methods used within the matrix were rudimentary, due to the absence of reliability and performance data for products currently on the market.

This project provides a new, more comprehensive assessment methodology for solar photovoltaic systems, focusing primarily on performance and reliability of products; while also providing a better understanding of factors and metrics affecting system quality for ATA consultations.

Methodology

In order to properly complete the project, the team completed the following four objectives:

1. **Research factors affecting solar PV quality**
2. **Evaluate metrics indicative of solar PV quality**
3. **Develop an understanding of consumer priorities**
4. **Design a more comprehensive multiple-criteria decision-making matrix to compare photovoltaic component quality**

To begin, the team researched factors affecting solar photovoltaic system quality and common failure modes of systems. The team conducted interviews with industry leaders including manufacturers, retailers, installers, and researchers to gain a better understanding of the operation of solar photovoltaic systems and what factors an industry leader would utilize to classify a system as "high quality". A coding mechanism was constructed to turn qualitative interview data regarding system quality into quantifiable data backed by industry leaders. Table 1 represents the industry leaders interviewed and their combined years of experience in the solar industry.

Table 1: Interview sample distribution

Industry Leader Category	Interviews Conducted	Total Years of Experience in the Solar Industry
Retailers & Installers	10	160
Researchers / Industry Experts	2	32
Solar Manufacturers	3	39
TOTAL	**15**	**231**

Through the data collected in the interviews, the team determined the types of reliability data used by industry leaders to determine system quality. The team made use of various research institutions' data, online databases, product data sheets, and independent research to draw conclusions regarding reliability and performance of solar products and metrics which best identify them. A survey was sent out to solar consumers to determine consumer priorities when purchasing a solar photovoltaic system. The survey also provided a section for solar photovoltaic system owners to provide information about their system. The survey received 868 responses from consumers across Australia. Figure 1 displays the distribution of survey responses across Australia in comparison to the population distribution.

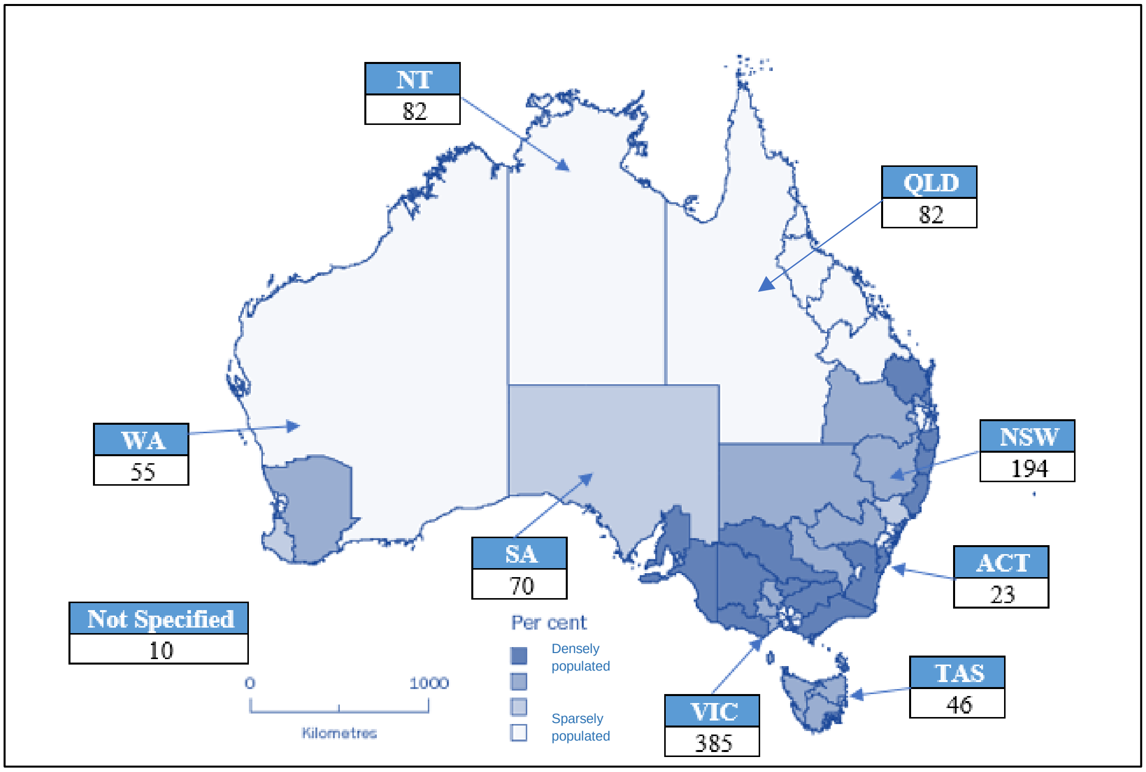

Figure 1: Survey distribution by region

Findings

Consumers recognize the importance of purchasing high quality solar PV systems

Based on the results of the ATA subscriber survey, 70.62% of respondents value the quality of their system over other factors such as price, warranty, customer service, and company experience. This is critical because it reinforces the value of a more comprehensive quality assessment methodology for solar PV systems. This provides both context and importance to the project detailed within this report.

Importance of various factors affecting the quality of solar photovoltaic systems

Factors such as company reputation and location, system design, and installation were determined to affect the quality of PV systems. Interviewees continually mentioned the reputation and location of a company as important factors to consider when purchasing PV systems. A company with a good reputation and local office has proven the quality of their products and is capable of providing proper after-purchase support. In addition, it is crucial to properly design the system for a given application. The various construction types of solar PV components perform differently from application to application, and failure to account for this during design can affect the long-term reliability and cost of the system. Lastly, selecting a Clean Energy Council (CEC) accredited installer is critical to the performance and reliability of the system. Improper installation can lead to microfractures, water damage, and short circuits that limit the effectiveness of the system.

The Australian energy market currently lacks standardized shipping guidelines

Microfractures are a common failure mode identified by this study that can be mitigated by proper shipping and installation. Microfractures are caused by increased stress on the module glass. This can be caused by loading the glass above its rating. The Australian market currently makes use of CEC installation guidelines, but lacks a similar system for the shipment of PV systems. This creates major uncertainty for consumers when purchasing these systems.

Importance and lack of metrics quantifying the overall quality solar photovoltaic systems

Throughout the team's research it was identified that the solar photovoltaic industry lacks metrics indicative of system quality. Manufacturers are extremely hesitant to publish failure information regarding their products, third party test results are not always unbiased or comprehensive, and products are changing so rapidly that performing reliability tests is extremely difficult. However, use of information of this nature has the potential to provide justifiable, uniform comparisons of PV system quality. For this reason, the team developed a methodology for performing a reliability analysis capable of generating this quantifiable data.

Recommendations

We recommend that consumers only hire installers that are accredited by the Clean Energy Council.

This study identified installation as one of the most common causes for failure with solar photovoltaic systems. Therefore, to improve the reliability and performance of PV systems, it is critical that they are installed correctly. In an effort to mitigate the risk of these improper installations, we suggest consumers only make use of CEC accredited solar installers. A company that maintains CEC accreditation has been successfully installing products for an extended time period.

We recommend that consumers solicit post-installation inspections of their systems to ensure the quality of shipping and installation and perform regular maintenance on their systems.

Consumers can solicit these inspections from their CEC accredited installer or from their state government. By conducting these inspections consumers will be able to determine the quality of the installation work. Using Maximum Power Point Tracking will allow the inspector to determine the initial functionality of the system compared to its manufacturer rating. This comparison makes it possible to identify any defects in installation, and correct them before they become more serious post-warranty problems. These inspections should be performed regularly following installation to ensure optimal system functionality. We also recommend that consumers keep a log of all inspections and maintenance done on the system to make potential warranty claims simpler if issues do arise.

We recommend that the ATA work in conjunction with the Clean Energy Council to develop industry guidelines regarding the shipping of solar PV system components.

There are currently Australian regulations regarding both the manufacturing and installation of solar PV components, but there are no such regulations for shipping. Through our interviews and research it was identified that microfractures and other damages are often caused by poor shipping methods such as stacking panels or insufficient protective packaging. This is often because the shipping protocols are currently established by the manufacturers themselves. For this reason, we recommend that the ATA work with the Clean Energy Council to develop a set of guidelines for the proper transportation of solar PV components, especially solar modules.

We recommend that the ATA solicit failure rate data from solar PV manufacturers.

We recommend that the ATA request manufacturer failure data. Whether this data be from accelerated life testing or warranty claims, it will increase the amount of reliability data available to the ATA and enhance the certainty to which they can make their assessments. The team was only successful in soliciting failure rate information from one solar manufacturer. If the ATA uses their leverage to request this data it will greatly enhance their assessments. This failure data could also be included in their published buyer’s guides for personal use by their subscribers, assuming the ATA does not need to sign a Nondisclosure Agreement to acquire the data.

We recommend a project be completed analyzing the quality of off-grid system components to the ATA's assessment methodology for these systems.

The current ATA assessment methodology is primarily focused on the evaluation of grid-connected photovoltaic systems. However, as the Australian energy market continues to change many consumers are making the switch to off-grid and hybrid systems. These systems require additional technology such as batteries and charge controllers. As these two system types become prevalent within the Australian market it will be crucial for the ATA to have the capacity to provide justifiable recommendations to its members regarding these technologies.

Deliverables

Equipped with survey results representative of Australian consumer perspectives, as well as factors and metrics to assess system quality provided by industry leaders and additional research, the team was able to create an enhanced assessment methodology for the quality of solar photovoltaic systems. While the five categories themselves remained unmodified, each category was reweighted based upon consumer priorities derived from the survey. The quality section included more quantifiable metrics of performance and reliability, allowing for a more accurate analysis of system quality. An application specific tab was also created for the purpose of reallocating weightings based upon the application of the system being assessed. With these modifications, the ATA will be able to provide more comprehensive assessments of solar photovoltaic systems and have more confidence in the data used for consultations.

Other physical deliverables include a registry of both solar modules and solar inverters relevant to the Australian market, a new tender request form for the ATA to easily gather data for their assessment matrix when providing a consultation, and a survey for their website that consumers can access to report system failures. In addition to these deliverables, the team also provided the ATA with research regarding material performance, common failures and how to mitigate them, a comparison of the main categories of solar modules and inverters available on the market today, and an analytical tool that could be used to assess system reliability based upon survey responses.

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1. Introduction

In recent years, there has been an increased movement towards adopting clean and renewable energy sources as global climate change has become a much more pressing issue. This stems from a drastic increase in the Earth's surface temperature, 0.6±0.2°C since the year 1900 (Hughes, 2003). The largest contributing factor to this change in global climate is the emission of carbon due to the burning of fossil fuels (coal, oil, and natural gas) to produce power (USEPA, 2017). While this is a global concern, it is especially pertinent to the current Australian energy market. Due to its extremely plentiful fossil fuel reserves, Australia has relied heavily on these non-renewable sources for the vast majority of its energy generation (Denniss, 2016). Fortunately, solar radiation is abundant in Australia, which provides the opportunity for solar photovoltaic systems to reduce Australia's dependence on fossil fuels. In recent years Australians have begun to take advantage of the widespread availability of solar energy, and have quickly begun making the shift to reliance upon renewable energy, rather than fossil fuels.

As solar power becomes more prevalent in Australia, the need for educating the public on optimal solar photovoltaic systems and designs arises. It is crucial to increase the public's solar knowledge because while solar PV represents a great opportunity, it is not without its deterrents. One major concern is the cost-effectiveness of making the switch to solar PV for primary power generation (Wustenhagen, 2007). Photovoltaic systems are cost beneficial in the long term, but have costly implementation expenses early on. Often times to make solar photovoltaics more cost competitive, system quality is sacrificed. Issues such as inferior materials and poor installation reduce the overall quality of the system, and can eventually lead to higher lifetime costs due to increased frequency of maintenance (Energy Matters, 2017a). The Australian Government has introduced incentives such as Feed-in Tariffs and Renewable Energy Certificates in an attempt to better reflect the full value of solar photovoltaic generation (Clean Energy Regulator, 2016). Therefore, in order to reduce the life cycle cost of solar PV and allow consumers to take full advantage of current renewable incentives, the optimal balance between quality and cost effectiveness must be identified.

The Alternative Technology Association (ATA) recognizes the potential that solar power has to change the Australian energy landscape, and provides consultation to citizens hoping to find the ideal PV system for their application. The ATA is often enlisted by municipalities to provide these services to its residents through a municipal bulk-buy program. By purchasing the systems in bulk, the townspeople receive a reduction in the initial system price. Currently, the ATA utilizes an assessment matrix to suggest the best option for each application based upon price, warranty, component quality, company experience, and customer service (ATA, 2017). Quality is an important consideration when comparing solar photovoltaic systems, but due to the rate at which component technology is changing and improving it is difficult to properly provide quantitative assessments of system quality (Barnes, 2017). The prior method made use of customer reviews and opinions from industry experts, but did not take into account various factors indicative of quality that could potentially provide a more robust, uniform assessment of PV systems, due to lack of available information.

The primary objective of this project was to provide the ATA with an improved assessment methodology that more comprehensively evaluates the overall quality of solar PV systems. The final deliverables include a product quality registry able to be used for small-scale consultations, an enhanced quality assessment matrix, and a concise report summarizing the work completed within the project. Initially, it was important to analyze the current state of the Australian solar industry to provide a clearer perspective on the requirements of the assessment methodology. Following this, it was necessary to investigate the most practical methods for assessing module and inverter quality, and to triangulate the data gathered to provide the most comprehensive quality assessment possible. The necessary data was obtained through interviews and surveys given to primary stakeholders, manufacturer specifications, third-party test data, and assistance from the ATA. By compiling this data and expanding research the project provided the ATA with the desired deliverables and recommendations to improve their previous quality assessment methodology.

2. Background

Global warming has become a more prevalent societal issue in recent years. Studies indicate that greenhouse gas emissions are the main cause, and many organizations are turning towards clean energy alternatives such as wind or solar power to provide a consistent source of clean energy. This background chapter explains the need for solar power within Australia, touching upon the continent's solar potential. The Australian perception towards renewable energy has been generally positive; however, cost effectiveness is a main issue deterring the public from switching to solar energy. To incentivize citizens and organizations to install photovoltaic systems, the Australian government has created several pieces of legislation to streamline the acquisition process and promote the use of renewable resources. This is discussed further in Appendix A. However, with the solar energy industry constantly growing, consumers often need assistance from industry experts when analyzing the material properties and construction of solar photovoltaic systems. The Alternative Technology Association provides consultations for individuals, organizations, and municipalities to further aid these groups in identifying quality renewable energy options for both residential and commercial applications. Over time, the ATA has created an analysis matrix for solar energy systems. However, there is room for improvement in the assessment method, resulting in a demand for a new analytical methodology including qualitative feedback from consumers and installers. This section provides the information necessary to support findings and recommendations to the ATA, such as operation of solar PV, common failure modes, and how to quantitatively assess system quality.

2.1 Australian Energy Crisis

Australia is a nation of roughly 24 million people with the majority densely settled (between 10 and 100 people/sq. mile) along the eastern coast of the landmass in the states of Queensland, New South Wales, and Victoria (Pink, 2012). Australia emits the 11th most carbon per capita into the atmosphere, just behind the United States of America (World Bank, 2017). In 2016, the average Australian adult earned a substantial 1,573.30 AUD per week (Australian Bureau of Statistics, 2016). This is more than 700 AUD per week than the average American (Bureau of Labor Statistics, 2017). Based upon this earning data, Australians have the means to utilize modern technology such as cars and electricity on a large scale, which has resulted in a consumer society that requires a large amount of base-load electricity.

For as long as this energy demand has existed, fossil fuels have filled this need. Home to some of the richest coal and natural gas deposits in the world, Australia lays claim to roughly 10% of the world's black coal resources and about 2% of natural gas, while having only 0.3% of the world's population (Parliament of Australia, 2013). This has led to a nation with a great surplus of energy that is heavily reliant upon fossil fuels. Despite Australia's reliance on these non-renewable sources, the country has seen a large push for increased clean energy generation. As seen in Figure 2, renewable energy accounted for 14.6% of Australia's electricity generation in 2015. This was an increase of 1.1% from the previous year (Clean Energy Council, 2015).

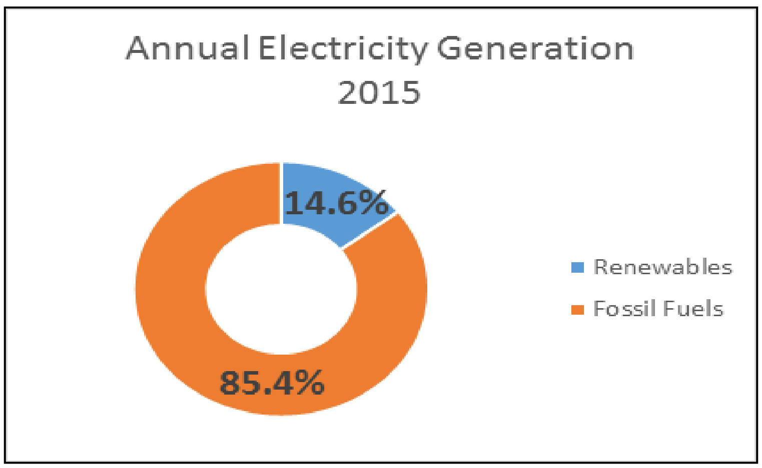

Figure 2: Electricity Generation Distribution 2015 (CEC, 2015)

Recently, parts of Australia have been experiencing issues regarding electricity production and availability. In particular, South Australia has experienced multiple large scale blackouts in the past year, and has been forced to complete load shedding in order to keep the majority of the grid running properly. This has raised many concerns about the energy industry as a whole and its stability. On 9 March 2017 the Australian Prime Minister, Malcolm Turnbull, went so far as to declare an Australian "energy crisis" (O'Malley, 2017). Many potential solutions have been proposed to resolve this energy "crisis," and there are dissenting views surrounding the role of renewables in this situation. Supporters and investors of fossil fuels insist that the intermittent nature of wind and solar power are responsible for the blackouts and that coal and natural gas are the only viable solutions. However, the privatization of the Electricity Trust of

South Australia in 1999 has since resulted in companies attempting to maximize profits. Power plants carefully manipulate the amount of power produced depending on demand, in order to maximize profits. Numerous governmental schemes aiming to limit carbon emissions have also contributed to rising prices from non-renewable generation facilities. Legislation increasing the cost of shipping natural gas across the country and high taxes on the fossil fuels were spurred by the desire to reduce Australia's carbon emissions by penalizing fossil fuel based energy. Though, rather than limiting natural gas production, these regulations merely shifted the companies' focus to Asian markets, Japan in particular. For instance, Australia exported 37 million tons of liquid natural gas in 2015, and is on pace to be the world's largest LNG exporter by 2020 (Appea, 2016).

These complex market conditions have, however, resulted in renewable energy options such as wind and solar becoming more appealing, and possible solutions for the energy sector. As electricity prices associated with non-renewable fuels continue to rise, the cost of wind and solar continues to plummet. Renewable generation stations are now even more affordable than new coal plants. Though, these benefits associated with renewable power are not strictly afforded to large scale generation sites, and small scale systems have been increasing more common in Australia. Many homeowners throughout Australia have been switching towards renewables, specifically solar, in order to cut their electricity bill and carbon footprint. Private photovoltaic systems also decrease a consumers' dependency on the grid. A combination of environmental and market pressures have been improving the feasibility of renewables, and increasing the widespread adoption of solar photovoltaics.

2.2 Australian Solar PV Landscape

Fortunately, Australia is also home to the largest quantity of solar irradiance of any country on the planet (Zahedi, 2010). Solar irradiance is the amount of direct sunlight per unit area a region is subject to. The land mass receives 58×10^{21} joules of solar radiation each year; enough to completely fulfill the nation's consumption 10,000 times over (Byrnes, 2013). The solar potential in Australia represents an opportunity to overhaul their current energy structure. Harnessing even 1% of their solar irradiance would provide more than enough electricity to power their civilization, and far surpass their current renewable energy goals.

Despite this massive potential opportunity, solar power generation accounts for only 17% of Australia's renewable power production. This is because while supply is plentiful, there are hindrances to the uptake in solar power. One major problem facing the solar industry is the intermittency of solar PV generation. Due to its inability to generate during night time hours, there are concerns that solar PV cannot provide the base load power required for modern society. Although, it should be noted that solar systems operate at peak efficiency during daylight hours; this time period also happens to require the highest electricity demand (Sovacool, 2009). Despite this, in order to stockpile enough energy produced throughout daylight hours, PV systems require large, expensive battery storage systems (Sovacool 2009). These batteries lead to larger initial investments and a longer payback period for those attempting to install new solar PV, but when compared to the long-term cost of purchasing fossil fuels, this initial investment eventually becomes the more cost-effective option.

Despite high solar irradiance quantities, another issue with making solar power the predominant Australian energy source is geography. The highest quantities of solar irradiance are located in the north and west portions of the country (Maehlum, 2014). These areas are a great distance away from the large population centers. Figure 3 depicts the massive quantity of solar irradiance in Australia and how it is distributed across the landmass. This energy distribution causes an issue with power transmission to the areas where it is most needed. Currently, the Australian transmission system is lacking in lines running to and from areas with abundant solar

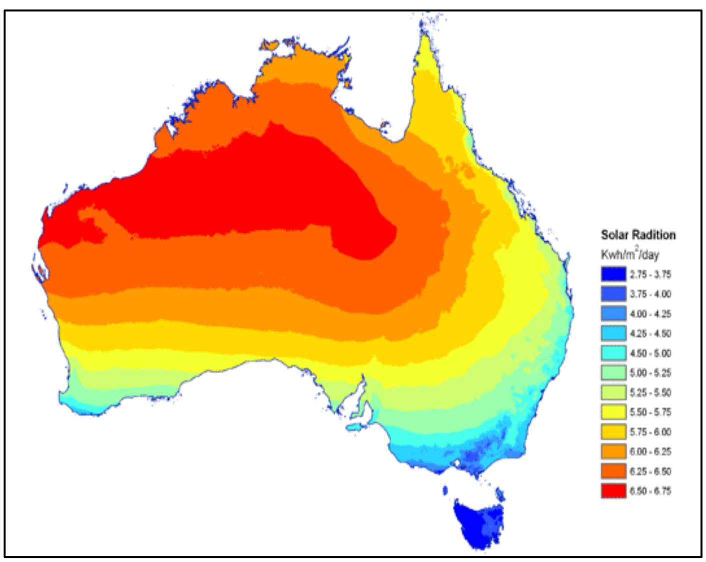

Figure 3: Solar irradiance per day in Australia (Shahan, 2015)

Figure 4: Australian power transmission in relation to solar irradiance (Orr, 2015).

irradiance. Expansion of this system would be costly; however, this may be a necessary investment in order to reduce reliance on fossil fuels. A map of the current Australian transmission system can be seen in Figure 4.

Possibly the most impactful hindrance to the growth of the Australian solar power industry is the balance between cost and quality. Renewable alternatives have yet to find the combination of design, materials, and installation necessary to consistently compete financially with the previously established fossil fuel market, while still being a viable source of energy production for consumers. Despite coal's harmful carbon emissions, the public is not willing to pay a significant amount more for an environmentally-friendly power source. However, aided by renewable energy incentives, fossil fuel tariffs, and improved technology, the cost effectiveness of renewables can successfully compute with Australia's coal (Clean Energy Council, 2015).

Currently, solar photovoltaic systems represent an opportunity to greatly reduce and potentially eliminate fossil fuel usage in Australia. While there are major obstacles such as intermittency and geography, it is clear that cost is the primary hurdle. In order for small-scale solar photovoltaic technology to reach its full capacity in Australia, the correct balance between cost and quality must be found. Quality systems increase life span and reliability, while decreasing costs, which in turn makes solar PV a far more viable option within the Australian energy landscape.

2.3 Operation of Photovoltaic Systems

2.3.1 Operation of Solar Modules

Photovoltaic systems are designed to convert electromagnetic energy from the sun into usable electricity. The primary component of PV systems is the photovoltaic module itself. There are a variety of PV modules (panels), yet all operate under very similar principles. The most common PV modules are made from silicon. Silicon modules are classified as either monocrystalline cells or polycrystalline cells. Monocrystalline cells are made from high-purity silicon ingots that are cut to shape whereas polycrystalline cells are formed from less pure silicon that is simply melted and poured into molds (Mohanty, 2016). The pronounced grain boundaries of polycrystalline cells make them less efficient than the high purity of monocrystalline cells. Silicon modules operate by creating an electric field from doped, or tainted, silicon. Silicon PV cells have two layers, one is doped with phosphorus, creating a negative charge (N-Type), and the other is doped with boron, creating a relative positive charge (P-Type) (Singh, 2013). The oppositely charged layers of silicon generate an electric field across the junction where they meet. The cells generate electricity when photons from the sun strike and release free electrons in the silicon. The electrons move in the opposite direction of the electric field gradient, and this movement of electrons generates the electric current. Individual cells do not generate much power, so many cells are connected together to form an entire solar module. The amount of cells, panels, and specific wiring can be configured to produce the desired voltage and current characteristics. Figure 5 displays a common system-level solar PV design.

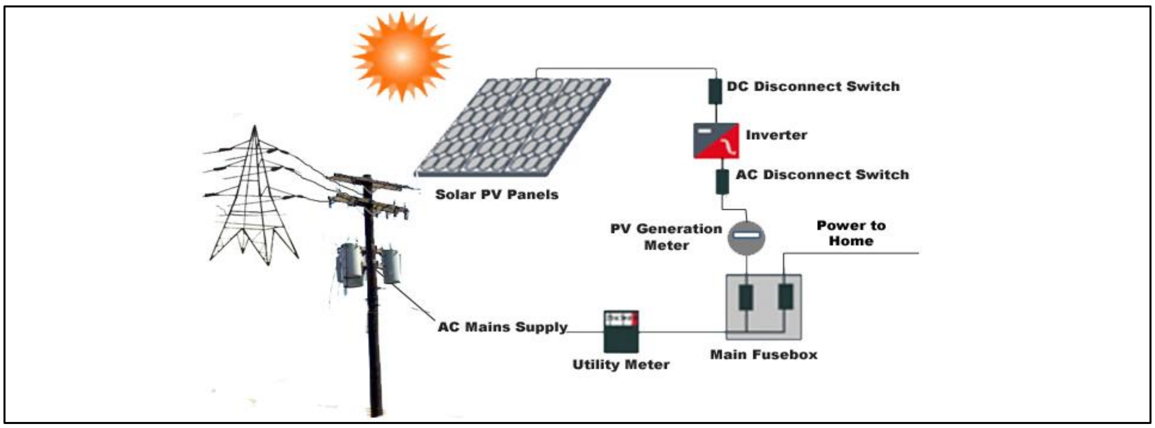

Figure 5: Schematic depicting solar PV technology (SunLife, 2016)

Thin-film solar cells represent another common type of PV module that operate similarly to crystalline silicon cells with one distinct difference; much less dielectric material is required to manufacture thin-film solar cells. Thin layers of material, such as cadmium telluride (CdTe) or copper indium gallium selenide (CIS/CIGS) are applied to a substrate which supports similar electrical properties (Mohanty, 2016). Thin-film solar cells are less expensive because the manufacturing process is simpler, yet are less efficient than crystalline silicon cells. Thin-films also have a much smaller temperature coefficient which allows them to work much better than other panel types in hot climates. Thin-film solar cells do not command a large market share, but are becoming more popular as the technology develops and research improves efficiency.

Solar photovoltaic module construction is broken down into the five sections shown below in Figure 6. The front surface is typically made of tempered glass, acrylic, or polymers. It must be a highly transparent material with low reflection and high transmission properties, as well as possessing good self-cleaning properties in the event of dirt, salt, or other debris coating the front surface. Lastly, this layer must be watertight so no water enters the module and damages the system (Honsberg, 2017b).

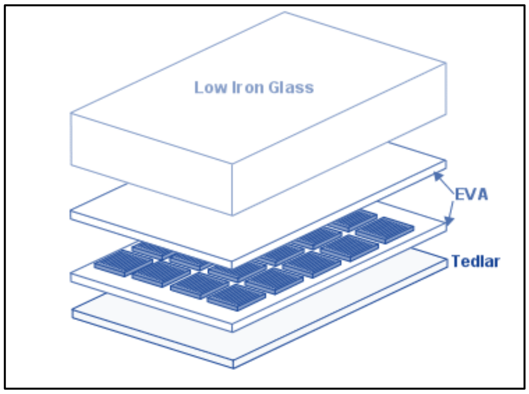

Figure 6: Material composition of solar PV modules (Honsberg, 2017b)

Below the front surface of the panel is the encapsulant. The encapsulant is a composite film that provides adhesion between solar cells and the front and back surfaces. The encapsulant must also be transparent and stable at elevated temperatures and high UV exposure (Honsberg, 2017b). It is also important that the encapsulant has a low thermal resistance. Ethylene-vinyl acetate, or EVA, is the most popular encapsulant material used to produce solar modules (Honsberg, 2017b).

The next layer of a solar PV module is the rear surface also known as the backing. Similar to the front surface, the backing protects the panel from the ingress of liquid or other debris (Honsberg, 2017b). However, because it is the rear surface, it does not need to be transparent. The backing only needs to be transparent if it is on a bifacial module, or a module that collects sunlight from both faces. The backing is typically a thin polymer sheet that has a low thermal resistance. Polyvinyl fluoride, or PVF, is the most popular backing material used today (Honsberg, 2017b).

Lastly, the frame and mounting system attach the module to wherever it is being mounted. The most common framing used is aluminum because it is lightweight for installation yet still provides rigidity to the system. There are a few varieties of mounting systems that can increase the speed of installation, which results in a reduction in the cost (ReNew, 2016). Mounting system designs include a clamping mechanism that clamps the panel in place against the mounting frame, or racking, and a frame with slots on the sides for bolts and mounts to easily slide into (ReNew, 2016). One company has developed a solar panel framing which acts as the racking so the module framing can be mounted to the roof with no additional materials, substantially reducing installation time and cost (ReNew, 2016). Mounting systems will be discussed in greater detail later in this section.

2.3.2 Operation of Solar Inverters

In order to turn the electricity generated from solar panels into consumable power, it must be converted from direct current (DC) to alternating current (AC) and elevated in voltage. This operation is accomplished through use of an inverter. Direct current (typically 17-35 volts at maximum power) enters the inverter and is converted to 230V and 50Hz (Australian Standard). There has been significant advancement in solar inverters over the past few years, and some commercially available products approach 98% efficiency (Singh, 2013). After leaving the inverter, electricity can be used to power household appliances or be exported into the main power grid. PV systems can also be outfitted with storage batteries to provide a bank of power if grid access is unavailable.

There are two commonly used types of inverters on the Australian market: string inverters and micro inverters. String inverters, the older of the two technologies, are utilized more often than the newer micro-inverter technology. These string inverters typically consist of a large box situated far away from the solar array to which all panels feed their DC power. These models are cost effective, allow for design flexibility, and are a trusted technology. However, because string inverters receive current from a multitude of panels (often the entire system) they operate at a much higher voltage level than micro inverters and are incapable of providing Maximum Power Point Tracking (MPPT) for each individual panel without purchasing additional equipment (Energy Matters, 2017b). A device called an optimizer can be installed onto solar modules for systems using string inverters to provide MPPT to each individual panel. In a typical string inverter system, any panel that is underperforming will negatively affect the entire string of panels. However, optimizers interact with each other while allowing each panel to operate independently at the maximum possible output, even when panels are connected in series (ReNew, 2016).

The true value of the micro-inverter is the increased reliability provided by inverting directly from the module rather than a string of modules. The increased number of inverters does cause a larger initial start-up cost, which leads many consumers to purchase the less expensive string inverters. However, over time, the potential for the loss of system operation capability (and the associated revenue) can allow for micro inverters to have the more favorable life cycle cost. It is important to note that the correct inverter technology for a system is highly reliant on the application in question. Factors such as shading, system size, and geography affect the output and efficiency of each solar module differently, as discussed throughout Section 2.2. Each individual application has a unique combination of these factors. Therefore, it is crucial to identify the proper balance between life cycle cost and the correct technology for the conditions of the application.

The primary electrical components responsible for converting direct current into alternating current within a solar inverter are power semiconductors, inductors, and capacitors. Power semiconductors (commonly MOSFETs or IGBTs) are typically arranged in an H bridge circuit configuration and convert DC to AC by cycling pairs of transistors on and off (SMA, 2009). The inverters are able to create a sinusoidal waveform pattern with pulse width modulation. The transistor gates are rapidly activated and pulses of varying lengths are combined and passed through an inductor to smooth out and form a pure sine wave. The inverter is also responsible for monitoring the frequency of the grid and matching the generated AC frequency with that of the grid. This allows for smooth integration as the grid frequency can fluctuate from 50Hz (SMA, 2009). The inverter also increases the voltage from the solar modules to 240V RMS. Many conventional inverters use a transformer to increase the voltage after the conversion to AC. Alternatively, some inverters use an additional transistor and inductor to create a boost converter and elevate the DC voltage as the first stage in power conversion. The boost converter often lifts the voltage to over 700V, such that high frequency switching can be performed (Chisenga, 2011). High frequency switching is more efficient and requires less capacitance. This allows for transformer-less inverters to be significantly lighter and attain higher system efficiencies. Capacitors are required to filter and store energy in order to limit DC ripple currents. Electrolytic and film are the two types of capacitors that are most commonly used in solar inverters. Electrolytic capacitors are less expensive yet are more susceptible to harsh environmental conditions. Electrolytic capacitors can “dry out” due to continuous cycling and high temperatures (Chisenga, 2011). Film capacitors have much longer data sheet lifetime ratings, yet are larger and cost more. Capacitors are one of the most sensitive electrical components within the inverter but are vital to attain high efficiencies and support accurate maximum power point tracking.

Maximum Power Point Tracking is crucial in ensuring modules are generating at the highest efficiency possible, and is almost exclusively used in grid-connected systems. This automatic tracking system utilizes algorithms that adjust the system's settings to provide the highest possible electricity output at any given time, this point of peak efficiency is known as the Maximum Power Point (Eltawil, 2013). This technology is continuously altering system output by comparing the system's current readings to the previous reading (usually at 30 ms intervals), which allows the system to account for changes in irradiance, shading, and temperature (Eltawil, 2013). Figure 7 displays the Maximum Power Point in relation to the system's current and voltage curve. The majority of inverters currently on the market have the capability to provide MPPT data, but because micro inverters are attached to individual panels they are able to provide more detailed data and increase the efficiency of the specific panel it is attached to. This helps to increase the overall efficiency of the system as a whole.

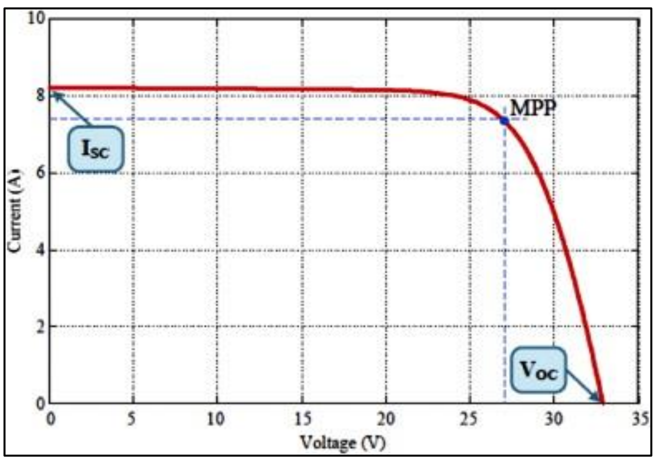

Figure 7: Maximum Power Point (Eltawil, 2013)

2.3.3 Mounting Systems

The final major component required to complete a photovoltaic system is the mounting hardware. There exists a variety of mounting options depending on application, such as roof-mounted, ground-mounted, or one axis ground-mounted. Ground mounted systems are typically used at large-scale generation facilities while roof mounted units are used at residential or small commercial sites. Most ground mounted units are stationary, but some generation plants have one axis mounted units that have the capability to track the sun and produce more energy. Roof mounted units are either attached directly to sloped roofs, or attached to a ballast system to achieve the ideal angle to maximize power generation. Solar racking systems attach directly to roofs and require that holes be punctured and flashed within roofs, while ballast systems employ additional weight on the frames.

2.4 Cost Effectiveness of Solar PV Systems

A recent study was conducted in Australia in partnership with the ATA regarding the approximate return on investment times for 2.0 kW solar systems in each state and territory. A 2.0 kW PV system is typically enough electricity to provide for a two to three person household (Energy Matters, 2017a). According to the ATA's calculations, it takes about seven or eight years to return the initial investment when exporting 50% of power via the solar system with an installation cost of 4,400 AUD (Sheftalovich, 2013). Solar photovoltaic systems have a degradation rate of about 0.5% per year and lose about 20% of their generation capability after 25 years. The inverter must also be replaced every 10 years on average, resulting in an approximately 800 AUD charge each time. A good solar panel is expected to last 20 to 25 years before it needs to be replaced. The ATA also calculates a 0.25% increase in annual retail electricity cost (Sheftalovich, 2013). If the system is expected to last about 20 to 25 years, with a return on investment taking about seven to eight years, replacing the system will pay for itself and the consumer will still receive a hefty profit.

However, not all systems have the same cost as the prediction. It is important for a consumer to find the optimal balance between quality and price when purchasing a photovoltaic system. A low system cost can sometimes be the result of manufacturers cutting corners or not using the best manufacturing practices and materials. A high cost can signify a system of higher quality, however it may not be worth the extra expenses when compared to the performance and reliability of an average priced system. This project worked to better identify system quality to assist consumers in finding the correct balance between quality and price of photovoltaic systems throughout their life cycles.

Something to consider when evaluating the cost-quality ratio is the willingness of the consumer to pay more. A recent survey was conducted on Australian tourists regarding renewable energy supply in hotels. When asked if Australian consumers would be interested in a hotel that used renewable energy sources, the majority of the consumers responded positively. However, when asked if they would be willing to pay extra for this service, only 49% responded positively. Of those willing to pay more, 92% said they would only be willing to pay between 1% and 5% extra (Dalton, 2008). This shows a population willing to make the change to solar PV, but only after a reduction in system price. Therefore, it is crucial to find the correct balance in system price and quality when advising a consumer on what product would be best for them.

Quality is not the only factor that affects system cost. In order to minimize life cycle expenses, an accredited solar system installer should be used. These installers ensure the system is properly wired and positioned for maximum efficiency (Energy Matters, 2017a). There are numerous components that make up a solar panel installation that can inhibit the production or cost effectiveness of a solar system. Failure to use an accredited solar installer could result in serious repair expenses, damaging the return on investment. Therefore, it is important to consider the experience and practices of a solar provider when assessing PV systems.

2.5 Common Failure Modes

Photovoltaic systems are typically dependable sources of electricity, yet there are a number of common places for issues to occur. Photovoltaic modules are complex pieces of equipment, and are designed to withstand various forces of nature. As photovoltaic systems are exposed to the elements, modules must be able to survive thermal stress from changes in temperature, high wind speeds, rainwater, hail, snow, and high humidity levels. Modules are designed to withstand severe conditions, and have a variety of safeguards built in to keep the panels functioning properly.

Nevertheless, modules can fail and common problems include open or short circuit failures, module delamination, hot-spot failures, and microfractures (Honsberg, 2017a). Open circuit errors often happen when the bus wires that connect each individual cell are broken, preventing the flow of electric current. Individual cells can also be short circuited, and not generate power as a result of weathering, delamination, or manufacturing defects. Module delamination occurs when the protective coating surrounding all of the cells begins to form bubbles or peel off the module. This is caused by weathering or poor adhesion to the surfaces. Figure 8 displays a module with delamination failures. The solar panel protective glass can also break for a multitude of reasons such as thermal stress, wind, hail, rough handling, or being struck by an object. Hot spots begin when many cells connected in series receive sunlight, but one or two cells are left in the shade

(Honsberg, 2017a). Figure 9 displays a module with a hot spot failure. This will cause high power dissipation and overheating in the shaded cells, and cause hot spot damages. PV manufacturers are aware of these different types of failure modes, and attempt to mitigate the issues. For example, lamination techniques have dramatically improved in recent years, strengthening the entire module and making it more resilient to changes in moisture and temperature levels.

Figure 8: Module delamination failure (First Green, 2014)

Figure 9: Module hot spot failure (First Green, 2014)

One of the most common modes of solar module failure is the development of miniscule cracks within solar cells that cannot be seen by the human eye, known as microfractures. Microfractures can span across cells and in a wide variety of shapes and directions, and can have a significant impact on a module's performance. This form of degradation is caused by numerous factors, but can typically be traced to excess stress on the module or manufacturing defects (Köntges, 2011). The excess stress can be caused by environmental factors such as a large thermal variance between day and night, humidity, and high wind speeds which are all pertinent in the Australian case. Due to their miniscule size, microfractures often go unnoticed for up to two years, and slowly degrade the module without the consumer knowing. In addition to environmentally-caused stress, mechanical stress can arise during shipping and installation. Examples of this include improper shipping techniques, installation that allows for module flexure, and dropping of or stepping on panels during installation. No matter the cause of the microfractures, these defects have the capacity to separate cells and render them inactive, causing a decrease in panel output of upwards of 2.5% (GSES, 2015). Microfractures also have the potential to cause the aforementioned hot spots which further reduce panel efficiency. These defects cannot be repaired, and therefore extreme care in manufacturing, installation, and maintenance must be employed to minimize their effects. Figure 10 displays advanced microfractures that have been allowed to expand to a size visible to the human eye.

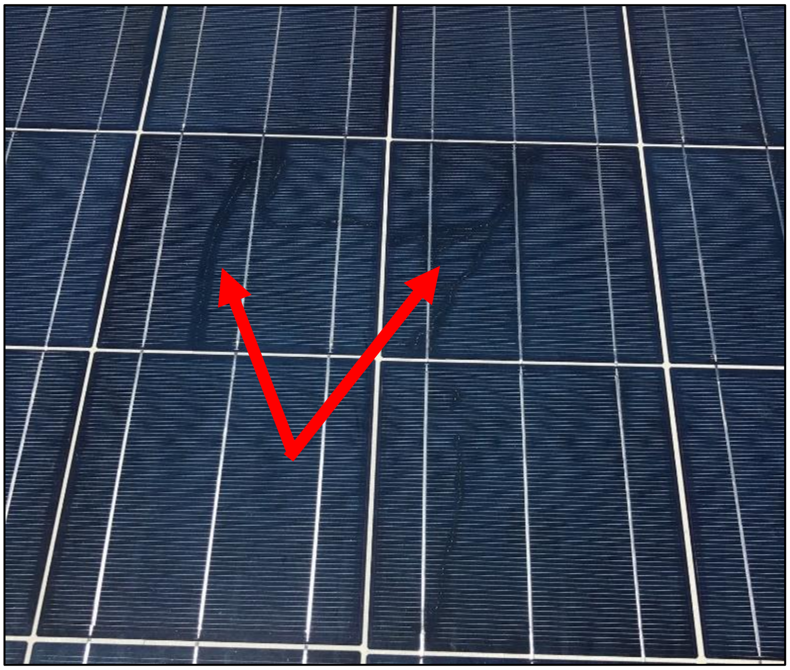

Figure 10: Microfractures that have expanded over time (Fletcher, 2017)

In an attempt to minimize the presence of microfractures, some manufactures conduct Electroluminescence (EL) tests. EL testing makes use of non-visible light emitted by passing current through solar cells. This light is then detected by a special camera, and any present microfractures are identified. However, the Clean Energy Council does not require EL testing and not all manufacturers perform these tests. Therefore, selecting a manufacturer that conducts these tests is helpful in ensuring the long-term quality of the solar modules. Figure 11 indicates the different types of errors found in solar systems globally, by percentage, accounting for failures in solar modules after being in use for eight years (Köntges, 2014). It is also important to note that only 2% of the modules observed had failed after eight years.

While photovoltaic modules are susceptible to failures, inverter problems pose a much larger threat to a system's continued operation. A failure modes analysis completed in Italy found that 76% of outages at solar PV plants are caused by inverter failures (Cristaldi, 2014). These failures are often caused by problems with thermal management, heat extraction, or lightning. Lightning commonly causes electrical overloads in inverters if proper precautions such as

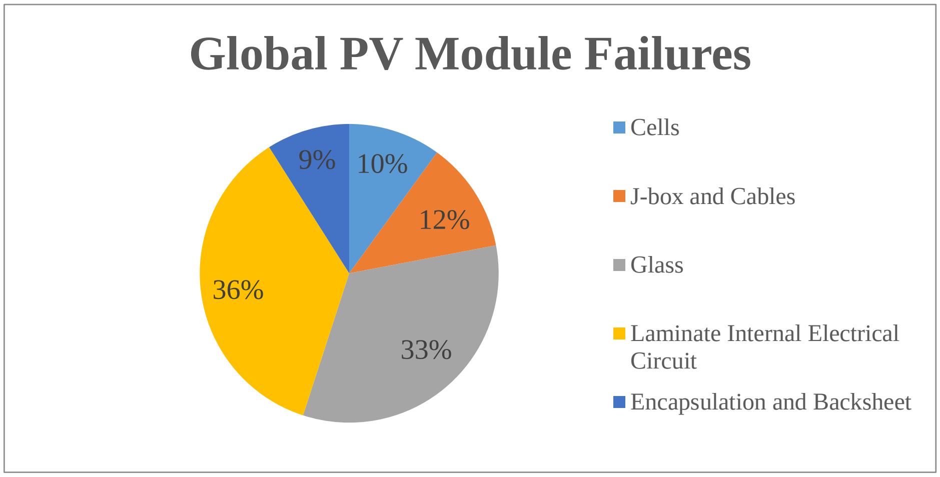

Figure 11: Global failure mode distribution (Köntges, 2014)

lightning rods or internal grounding are not implemented. The most sensitive components within inverters are often considered to be the electrolytic capacitors and the insulated gate bipolar transistors (Cristaldi, 2014). These devices are commonly exposed to both thermal and electrical stresses which compromise the inverter's lifespan. Additionally, inverters are commonly plagued with manufacturing flaws that contribute to decreased performance and efficiency. Inverters are not expected to last the 25 year lifespan of solar modules, and must be replaced approximately every 10 years.

While manufacturing issues do occur, most issues are not a result of poor manufacturing methods, but are caused by faults introduced during installation instead. Installers of PV systems must have a comprehensive understanding of the different components involved in creating a successful system. A study completed by PVTRIN (Training of Photovoltaic Installers), which operates under Intelligent Energy Europe, found that 5% of inspected PV systems had loose terminal connections, 24% of solar generating cabling was not mechanically secured, and 60% of string diodes lacked heat dissipation (Tsoutsos, 2011). Improper installation can result in electrocution, leaky roofs, broken glass from thermal stresses, overheating at the inverter, loss of warranty, and a variety of other concerns. Installers in Australia must be especially attentive to mounting solar panels because much of Australia is affected by extremely high temperatures and wind speeds. High temperatures reduce the efficiency of photovoltaic cells and increase the risk of fires. In some parts of Australia, particularly western and northern parts of the country, cyclones are a major threat, and PV systems must be installed to withstand excessive wind speeds.

2.6 Assessing Solar Panel Quality

The quality of panels varies greatly with different manufactures. However, most small-scale PV owners are unaware of the manufacturer of their system, and subsequently the quality standards to which it was built (Duke, 2002). While cost is a major factor effecting the decision to purchase a solar PV system, the quality of the overall system is an extremely important component that is often overlooked by consumers in exchange for a more cost effective system. Quality is characterized by two attributes: performance and reliability. Quality affects the longevity and return on investment of the system, which is vital to ensuring a successful solar PV venture. Fabrication materials, system design, and installation are all factors affecting quality (Duke, 2002). This section will investigate the different methods to properly assess these two crucial system attributes, as they pertain to both the solar module and inverter.

There are many options to customize a PV system with ideal components to match specific environmental, political, or economic situations. The Australian government also has strict regulations regarding which products are suitable for use in the country. Every module, inverter, and PV mounting system must be approved by the Joint Accreditation System of Australia and New Zealand (JAS-ANZ) (Clean Energy Council, 2014). In addition, they must also abide by the Clean Energy Council's guidelines for the installation, design, and supervision of photovoltaic systems. These regulations guarantee a certain quality standard by addressing concerns such as safety, reliability, efficiency, and environmental implications. While all systems must adhere to this standard, a variance in quality of systems still exists. Therefore, a comprehensive assessment methodology is required to differentiate between system components.

The most commonly used metric to quantify solar system performance is efficiency. Efficiency can be defined as the percentage of solar irradiance a system converts to electricity. A typical panel converts between 8-20% of solar irradiance into electricity (Australian Energy Council, 2016). It is crucial that solar systems operate at a high level of efficiency in order to produce the maximum profit for investors. Therefore, monitoring and recording efficiency data can provide insight into the system's degradation over time, and help to quantify its life-long performance. However, panels begin degrading and lose their efficiency in electricity production each year. Many manufacturers guarantee a maximum loss of 20% efficiency over the first 25 years after the installment date (EnergySage, 2016). This loss in efficiency creates the need to record the annual degradation rate of a panel. The majority of solar PV modules have a degradation rate of approximately 0.7% each year (EnergySage, 2016). Metrics such as efficiency data are essential in quantifying PV system performance, and in turn quality.

In order to properly gauge a PV system's performance, analysis must be done over time, with respect to change in impactful factors such as irradiance, temperature, and shading (Kurtz, 2013). This means that the same solar system will perform differently as a function of geography, rather than simply a linear function of solar irradiance (Huld, 2010). Climatic data is combined with the material and system properties of the solar module in question, and an expected system performance is calculated using various algorithms (Huld, 2010). It should be noted that as technology continues to improve, assessments must be revised to account for these changes.

Another important factor to consider is power tolerance. This metric indicates how the power output of a solar panel differs from its nameplate rating. Unavoidable factors can impact power output during solar panel manufacturing. Tolerance is typically measured as a plus or minus percentage, indicating the range in which its efficiency lies. For example, 250-watt panel with a ±5% power tolerance could produce anywhere from 237.5 watts to 262.5 watts under ideal conditions (EnergySage, 2016). A smaller tolerance percentage range means more certainty and is to be viewed in correspondence with solar panel ratings.

The temperature coefficient of the panel also plays a role when examining system quality. While solar panels are designed to absorb the sun's energy, efficiency can decrease once the ambient air temperature reaches 25 degrees Celsius (°C) (EnergySage, 2016). The temperature coefficient quantifies how a panel's power capacity decreases after it reaches this cap. Many panels produce 1% less electricity for every 2°C increase after 25°C. Panels with a smaller temperature coefficient perform better in higher temperature regions and are more reliable long term (EnergySage, 2016). This is an important metric to review for the Australian case due to the high temperatures the country experiences.

Reliability can be seen as the probability of adequate function (Ahadi, 2014). Solar PV systems can be susceptible to damage, both inside and out. The lifecycle reliability can be massively altered by changes in temperature, power surges, and other environmental factors (Zhang, 2013). Therefore, assessing this makes it possible to optimize design, service, and cost in the face of these damaging factors. Methods for quantifying reliability are discussed below.

Mean time to failure (MTTF) is one of these quantitative metrics. This quantity represents the average amount of time it takes for the system to lose its functionality for the first time. This is often considered the average life span of the solar panel (Ahadi, 2014). MTTF requires product testing over time. However, this data is not readily available on product data sheets, making it difficult for consumers to understand how long their system will last. Instead, most panel manufactures provide a certification of compliance with ISO 9001:2015. The International Organization for Standardization (ISO) created the ISO 9000 series to ensure quality assurance standards for the manufacturing industry. Manufacturers that are ISO 9000 certified have met industry standards. If a manufacturer is not ISO 9000 certified, it does not necessarily reflect their products as non-quality, but lack of certification represents a company without an established mechanism for assuring the quality of their products (EnergySage, 2016).

Another key metric used for quantifying solar system reliability is mean time between failures (MTBF). MTBF values are determined using the “bathtub curve” shown in Figure 12. This graph depicts the three simplest stages within the total life of a solar system. The beginning and end stages of the system’s life span experience higher failure rate due to start-up problems and wear-out respectively. The “useful life” stage, which accounts for the majority of the curve, fails at a far lesser rate (Engle, 2010). Mean time between failures is calculated based solely upon the useful life period. Thus, MTBF does not properly evaluate the full lifespan of the system (Engle, 2010). This stat is useful in determining how long the equipment will remain functional, however it does not fully take into account the extremities of a system’s life.

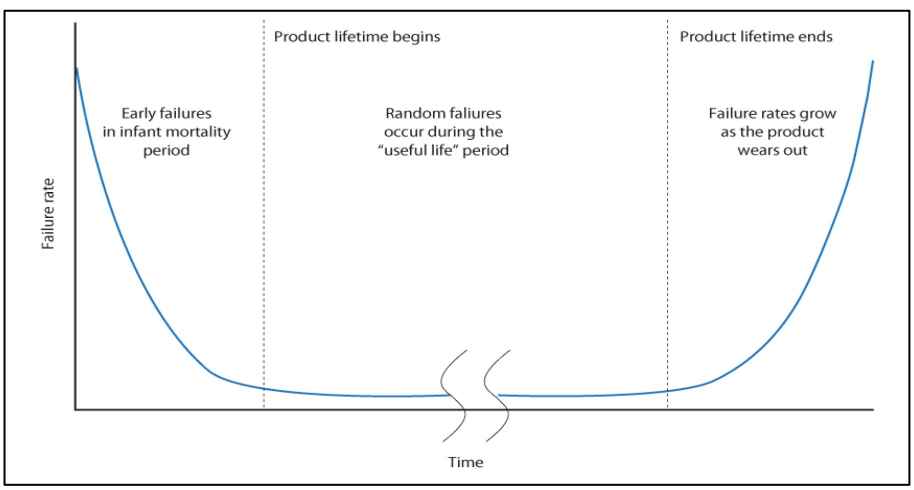

Figure 12: "Bathtub curve" (Engle, 2010)

In most cases, PV systems are accompanied by warranties that offer reimbursement to the consumer in the event of a failure post-installation. These manufacturer assurances are also important in determining quality because their period length indicates both technical and business constraints. Companies will not attach lengthy warranties to a product whose quality they are not confident in. Therefore, they are good metrics for investigating system lifetime quality. Most companies offer power production warranties ranging from 20-25 years in duration. This warranty guarantees that while the system is operational, it will produce the specified amount of electricity.

Aside from the power production warranty, most panels also come with a 10-12 year material warranty. “This warranty guarantees failures due to manufacturing defects, durability, and environmental issues” (EnergySage, 2016). This guarantee reassures consumers that the system and its components will not deteriorate and remain operational for the duration of the warranty. Generally, manufacturers guarantee that their panels will be failure-free for 10 to 12 years, but some consumers extend their warranties for reassurance.

Warranties are strong indicators of quality, but they cannot be solely referenced to determine system quality. While it may not be financially sound, companies can arbitrarily assign warranties for their products. Therefore, it is crucial to investigate the reputation and longevity of a company. A business that has years of experience is more likely to provide proper warranties. Longevity also provides insight into the competency of a company. Selecting a competent company that has industry experience, proper warranties, and a good reputation in the industry is crucial for ensuring PV system quality. Therefore, competency, along with warranty and the other reliability metrics, are sufficient evaluation tools for the quality of solar photovoltaic systems.

Table 2: Common factors used for quantifying PV system quality

Assessment Metric	Characteristic Quantified	Description
Mean Time to Failure	Reliability	The average time for a PV component to experience its first failure
Mean Time Between Failures	Reliability	Calculated based upon the average time span between component failures during the useful life stage of a system
Efficiency	Performance	Percentage of solar radiation the PV system converts to usable energy
Power Tolerance	Performance	The certainty with which the system’s power output is rated
Temperature Coefficient	Performance	Quantifies panel efficiency above optimal temperature
Warranty	Reliability	Manufacturer coverage of electricity output and material operability
Degradation Rate	Reliability & Performance	Declination percentage of electricity output

2.7 Alternative Technology Association

The Alternative Technology Association is a non-profit organization established in 1980 in Melbourne, Australia that encourages, promotes, and enables homes and communities to live sustainably (ATA, 2017). The organization has 14 active branches in Australia that hold informative seminars, sustainable house tours, and other events. In addition, the ATA provides energy efficiency, water conservation, and solar power assessments. The organization has helped reduce household environmental footprints and, in turn, Australia's overall footprint (ATA, 2017).

The two main departments of the ATA are the Projects Department and the Communications Department. The Projects Department makes use of a decision-making matrix to provide recommendations on renewable technologies to governments and community organizations. The Communications Department holds events and produces magazines and newsletters that are circulated to their nearly 6,000 members to raise awareness on the need to switch to renewable energy technology. The ATA's two magazines on sustainable living include: *ReNew: Technology for a sustainable future*, and *Sanctuary: Modern green home*. In addition, the ATA produces a large amount of prints, e-books, booklets and other publications (ATA, 2017).

The ATA provides consultation services to local governments and other community organizations regarding financial, technical, regulatory, and operational aspects of sustainable technologies. This is vital in order to continue relaying correct information and advice to current and prospective consumers (Gaudet, 2015). The ATA is able to remain an unbiased consultant, as they are a non-profit organization that does not manufacture or sell products. This project focused on communities whose citizens are interested in and/or currently purchasing solar photovoltaic (PV) technology for residential and commercial environments.

In 2014, the Borough of Queenscliffe solicited the ATA's services when their citizens were interested in a community solar PV bulk-buy. In March of 2015, Queenscliffe began receiving bids and quotations from solar suppliers for supply and installation of systems in both Queenscliffe and Point Lonsdale. Their ideal solar supplier and system would provide lifelong system value by meeting five general criteria: price, quality, warranty, customer service, and company experience (Borough of Queenscliffe, 2016). Figure 13 is a photograph of a workshop held by the ATA where representatives within the organization are informing the residents of the Borough of Queenscliffe of their solar assessment methodology.

Figure 13: ATA information workshop (Borough of Queenscliffe, 2016)

The project was divided into three phases: inspection of properties, acceptance of quotations, and installation of systems. For inspection of properties, registered residents booked a time for a personal property inspection to evaluate their roofs and discuss site constraints and the residents' expectations from a solar system. By June of 2015, over 95 inspections on houses, businesses, and community organizations were completed in Queenscliffe and Point Lonsdale. By July 2015, the first set of solar PV systems acquired through the community solar project was completed in Point Lonsdale with eight system installations and another twenty ordered (Borough of Queenscliffe, 2016). This project made use of the solar quality methodology utilized within the Queenscliffe bulk-buy program assessment. The ATA has identified that there is room for improvement in their decision making process and has requested assistance in enhancing this methodology.

The Queenscliffe PV assessment matrix is an excel spreadsheet created specifically for the community of Queenscliffe. However, the basic functionality can be applied to all ATA evaluations and was therefore used as a test case. This assessment matrix compared different factors to provide an overall score for each solar provider (out of 100%). The five sections of the matrix are broken down as such: price (30%), warranty (25%), quality (25%), experience (10%), and customer service (10%). Figure 14 displays the summary page of the current assessment matrix and how systems are compared using their given score.

Sub	Supplier	System components	Rank	Final Score 100%
1	Aus1Energis	Risen/Goodwe	9	70.3%
2	Aus1Energis	Risen/SolarEdge	15	64.2%
3	City to Surf Solar Plus	Sunpower E327/Fronius	6	74.3%
4	City to Surf Solar Plus	Sunpower P340/Enphase	13	65.7%
5	Efficient Energy	Jinko/Fronius	3	76.2%

Figure 14: Queenscliffe assessment summary page (ATA, 2016)

The price section is supported with quantifiable cost data provided by each supplier. It evaluates the size of the system, in kW, the price of the system, and the price per kW. Though, the price section only considers the smaller of the inverter or array, and has no consideration for under sizing or over sizing. The warranty section is also supported with information provided by the supplier. The warranty section provides a score based upon the scope and time span of the warranty. While these first two sections of the matrix use quantitative data, the remainder of the matrix relies largely on qualitative measures, including consumer reviews and assigns scores based on the qualitative assessment in order to generate a final quantitative ranking.

The main area of improvement within the matrix is the quality section of the assessment matrix. Quality was broken into categories such as efficiency, tolerance, temperature coefficient, and fail rate. Efficiency, tolerance, and temperature coefficient were backed with quantifiable data, however these numbers only made up about 10% of the total quality score. The remaining 90% of the quality assessment was dependent upon the fail rate category. The purpose of the fail rate column was to provide useful information about the quality of the product. The fail rate column included notes about reputations of companies and (in some cases) about test results, but no quantitative data on the quality of their panels. As seen in Figure 15, fail rate notes do not differ greatly, but the scores associated with them do. Investigation of the matrix revealed only a slight difference in fail notes between a perfect score and a half score. The note receiving a perfect score had no mention of failure statistics, only the reputation of the panel and company. While these factors do provide insight into system quality in the absence of quantitative data, inclusion of such data would make the assessment more robust. The note receiving a worse score mentioned that there was no record of these models failing, despite being a new panel.

FailRate	FailNotes
7.5	Very good test results in Choice. Very good feedback from installers.
8.0	Very good reputation for quality and company backing amongst installers.
7.5	A good midrange panel. Fairly new so not much information on failure rates.
4.0	New panel on the Australian market. Very limited information available. No failure notes evident online.

Figure 15: Failure rates of solar panels within the quality section (ATA, 2016)

The primary issue with the current quality tab is that in the absence of quantitative data on failure rates or other quality metrics, it relies on reputation but with no supporting evidence or quantifiable reasoning for the score. Also, the overall weightings of the matrix are based on ATA's assessment but not informed by research into consumer preferences. In this project, our team aimed to reassess the overall weightings of each section, focusing primarily on the quantifying the system quality tab. Through our methods our team achieved our goal of reassessing the matrix weightings and quantifying quality.

3. Methodology

This project is intended to assist the Alternative Technology Association by providing an enhanced assessment methodology for solar photovoltaic systems, emphasizing development of a quantifiable evaluation of reliability and performance. This project offers a more comprehensive recommendation to consumers interested in purchasing solar photovoltaic systems. In order to accomplish our mission, we have created four primary objectives:

1. Research factors affecting solar PV quality

2. Evaluate metrics indicative of solar PV quality

3. Develop an understanding of consumer priorities

4. Design a more comprehensive multiple-criteria decision-making matrix to compare photovoltaic component quality

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3.1 Research Factors Affecting Solar PV System Quality

As discussed in section 2.7, when investing in a solar photovoltaic system, it is vital to explore factors affecting performance and reliability. This section discusses the process by which the most pertinent factors affecting system quality in Australia were identified. In order to determine the most important factors the team conducted interviews of Australian solar industry leaders and utilized available 3rd party and manufacturer test data. These interviews were transformed into quantifiable data by using the coding mechanism discussed later in this section. Once the quality factors were determined, research was conducted to provide in depth information regarding quality factors to the ATA.

Australian solar industry leaders were interviewed to determine what factors affect system quality. The preliminary contacts were selected using convenience sampling, with the assistance of the Alternative Technology Association. In an attempt to increase sample size, the team contacted all suppliers and installers who took part in the Queenscliffe bulk-buy assessment and all companies listed on the solar panel and inverter buyer's guides (in *ReNew* editions 134 and 137 respectively). These companies were asked to share their experiences in the solar industry with system failures, how they define quality, and what they view as the most important factors determining system quality. We asked the suppliers what they look for when searching for a manufacturer to buy products from and how they perform analyses to understand system quality. The interview questions are outlined in Appendix E. The team also made use of snowball sampling at the conclusion of each interview to provide a greater number of potential interviewees and make the study more robust.

Since most solar PV system manufacturers are not present locally, most interviews were conducted over the phone. Manufacturer interviews focused primarily on material composition, manufacturing techniques, and how they affect different component models. The interviews also sought to answer questions regarding warranty projections and the quality data involved in establishing them. The questions for these interviews are outlined in Appendix F. Understanding different material compositions and manufacturing techniques for modules and inverters helped differentiate product quality.

After collecting data from interviews, we developed a coding system to identify common responses and categorize them accordingly. Coding is the process of systematically organizing and sorting qualitative data in order to develop quantitative values for analysis. The first step in creating the mechanism was to establish the overall goal of the study, which is outlined in the introduction to Section 3. Once the objective of the study was summarized, both predetermined and emergent coding were utilized. Predetermined coding makes use of code categories that are established prior to starting the coding process based on prior knowledge and information. Examples of predetermined codes for this study include: manufacturing, installation, reputation, materials, and warranty. While emergent codes allow for categories to be created based upon trends found in the qualitative data. Emergent coding was used to provide greater detail within the predetermined coding based upon the responses gathered from conducting interviews. The coding mechanism for this study can be found in Appendix H. After completing the initial coding for each interview, it was redone in order to ensure thoroughness and increase the code's level of detail. Anything deemed pertinent by the team after analyzing code results was researched further to gather more information regarding a factor's effect on system quality.

3.2 Determine Metrics Indicative of Solar PV System Quality

Through the interview data collected in Objective 3.1, the team became aware of reliability data used by industry leaders to determine system quality. Following further research of these metrics, the team set out to determine which metrics best indicate a solar PV system of higher quality. We made use of various research institutions' data as well as online databases, articles, and product datasheets to draw conclusions regarding reliability and performance of solar products and metrics which identify them. These quantifiable metrics of reliability and performance were added to the quality section of the assessment matrix and weighted properly, as described later in this section.

3.3 Develop an Understanding of Consumer Priorities

The ATA has a membership list of approximately 6,000 consumers, manufacturers, and people with a general interest in renewable energy that subscribe to their emails, newsletters, magazines, etc. We sent out a survey to this entire list to gather a better idea about what consumers value most in a solar system. The survey results allowed us to see what consumers value most in a system. These consumer priorities were considered when evaluating the weighting system of the new assessment matrix. The survey has multiple branches based upon whether the respondent owns a solar PV system or not. If the respondent does own a solar PV system, they were asked to answer a few questions about the performance and reliability of their system, the specific model they own, and the light exposure their panel receives. Those who do not own a solar PV system skipped that section and rejoined the owners of PV systems to answer some basic questions about consumer priorities when looking to purchase a system. This provided us with an overview of what a solar consumer looks for while also providing some reliability data when possible. The survey questionnaire is located in Appendix D.

3.4 Design a More Comprehensive Decision-Making Matrix

Many specific aspects within the ATA's decision matrix were identified as opportunities for improvement. Quality assessment previously relied heavily upon qualitative analyses and variable perception of solar companies and the products that they offer. The ATA desired to expand the matrix and include additional information indicative of component quality to improve the veracity and consistency of quality ratings. This revised matrix was created within Microsoft Excel, and supports continual modification and improvement. The new decision making structure includes information on photovoltaic systems tailored to current ATA consultations. This tool is capable of providing proper assessments for consultations of any size or scope.

Information collected from the objectives above was used to develop key aspects of this decision matrix. This included analysis of metrics gathered from independent test facilities, manufacturers, and providers. Analysis was performed on this data to arrive at useful metrics for assessing the quality of PV systems. Based upon these findings, a new tender request form to accompany the matrix was created for solar providers wanting to participate in bulk-buy schemes.

3.4.1 Understand Previous Community Assessments

In order to develop an understanding of the Alternative Technology Association's consultation process, past solar assessments and community bulk-buy programs were examined. Interviews were conducted with ATA employees and town officials who had been involved with the consultation process. Within the first two weeks of arrival in Melbourne, four key employees involved with the assessment and policy at the ATA were identified and interviewed about their experiences and responsibilities relating to photovoltaic system assessment. Specific questions were asked about data acquisition, assessment shortcomings, and relative value of factors affecting system quality. All questions can be found in Appendix B. The interviews with ATA employees were helpful in building a comprehensive understanding of the solar assessment process, from the time of tender request through the final recommendation package. Interviews with the ATA were crucial in identifying improvement points within the prior matrix. To gain a more holistic understanding of bulk-buy schemes, an additional interview was also conducted with the Queenscliffe Council Sustainability Officer, Jacqueline Wilson, who had worked to coordinate the Queenscliffe bulk-buy program with the ATA. This interview provided feedback about the council's experience working with the ATA and the crucial link between consumer, governmental agency, and the ATA. The specific questions are outlined in Appendix C.

3.4.2 Matrix Weighting System

The weighting scheme for the new matrix was structured to merge values and perspectives of the ATA, manufacturers, suppliers, and consumers. Surveys and interviews provided the information required to assess the desires and needs of the various stakeholders. Convergent validity delivered confidence that the final weightings accurately reflect the values and requirements held by each party involved with PV system acquisition. This assisted in allowing the decision matrix to provide a justifiable and consistent assessment across a multitude of photovoltaic system options.

As previously stated, the original decision matrix was structured into five main tabs with an assigned weighting for each factor affecting system quality: Price (30%), Warranty (25%), Quality (25%), Experience (10%), and Customer Service (10%). Each of these factors influences the calculation of the overall score, and sampling was conducted to confirm that these weights accurately align with consumer values. Since consumers are the direct beneficiaries of the products identified by the decision matrix, their priorities were identified in order to confirm or redistribute weighting percentages. The survey and interview results were used to examine the relative value of each of these factors. Survey participants were asked, “What is most important to you when purchasing a photovoltaic system? (Please click and drag to rank)” Responses from this ranking question supported a new distribution of weighting values.

A mathematical approach informed by rankings was used to assign weightings to each tab corresponding to the number and value of ranks received. A first place score was assigned 5 points, second received 4 points, third received 3 points, fourth received 2 points, and fifth place received 1 point. The equation below was utilized to arrive at each tab’s weighting within the matrix. This equation transforms the raw survey data into a percentage values representative of its importance to consumers. These percentages were used to determine the revised tabular weightings.

$$\frac{\sum_{R=1}^{5} n(6-R)_{Individual}}{\sum_{R=1}^{5} n(6-R)_{All\ Tabs}} * 100\%$$

Where:

R = rank
n = amount assigned ranking

After performing the summation in the numerator shown above, a score for each tab is calculated. These scores are then added together to get the total number of points available. The tabular score is then divided by the total number of points available. This gives a percentage which becomes the tab's weight within the assessment matrix. Due to the fact that it takes every ranking into consideration for all responses, the weighting will always stay somewhat balanced with a slight weight towards consumer preferences. The lowest percentage a tab could possibly receive is just over 6%, the highest percentage a tab could possibly be is 33%. Therefore, no tab can shift the overall assessment dramatically and no tab is overlooked. Each tab is weighed in a mathematical manner with quantifiable data backing each percentage, rather than subjectively. It is important to note that these weightings are baseline values, and are subject to fluctuation per the specific application values entered into the application specific tab.

A weighting system was also developed specific to each tab within the matrix. The information stored within each tab is more technically advanced, so information collected from research papers and interviews with solar professionals was used to develop intra-tabular weightings. Many potential metrics for quantifying photovoltaic system value were identified in Sections 3.1 and 3.2. Though, a number of these metrics were limited by confidentiality restrictions, limited availability, or industry-wide conformity. Sources for collecting metrics characterizing photovoltaic system value were identified, and assessed to determine accessibility and relevance. Metrics were invested to confirm that information was available for a wide range of products. Information for modules and inverters listed on the ATA's Buyer's Guide and Queenscliffe Assessment was searched for to confirm that metrics were accessible for the majority or relevant products on the market. Some of the best metrics indicative of failure rates were not published by many companies, so they were not included in the final matrix. These metrics are ideal for running a comprehensive reliability analysis, and therefore could be used in additional analysis to show how a robust quality assessment could be developed with use of reliability data.

Encoded interview data allowed the metrics to be processed and analyzed according to the factors that are most important to photovoltaic manufacturers, retailers, and installers. This information dictated which columns were included on each tab, and how much relative value each should contribute to the tabular score. Additionally, triangulation based off the different perspectives of industry leaders involved in construction, sales, or implementation provided confidence in the overall evaluation. Based upon the prevalence of key themes and concepts considered in the interviews with professionals, metrics were assigned weighting values. For example, if the majority of photovoltaic manufacturers and installers placed greater emphasis on particular aspects of quality, such as materials, efficiency, or reputation, those factors received more weight in the quality tab. The weighting values were assigned in proportion to the amount of times themes are identified by the coding scheme.

The matrix was also restructured to restrict the need for visual keys to assign scores based on product criteria. Rather, tables and corresponding equations were expanded to include direct data input and analysis. The ratings or scores for each sub-category were calculated based off difference from the optimal system. A benchmark value was often used as a minimal floor, and ratings between one and ten were assigned ranging from the floor to the greatest value. This simplified data entry, made the tabs more informative, and calculated the scores with greater accuracy. All weighting values incorporated in each tab were clearly labeled in reference cells, such that the weights could be adjusted as the industry expands.

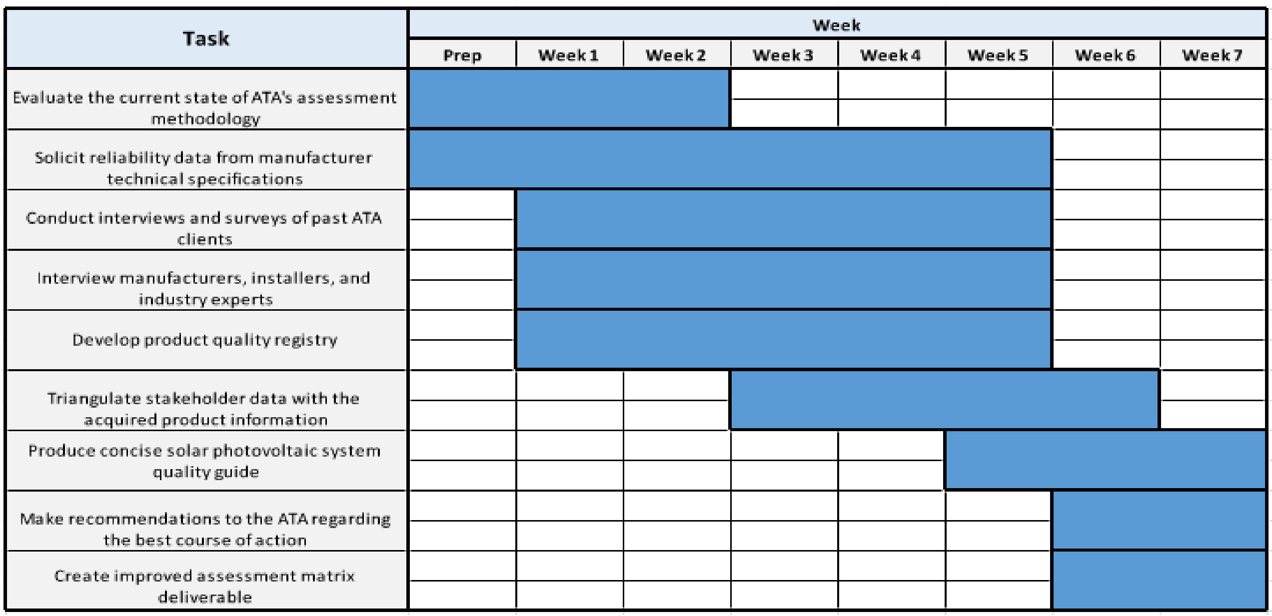
3.5 Project Obstacles

The project team conducted this evaluation of the ATA's quality assessment methodology in accordance with the methods described above. However, we recognized the variability of a study of this nature and magnitude, and after conducting the study have provided the obstacles encountered within this section.

The first obstacle to our project was the inability to gain access to manufacturer technical data sheets. A large portion of the improvements to the ATA's current assessment matrix were to involve the inclusion of reliability data metrics that allow for a more quantifiable approach to rating solar systems. Manufacturers were reluctant or unwilling to provide this product data in order to maintain confidentiality. Our project team reevaluated the desired metrics and identified alternative methods for quantifying the quality section of the matrix. However, rather than completely denying our team's data requests, some companies required completion of a Nondisclosure Agreement (NDA). In order to utilize the necessary reliability data, the ATA must have agreed to the terms and conditions established in the document. Data received after completion of the NDA would not have been available for publication in our final study.

Other obstacles of this study occurred when gathering interview and survey data. It was crucial while conducting these interviews to remain unbiased. A lapse in neutrality has the capability to cause bias and introduce the subjectivity that we tried to overcome within the current matrix. In addition, people were not always willing to participate and provide information in studies of this nature. To combat this, our group increased the sample size of the study in order to obtain data capable of making proper recommendations to the ATA. However, the team conducted surveys and interviews with a wide variety of industry stakeholders, allowing conclusions to still be drawn. Despite these obstacles, the team was able to adhere to the schedule shown in Table 4 for conducting the study.

Table 3: Project schedule



4. Findings & Analysis

The current need for increased renewable power generation and the growth of solar PV in Australia have created the need for a more comprehensive analysis of photovoltaic system quality. This chapter presents the alternatives for better assessing the performance and reliability of these systems. This data was compiled by utilizing available test data from various solar PV test agencies, interviews with solar industry leaders, conversations with key Alternative Technology Association employees, and survey data gathered from ATA subscribers. The combination of these findings resulted in a more comprehensive decision-making matrix for assessing the quality of bulk-buy tenders.

4.1 Factors Affecting Solar PV Quality in Australia

It has been established that there are several factors that alter the lifetime quality of solar PV systems. This study identified the most pertinent factors, and presents them within this section. This information was compiled through interviewing solar suppliers, manufacturers, and installers, in addition to conversations with Alternative Technology Association employees, and independent research. This section analyzes various factors that are important to consider that help optimize cost and quality when attempting to purchase solar photovoltaic systems. Considerations include construction of modules and inverters, mitigating common failure modes, company reputation, and office location.

4.1.1 Comparison of Solar Modules

The study has identified the importance of properly selecting the correct construction of solar modules for each specific application. The following section will provide a comprehensive analysis of the differences and benefits of the three most common module construction types: polycrystalline silicon, monocrystalline silicon, and thin film solar modules.

Monocrystalline silicon solar modules are commonly the most efficient solar modules on the solar market with an efficiency of roughly 15 to 20% (ENF Solar, 2017). This efficiency is due to the lack of grain boundaries within the cells. Grain boundaries are crystal structure defects that decrease electrical and thermal conductivity of the cells (Mohanty, 2016). However, these high purity and high efficiency silicon solar modules come at a cost. Monocrystalline solar modules are about 10 to 20 cents AUD more per watt than polycrystalline solar modules. On a 5 kW system, this results in a cost difference of 500 to 1000 AUD for a slightly higher efficiency. Monocrystalline solar modules perform the best in average climates, making them a good option for a wide variety of applications.

Comparatively, polycrystalline silicon solar modules are slightly less efficient, with an efficiency of roughly 13 to 18% (ENF Solar, 2017). While the efficiency is still high, it is lower than monocrystalline silicon due to the presence of pronounced grain boundaries (Mohanty, 2016). Similarly to monocrystalline modules, polycrystalline cells have a temperature coefficient of 0.45% to -0.50% per degree Celsius. This means that as the panels experience increased heat their output begins to decline. Polycrystalline modules are less expensive than monocrystalline modules and have a similar performance rating, but they are not the least expensive module on the market. Polycrystalline solar modules provide the best balance between price and performance, especially in a mild climate.

Thin film solar modules are currently the least utilized technology on the solar market. Previously, the efficiencies of thin film modules were inferior to the silicon crystal technology used in the previously discussed solar module constructions. However, with increased research and development focusing heavily on thin film technologies, efficiencies have increased and the benefits of thin film solar modules have become more apparent, especially for application in Australia.

The most recent thin film modules claim efficiencies of roughly 10 to 15%, which rival some polycrystalline modules. While the efficiencies are still slightly lower than those of silicon crystal composition, they come at a lower cost, creating an argument for thin film modules. Thin film modules are a few cents less per watt than a polycrystalline module, resulting in a 5 kW system cost that is potentially about 150 to 300 AUD cheaper. While cost is an important factor, the temperature coefficient is allowing thin film technology to grow in the solar industry. The temperature coefficient of thin film modules is significantly lower than that of crystalline modules. Thin film module efficiency decreases about 0.25% per degree Celsius, which is almost half that of its silicon based rival (ENF Solar, 2017). This means that thin film solar modules perform much better in hotter climates, and with a much higher base efficiency than in previous years, the performance of crystalline and thin film can be considered comparable. This makes them especially viable for the hot Australian climate. As research and development of thin film technologies continues, thin film modules may be more beneficial in hotter climates. A 2011 study was conducted on a CIGS thin film module, achieving record efficiencies of 20.1% and 20.3% in a laboratory environment (Jackson, 2011). While this was only in a laboratory environment, the methods proved reproducible, and as technology increases, eventually we may see thin film technology surpass that of crystalline silicon.

Another added benefit to thin film modules is their appearance. The modules are simply sheets of glass with photosensitive materials thinly layered onto them. This allows for more versatility with installation methods. With the backing consisting solely of glass, thin film modules can have varying opacity ratings. This means that thin film cells can be placed onto roofs as translucent skylights. This provides a more subtle implementation of solar technology that does not affect the overall appearance of a consumer's home. While thin film solar modules are commonly least efficient, they are a developing product that performs better in higher temperatures and introduce a new perspective in solar panel aesthetics.

The large variance between the three solar module construction types creates the need for proper system design when consumers implement systems. By installing the solar modules best suited for the application, consumers increase the life time performance and reliability of their system. Therefore, it is crucial to inform solar consumers of this and account for these differences when the ATA provides consultations.

4.1.2 Comparison of Solar Inverters

There are two major types of inverters that are used in residential and commercial photovoltaic systems in Australia. Ideal inverter selection is application dependent, and both string and micro inverters are commonly used. Neither type of inverter is superior to the other, but rather is selected based on specific applications. String inverters are often implemented on larger scale systems and when there are price constraints. Micro inverters are much more effective when individual modules are subject to shading or multiple panel orientations are desired. This section provides a comparison for the advantages and disadvantages of each type of inverter.

String inverters are the conventional solution to power conversion in photovoltaic systems. String inverters typically have a capacity between 1kW and 10kW and service many panels connected together in series or parallel configurations. String inverters support isolated power conversion in a single device. This allows for simple installation and convenient access to the inverter as it can be mounted at the ground level and either inside or outside (Energy Matters, 2016b). String inverters are highly efficient as well and typically have longer lifespans than other alternatives. The technology has been around for a long period of time, so the electrical systems have become very robust and affordable.

However, string inverters do have a few limitations. There can be long strings running from solar arrays to the inverter. This can make installation a bit more complicated and introduce hazards specific to the high voltage associated with string-based systems. Additional components such as the DC isolators must be integrated into systems with string inverters. Wires and electrical components must be rated to carry DC voltages that may be present within string-connected systems. These DC lines can present safety hazards to installers, maintenance workers, or emergency responders in the event of a fire or other disaster (Peacock, 2015). Additionally, since all of the panels are connected together, individual panels can compromise the entire system. All panels on the same string must receive similar light levels and have the same orientation. If a single module is shaded, for example, then the maximum system current is limited by that panel. This inhibits system performance and can result in excessive heat dissipation within the shaded cell, leading to hot spots or other failures. String inverters only perform system level maximum power point tracking and cannot monitor individual panels.

Despite some limitations of string inverters, their functionality can be greatly improved through the implementation of power optimizers. Optimizers are small devices mounted on the backside of each panel. They support panel level maximum power point tracking and data acquisition. The optimizer is a DC to DC converter and maximizes the amount of power that is delivered to the string inverter (Energy Matters, 2016b). Optimizers also allow panels to be mounted at many different angles allowing increased system customization. These devices are also equipped with additional safety features that automatically turn off the DC output from individual panels when the inverter or grid is powered down. While optimizers increase cost and complexity of installation, they significantly enhance capabilities of string-connected systems.

Micro inverters have been rapidly expanding their presence on the solar inverter market. The first commercially successful micro inverters were released by Enphase in 2008, and have since been becoming more and more prevalent. Micro inverters are different from string inverters in that power conversion is completed directly at the individual panels (Energy Matters, 2016b). Micro inverters are mounted to the back of solar modules and alternating current is delivered out of the micro inverter. This allows for each panel to be independent of each other and connected in parallel. Photovoltaic systems with micro inverters can be planned with greater flexibility in design and panel orientation because panels are not interdependent upon each other. Micro inverters support module level maximum power point tracking and thus improve total power output of a solar system. Micro inverters are also outfitted with data acquisition hardware, and panel level performance can be monitored to identify faulty panels. In the event of individual panel or inverter failure, micro inverters isolate the faulty panel/inverter combination, and do not impede performance of the entire system. Micro inverter manufacturers also commonly offer 10 year limited warranties, which are some of the longest in the industry. Another benefit of micro inverters is that they include built-in protections and safety features to restrict power generated from panels in the event of a system error.

One major drawback with micro inverters is the increased cost in comparison to string inverters. Micro inverters are significantly more expensive, but grant enhanced functionality (Peacock, 2015). Even systems outfitted with string inverters and optimizers, which deliver similar benefits, are less expensive than micro inverters. Additionally, micro inverters have not been on the market for very long, and thus the extended lifetime reliability is unknown. Since these inverters are mounted outdoors and on the back of panels which get extremely hot, (in excess of 45 degrees Celsius) the inverters are required to be extremely robust and durable. Furthermore, these inverters employ electrolytic capacitors which are temperature sensitive and have a limited lifetime. While the rest of a photovoltaic system can still function if a micro inverter fails, there are more possible points for a system to experience failure because there are so many inverters. This can increase lifecycle costs as failed micro inverters are also difficult to replace because they are mounted on roofs and connected to the panels.

Similarly to modules, it is important to identify these differences and how they affect systems within the given application. A high quality system that is improperly designed for the application will experience system failures and increased maintenance costs which reduce the benefits of purchasing a higher quality system. Therefore, correctly selecting the inverter will maximize the power output of the system and lengthen the product's life span, which is financially beneficial to the consumer.

4.1.3 Importance of Module/Inverter Capacity Ratio

One of the major design considerations when implementing a photovoltaic system is the sizing ratio between the solar array and inverter. There are many different views about the optimal relationship in capacity between the solar modules and inverters. It is not necessarily best to match a panel array to an inverter rated at the same value. Some believe that it is best to be conservative and oversize the inverter, while others find that the best solution is to undersize the inverter and maximize performance during off-peak hours.

One system configuration is to use an oversized inverter (one with a power rating larger than the maximum power output of the modules). This configuration was very common when modules were much more expensive, and installers wanted to maximize power during peak daylight hours. A matched or oversized inverter will never be power limiting, meaning the inverter will not be responsible for capping performance (Fiorelli, 2013). Additionally, oversizing an inverter and running it below maximum operating conditions will not severely tax or stress the device and may extend the life of the inverter. However, photovoltaic systems will rarely produce the nominal power ratings stated on the nameplate of the modules. Factors such as shading, orientation angle, irradiance quantities, and operational temperature cause panels to only operate at peak efficiency for a minimal period throughout the day (Morris N., 2017). Thus, even a "matched" system will never run the inverter at peak power. The costs associated with purchasing increased inverter capacity also detract from the proposition of oversizing inverters. Many installations today will actually opt to undersize the inverters in order to reduce initial costs and exploit the margin between inverter capacity and actual power generation.

Undersized inverter configurations allow the inverter to run at levels closer to peak capacity for longer periods of time during daylight hours. This ratio between inverter and array may limit, or clip, power during times of peak sunlight, but it also maximizes system efficiency during periods of lower solar irradiance (Morris N., 2017). Figure 16 demonstrates the compromise between clipping and increased energy during off-peak hours. Under sizing inverters both reduces start-up costs and limits operational expenses, as less power is consumed to run smaller inverters. Modern inverters are constructed with the intention of being installed with solar arrays of larger capacity. The inverter manufacturer SMA even states that their products can be paired with module arrays 20% larger than the inverter's capacity (Partlin, 2015). Inverters use maximum power point tracking in order to optimize the operating point on the current-voltage curve and deliver the most power. This same principle is used to enable power limiting for the inverter. The operating point on the inverter's current-voltage curve is manipulated to deliver higher voltage and reduced current, yielding reduced power (Fiorelli, 2013). This causes clipping and does not allow power to surpass the inverter's rated capacity.

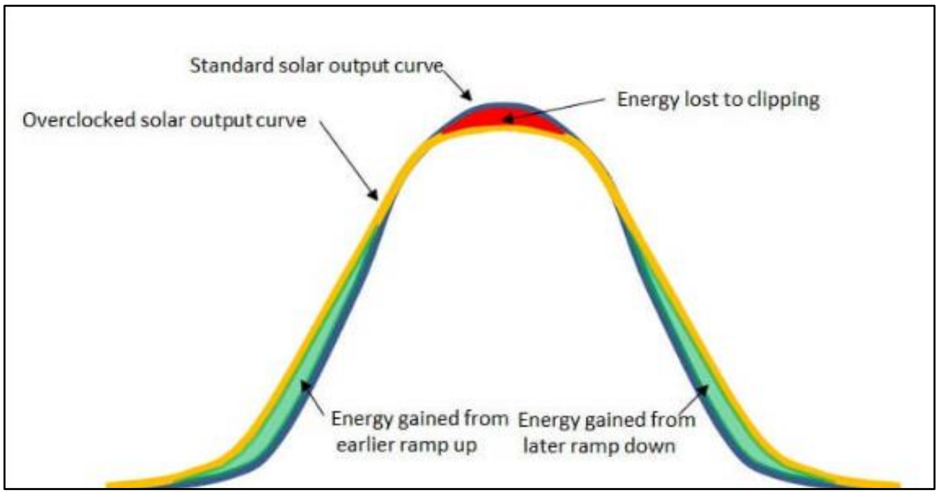


Figure 16: Solar output curve (Morris N., 2017)

Solar inverters are intended to be used in undersized applications, but there are certain limitations that must never be surpassed such as the maximum input power or voltage (Partlin, 2015). The Clean Energy Council (CEC) publishes guidelines that all Australian solar PV manufacturers, designers, and installers must abide by. In order to limit potential safety hazards, the CEC mandates that inverters must meet at least 75% of the rated capacity of the panel array (NECA, 2013). The CEC also requires that solar array capacity must not exceed any manufacturer specifications for maximum power input to the inverter. These restrictions provide a sufficient margin to allow for oversizing to occur, while assuring that system configurations do not compromise safety.

Utilizing our survey, the team used data given regarding each consumer's system to understand the current status of undersized and oversized systems in Australia. As shown in Figure 17, the most common configuration is oversizing the inverter in comparison to the module array. 47% of people have an oversized inverter for their system. Following that, having a matched ratio between the inverter and module is second with 33%. Lastly, undersizing the inverter is the least popular configuration with only 20% of consumers with these conditions.

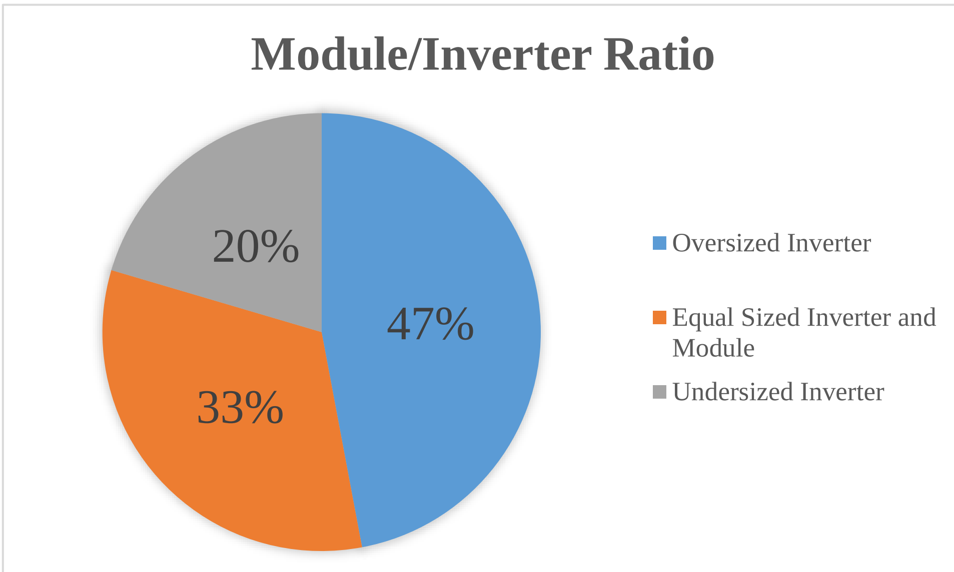


Figure 17: Survey data regarding module/inverter ratio

4.1.4 Mitigating Common Failure Modes

In addition to the failure modes established in Section 2.5, through interviews with industry leaders and manufacturers, this study identified additional failure modes in solar photovoltaic systems common within the Australian case. By coding these interviews in accordance with the mechanism shown in Appendix H the data presented in Figure 18 was compiled. This section will address the most common responses from these interviews and how to mitigate their effects. In turn, reducing the occurrence of these failure modes will improve the overall performance and reliability of a consumer's solar PV system. As seen in Figure 18 this study found that there are five primary failure modes of solar photovoltaic systems: DC isolators, installation error (faulty wiring, not mounted properly, not sealed properly, etc.), inverter failure, water damage, and microfractures. Each of these issues will be addressed within this section.

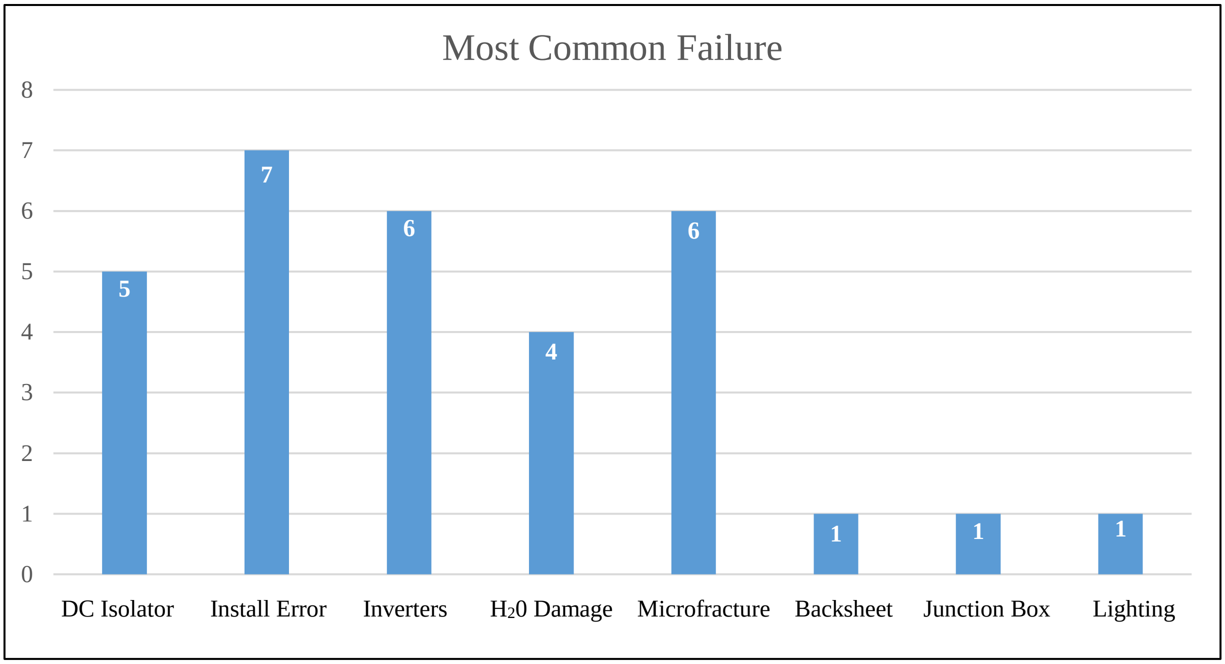


Figure 18: Distribution of most common failure modes

One of these primary failure modes in Australia, identified by this study, is the formation of microfractures within solar modules. These failures are caused by environmental events, manufacturing errors, and poor shipping or installation practices. As a result, systems experience significantly reduced output (GSES, 2015). The Australian climate is subject to high wind speeds (cyclones) and humidity levels which have the ability to cause these microfractures. However, it is extremely difficult to control the environment's impact on the formation of microfractures, which makes it critical to purchase a high quality system manufactured with durable materials. High tempered glass is the most durable glass option for solar modules, and should be used to mitigate the effects of impacts caused by the environment.

It is far easier to mitigate the occurrence of human error than the environment. These human errors are present in the manufacturing, shipping, and installation of solar modules. Fractures can occur at any point throughout the manufacturing process due to a wide variety of errors. For this reason it is crucial to purchase panels from a manufacturer that conducts Electroluminescence testing to check for these cracks. Although, EL testing is not required in the Australian market, subjecting modules to this testing not only mitigates microfractures, but can be seen as an indicator of good quality. When purchasing panels, consumers should ensure that the product they are purchasing has been EL tested.

However, the majority of microfractures occur in the shipping and installation process. There are currently no industry standards for regulating the shipping of these products, and specification for proper delivery is left to the individual manufacturers. This leads to a large variation in the quality of transportation methods, creating a problem because modules are so susceptible to microfracture degradation. Throughout the shipping process panels can be subject to harmful vibrations due to the delivery vehicle, excess loading caused by stacking panels above their weight rating to increase the number of panels per shipment, and insufficient packaging. All of these factors are capable of causing microfractures that decrease the long-term quality of the panel before it can be installed. Thus, this study has identified the need for a standardized shipping process that helps to mitigate microfractures due to shipping.

In addition to improving delivery methods, improving solar installation techniques will help reduce microfracture formation. There are three primary installation causes of microfractures: dropping of the panel, stepping on the cells, and installation on a nonplanar surface. These can cause the panel to distort in ways that it was not intended, causing microfractures in the cells to form. In order to mitigate these installation errors, solar consumers should only make use of Clean Energy Council Accredited Installers. These companies use installation practices that meet Australian industry requirements, and provide consumers with the highest likelihood of proper installation.

Microfractures can still occur even after the panels are delivered and installed. For this reason, it is important for solar owners to inspect their systems twice annually (GSES, 2015) and perform the necessary maintenance required of the system, such as cleaning and removal of debris from the modules. This will aid in increasing the long-term performance of the system following delivery and installation. Panel-level monitoring (provided by either micro inverters or optimizers) allows consumers to view the real-time output of individual panels. This information can inform consumers when their system is operating at sub-optimal levels and requires repair in between regular maintenance times. For this reason, system monitoring and maintenance are crucial to the sustained prevention of microfractures within systems and increased system long-term performance.

In addition to using higher tempered glass, an accredited installer, and properly maintaining systems this study has identified a design characteristic that has the potential to eliminate the formation of microfractures in solar modules. For many years, solar cells were consistently thicker than 1mm. This made it extremely difficult for microfractures to form, but as technology advanced, manufacturers reduced cell thickness in attempt to save money on materials. In fact, cell thickness has reduced so much that they can currently be as thin as 0.1mm (Morris G., 2017). Cells that are thinner than 1mm lose their structural stability but maintain their rigidity allowing vibrations and impacts to cause these harmful microfractures. It has recently been proven that these cells are able to become thinner than 0.05mm. At this point the cells become flexible and the risk of microfracture is eliminated (Morris G., 2017). Therefore, in an attempt to minimize the potential risk of microfractures, consumers should be aware that panels ranging from 0.05-1mm have a higher tendency of forming these defects.

The inverter is a vital PV component that is widely known to cause system failure. In fact, 51% of consumers that provided failure information claimed that the cause of their system failure was the inverter. Survey results show that water damage, overheating, and damage by impact or wildlife are the leading causes of inverter failures. In order to reduce these failures it is critical to operate the product in a dry, cool, and secure location. Due to their construction, these products will still fail at a much faster rate than modules, and consumers should expect to purchase at least two inverters throughout the life of their modules.

Installation error was discussed briefly earlier in this section, but its effects are far more broad than solely microfractures. The data in Figure 18 suggests that installation error is the most common cause of failure within PV systems. Improper installation can lead to decreased efficiency, loss of power generation, and potential system fires. Analysis of consumer data gathered from the study’s survey shows that 23% of consumers who experienced a system failure attribute it to incorrect installation. As previously stated, hiring a CEC accredited solar installer will reduce the risk of an installation failure. In addition, consumers should be informed of the installation company’s experience in years and number of installations. These values are utilized in the current assessment matrix, and when used in conjunction with a CEC accreditation will improve the overall quality of solar PV installations.

Lastly, the interviews identified water damage to both the inverter and modules as a major problem with solar photovoltaic systems. Introducing water to the electronics within both the modules and inverters causes short circuits and reduced output. Properly sealing the modules during installation and choosing products that have high quality backsheets will make it difficult for water to reach the electronics. Sealing the modules is performed by installation professionals, and sealant errors can be mitigated using the same methodology discussed for installation earlier in this section. Polyvinyl fluoride is the most commonly used backsheet material and is sufficiently water resistant. Consumers should be sure the system they are purchasing makes use of this material or a similar polymer.

4.1.5 Company Reputation and Location

Based upon the team's interviews with solar industry leaders, there is a trend within the solar industry to determine a product's quality based on the reputation and location of the product manufacturer. Similar to the ATA, the majority of solar suppliers and installers determine a product's quality using previous experience with a manufacturer and customer review forums. This method of assessing solar system quality makes it difficult to draw comparisons and allows for bias to alter results. While these companies do have access to limited reliability and performance data, they do not make use of them due to the speed at which manufacturers produce newer technologies and difficulty in obtaining pertinent data.

Figure 19 displays the distribution of metrics utilized to determine solar photovoltaic system quality. This information was gathered by implementing the coding mechanism found in Appendix H for interviews with 15 Australian solar industry leaders. Reputation was the most overwhelming interview response. This study found that most experts were concerned with the existence of companies created to make a quick profit rather than long-term success. Numerous interviewees felt that consumers should only utilize companies (both manufacturers and installers) that have been in the market for an extended period of time and have positive reviews from past customers. With limited quality data accessible to the public, company reputation is a good way to estimate the eventual quality of a product or installation.

In addition to company reputation, many experts felt that company location also played a vital role in the quality of solar PV systems. While it was found that the majority of products were manufactured in Asian countries, using similar materials, experts felt that having at least one Australian office or branch helped to ensure the long-term quality of systems. One interviewee stated, "Having an Australian office shows a commitment to the market and to providing quality products to their customers" (Morris G., 2017). Having an Australian presence allows companies to provide maintenance and advice quickly, honor warranties, and become more knowledgeable of the Australian solar landscape. This is important because assuring the life time quality of a system is a primary contributor to the financial benefits of solar photovoltaic systems. These companies have the resources necessary to establish international markets, which indicates corporate stability and success. Solar PV consumers should make note of the nearest location of both their manufacturer and installer when purchasing systems. This should provide peace of mind and ease of future support.

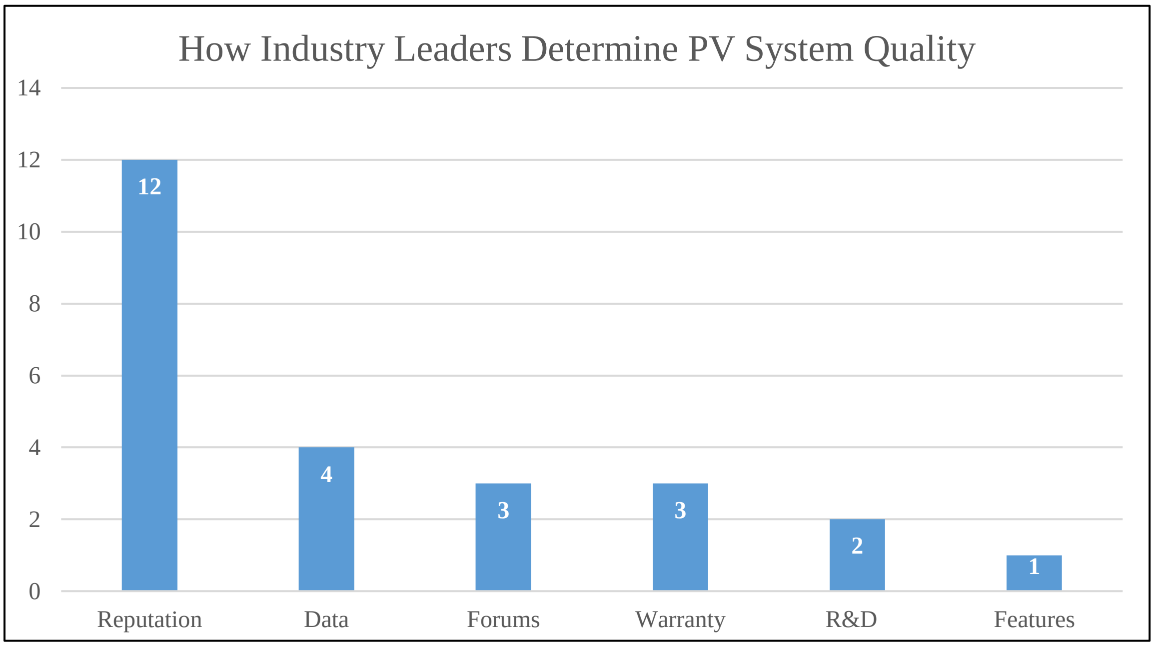


Figure 19: Interview results of how experts assess quality

4.2 Metrics Indicative of Solar PV Quality

The following section was compiled through investigation of available third party test data, product data sheets, and independent research. Similarly to Section 4.1, this section will address the analysis of PV system quality. However, this section consists of data metrics that can be utilized to provide quantifiable analysis and comparisons of products. The metrics evaluated in this section include: certification testing, performance ratio, and PTC data. This section also includes a potential methodology for creating future reliability data.

4.2.1 ENF Solar Online Database

Through the team's research, the ENF Solar Database was discovered. This represents a free database that is continuously updated and provides relevant data regarding all major components of solar PV systems. It utilizes its contacts and employees to identify any new solar products or companies entering the industry and will remove any system components that are no longer available for sale anywhere in the world. The database contains pertinent information for 28,020 solar panels, 8,675 inverters, 1,399 mounting systems, 98 EVA encapsulant varieties, and 213 back sheets. These product pages list information found on datasheets as well as performance data, material composition, any lab testing performed on the product, and consumer reviews. There is also an option to compare two products side by side, displaying all the information for both products in a comparable format. In addition to manufactured products, the ENF database keeps a running list of all solar installers. They have a list of 22,780 solar installers to date. These installers can be separated by region. For example, there are 1,485 solar installer companies in Australia. Each company contains information such as important contacts, location, what panels and inverters they provide (and links to those products), and any reviews on the company they could find. The ENF website is constantly updating and easily navigable, making it very useful for maintaining ATA product data.

4.2.2 Certification Testing

Solar photovoltaic systems must meet standardized codes in order to be installed in every state within Australia. Photovoltaic systems must abide by the Australia and New Zealand Electrical Installation parameters (AS 3000). These are widespread wiring regulations for all electrical systems throughout Australia and New Zealand. However, photovoltaic systems also have their own specific requirements that must be addressed. Each solar module is required to meet the International Electrotechnical Commission's (IEC) standards for solar panels. According to the AS 3000 regulations, every module must be IEC 61730 certified and either IEC 61215 or IEC 61646 certified (Clean Energy Council, 2014). These certifications are attained by meeting multiple construction, material, and manufacturing requirements.

IEC 61730 and IEC 61215 certifications pertain to lifecycle and failure testing for solar modules. IEC 61730 standards exist to test crystalline silicon panels while IEC 61215 standards are in place to evaluate thin-film solar modules. These standards enforce that manufacturers complete failure mode analyses and accelerated lifecycle testing. These tests exist to mitigate the odds of infant mortality in solar modules. These tests grant confidence in solar panels because manufactures subject the panels to many different cycling stresses such as thermal, electrical, luminescence, wind, hail, hot spot, and humidity. The team's desire was to find test data on accelerated life testing, but no research seems to be published relating to lifecycle testing on a wide range of models of solar panels. In lieu of this, this certification provides an indication that the companies have completed this sort of analysis internally on their products and that modules in the field are up to specification regardless of the availability of the data. National Renewable Energy Laboratory believes that IEC 61215 is a main contributor to helping the solar industry attain field failure rates and warranty returns below 0.15% (Wohlgemuth, 2012).

Another type of certification that exists for flat-plate solar photovoltaic modules is the UL 1703 Standard. This is a set of requirements that define engineering design and construction. These manufacturing guidelines outline proper procedure for materials, wiring, fire protection, impact testing, and performance testing. This certification is not required by the Clean Energy Regulator, but is an indication about further attention paid towards system quality. The Australian Solar Council has also recently introduced Positive Quality standards. This is a much more in depth evaluation that runs certification checks, factory inspections, and randomly selects panels available on the market to run through a series of performance and accelerated lifecycle tests. However, this is an expensive certification process for manufacturing companies to engage in, and only three companies in Australia currently participate (Positive Quality, 2014). Though, as greater market pressure is placed on companies to deliver more efficient and resilient products, stricter standards and manufacturing processes will continue to be adopted across the industry. Referring to these certifications is important in assessing system quality because failure to obtain these certifications is suggestive of a manufacturer less committed to quality assurance, which, in turn, suggests that their products are of lower quality.

4.2.3 Utilization of Previous Model Data

Reliability and quality test data allows for a more comprehensive quantitative analysis and comparison of various products. However, it is quite difficult to keep a current list of product data due to its limited availability and the extended period of time needed to test the longevity of systems. Through investigation of a solar quality test agency, Choice, the team identified that data from a previously tested product that is now superseded by a more updated technology can be used to assess the newer product, within reason. The direct quote can be found below:

"Tested models are mostly now superseded by newer, higher-spec versions. Regardless of their score, we don't recommend models that are not currently available for you to buy. But you can still use our test results for them; if a panel performed well in our test, you can reasonably expect a good result from any higher-yielding panel that replaced it." (Choice, 2017)

This helps solve the issue of maintaining the most up-to-date quality test data for products on the market. While the reliability data will not always be completely current, it is reasonable to utilize similar data to draw conclusions and make comparisons between various solar photovoltaic products.

4.2.4 Performance Metrics

There are a number of independent organizations that test photovoltaic components in order to better understand performance and confirm nameplate values released by manufacturing companies. The majority of these laboratories are concerned with checking the actual power generated under electroluminescence testing and yield testing. There are two different types of testing that are commonly used to evaluate the initial performance of photovoltaic modules. These tests are either completed under standard test conditions (STC) or photovoltaics for utility scale applications test conditions (PTC). STC testing is completed with ambient and cell temperature both at 25 degrees Celsius. Photon Laboratory and Choice have completed STC power testing on many of the leading solar modules on the market. PTC testing is completed under conditions that solar modules are more likely to experience under normal operation. The ambient testing temperature is set to 20 degrees Celsius, cell temperature is brought to 40 degrees Celsius, and a cooling air speed is blown across the module at 1 meter per second. PTC power measurements are lower than that of STC because solar modules are less efficient at higher temperatures. Go Solar California has compiled a very large public database of solar modules tested under PTC.

Power yield data is also collected by photovoltaic research laboratories. The research facilities often acquire a wide range of commercially available solar modules and measure the amount of energy produced over a long span of time. Climate data such as temperature, wind speed, and global horizontal radiation are also recorded continuously throughout the day. These sorts of measurements allow for yield data to be calculated and compared across many different products. Additionally, using the recorded power and irradiance values, the performance ratio, or quality factor, can be calculated. This allows direct comparison across any model or type of panel because it assesses the amount of power produced in relation to the rated nameplate values. Desert Knowledge Australia Solar Centre (DKASC), Photon Laboratories, and CSIRO each run extended lifecycle tests on solar modules. Photon and CSIRO publish rankings for each of the modules in the tests while DKASC releases the data as it is recorded.

4.2.5 Reliability Analysis

In the future, as standards become more enforced and the solar industry continues to grow, reliability data is expected to become more readily available. With reliability data, the ATA can perform calculations to determine the reliability of different solar photovoltaic systems. However, due to a lack of standards set within the industry, as well as company privacy issues, the team was unsuccessful in obtaining manufacturer reliability data, such as time to first failure. The methodology makes use of time to first failure data and performs a statistical analysis based upon real world failures. This section addresses this method and provides a mechanism for performing accurate, numerical based calculations of system reliability that the ATA can utilize as reliability data becomes more readily available.

While there is a lack of readily available data points, the Alternative Technology Association has the ability to obtain this data in two ways. The first being solicitation of failure test information from manufacturers and installers within their tender request form. Companies must conduct these tests in order to calculate their warranty values, but are unwilling to make these results public without signature of Non-Disclosure Agreement. However, requirement of this information within the tender document could potentially make companies more likely to comply. The second alternative involved the creation of an ATA subscriber failure data base. This data base should include product make and model, time to first failure, and what type of failure occurred. Generation and maintenance of this database would create the necessary data points to calculate a reliability metric capable of comparing the quality of products. The analysis shown within this section makes use of coded failure data gathered from the ATA subscriber survey as an example of the potential for this database. We have included a similar survey for the ATA's use.

The first reliability analysis method makes use of time to first failure to measure reliability. The data from the subscriber survey was gathered and entered into Microsoft Excel to provide failure data for this analysis. By utilizing the software's computational abilities a regression analysis was performed on failure data. A linear regression was used to find the relationship between the failures and the time it took for them to occur. This analysis then makes use of a two-parameter Weibull reliability distribution to output the probability the product will fail with time. The Weibull distribution treats the data as a linear function and makes use of the line's slope and intercepts to alter shape and scale of the probability curve. The Weibull distribution was chosen for this application because it mathematically makes predictions regarding a product's life span by fitting a statistical distribution to failure data from a sample of failed products. This outputs a probability distribution capable of making life-expectancy estimates.

It should be noted, that the distribution is created using only a sample of failed products and does not take into account systems not reporting errors. This creates the possibility for data that is partially skewed towards having shorter life expectancies. However, the Weibull analysis is intended for use using only failure data and accounts for systems that have not failed. Based on the data gathered from consumer survey, only 15% of consumers experienced an inverter failure. This should be considered when interpreting the data presented in the section. It should be known that this analysis was not performed to draw conclusions regarding products, but rather to provide a potential method for quantifying the reliability of PV products which currently lack these metrics. This analysis can be used to make predictions about when a product will fail. Figure 20 displays the first year life estimates from the Weibull analysis performed. This data displays the probability that the inverters will fail at a given time (in hours). This can be used for large warranty milestones, such as five and ten years, to determine the probability the product will still be functioning under warranty. Figure 21 displays the inverter's failure probability curve. This graph displays the distribution of inverter failure expectancies with respect to time, and can be used to make more informed assessments of product quality, and could be included within the assessment matrix to enhance ATA consultations. The graph below is representative of the data received from the survey, but it is important to note that the probability of early failure is increased because the majority of systems are young, and only infant failures actually have the opportunity to present themselves. Additionally, the vast majority of systems has not failed, but cannot be included in this analysis as there is no specific time of failure. The probability of failure can be used to determine the value of product warranty based upon when the system is likely to fail.

		Time (hours)	Failure Probability
		0	0%
		730	2%
		1460	4%
		2190	7%
		2920	9%
		3650	12%
		4380	14%
		5110	17%
		5840	19%
		6570	22%
		7300	24%
		8030	26%
YEAR 1		8760	29%

Figure 20: Reliability analysis data

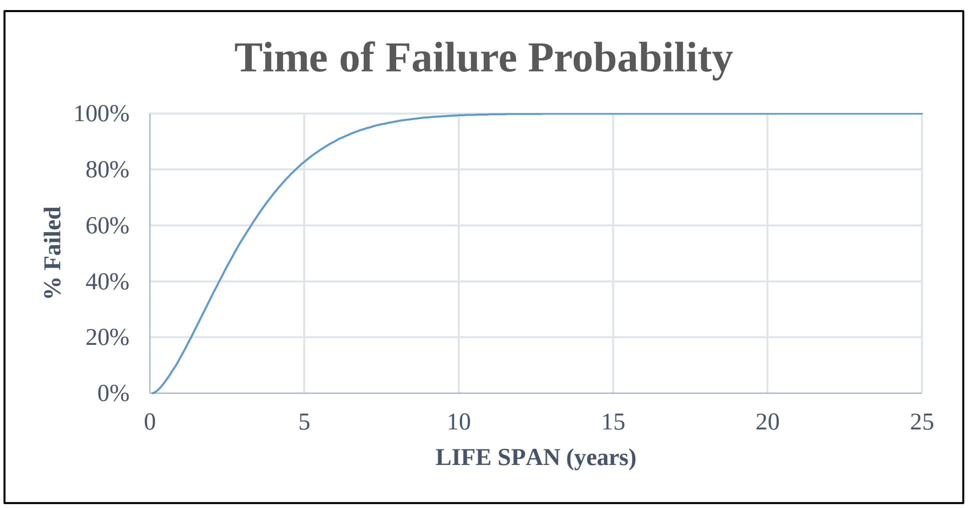


Figure 21: Inverter failure timing probability curve

In order to account for systems that have not yet failed, analysis can be performed that treats failure data as a proportion of the entire population at various system ages. The percentage of system failures due to specific component failure was calculated as a function of time. This provides a more accurate representation of the survey results as many have not yet suffered failure. This supplies more realistic results when determining the probability of component failure for populations with still-functioning components. Figure 22 displays the results of analysis performed on the survey data that can be used to estimate the probability of system failure with time. Notice that the probability of failure is significantly higher in inverters is significantly higher than modules, especially at young ages, which justifies longer warranties offered by module manufactures than those of inverters. The entirety of the analysis performed on present failure data can be found in an accompanying Microsoft Excel Spreadsheet.

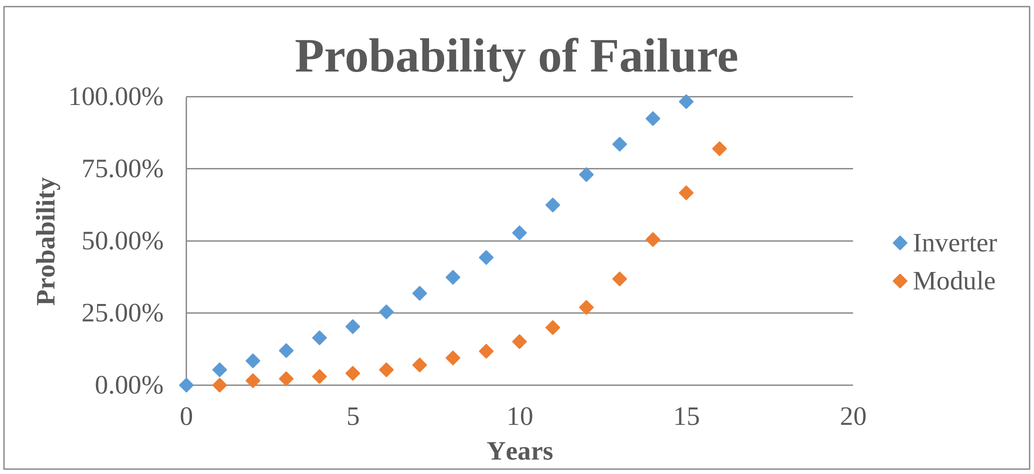


Figure 22: Probability of module and inverter failure

4.3 Analysis of Consumer Experiences

The assessments provided by the ATA aim to provide consumers with the most optimal solar system for their needs. For this reason it is important to account for current consumer priorities when making these evaluations. In an attempt to better represent the needs of consumers when providing consultations regarding solar PV systems, a survey was distributed to Alternative Technology Association members. The data below is derived from a sample size of 868 survey responses using statistical analysis performed within Microsoft Excel. This section provides the results of this survey and analysis performed upon this data. The full results of this survey can be found in Appendix J.

Figure 23 displays the results of the survey provided to ATA subscribers regarding the most important factors when purchasing solar PV systems. Consumers were asked "What is most important to you when purchasing a photovoltaic system? (Please click and drag to rank)". The results show that 70.62% of the consumers surveyed value the quality of their system above factors such as customer service, warranty, installer experience, and price when purchasing solar PV. The factor receiving the second highest amount of #1 rankings was Price, with only 9.75% of consumers ranking it first. This desire for high quality products displays the importance of developing a more comprehensive method for assessing the quality of solar PV components.

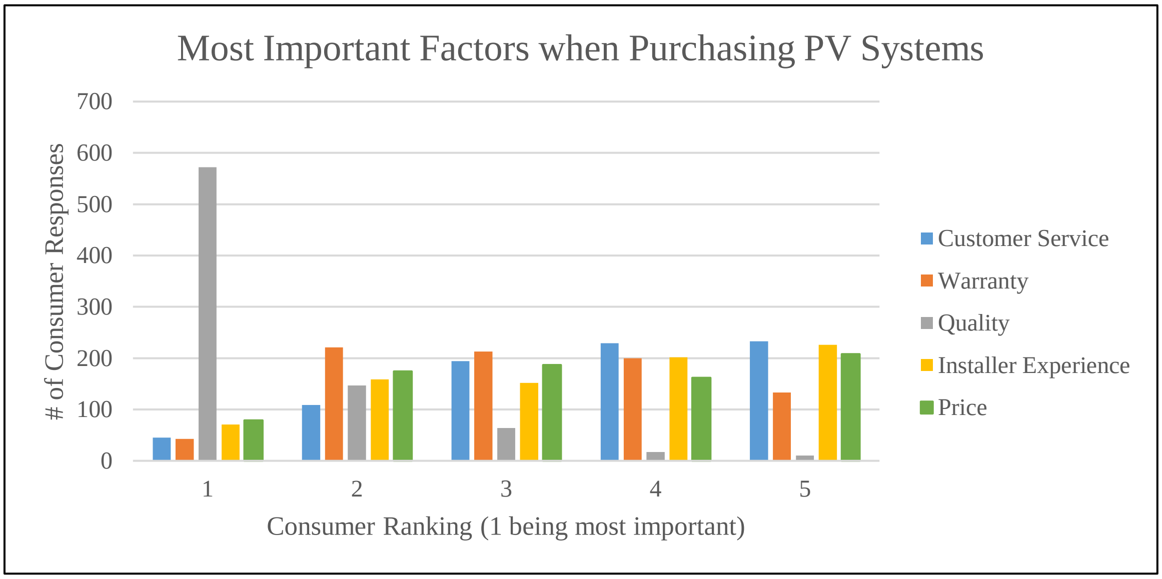


Figure 23: Survey results ranking the importance of various factors when purchasing solar PV

4.3.1 Analysis of Consumer Failures and Failure Timelines

Through the questions "How many times have you had an issue with your system?", "When did you first have an issue?", and "What was the cause of this issue?" the team was able to analyze common failure modes among consumers to gather real world data regarding system failures and expected timelines for these failures. Figure 24 depicts the number of consumer failures that occurred within specific timelines of owning a system. It should be noted that this anlysis was done on a sample of failed systems, rather than the entire population. The slope of this curve represents the failure rate of systems over time. As the graph shows, the majority of failures occurred in the early stages of the system's life, with limited failures occurring beyond year eight.

However, with the average lifespan of solar PV systems being 25 years, the failure rate is expected to increase again as time continues. Due to the youth of the industry, failure data for systems reaching the end of their life spans is unavailable and is reflected in Figure 24. This graph is a real-world representation of the MTBF "Bathtub Curve" depicted in Figure 12, Section 2.6.

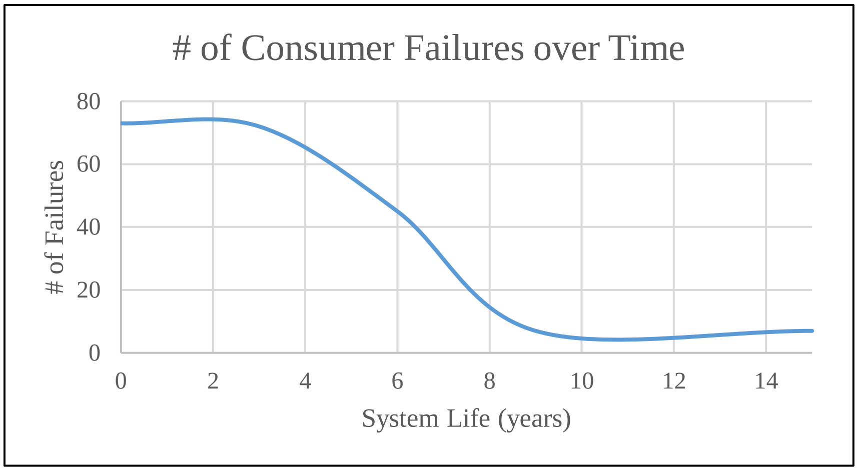


Figure 24: Consumer Failures over Time

As discussed in section 4.1.4, industry leaders were interviewed to determine common failure modes among systems. From our survey, real-world results regarding common failures among consumer systems was also gathered. Figure 25 depicts consumer system failure data for 205 consumers. As the pie chart shows, inverters were the most common system failure with 51% of consumers experiencing an inverter failure. The next most common was failures due to installation errors at 23%. This compares similarly to industry leader opinions regarding the most common failure. As the two most common failures were installation and inverter failures.

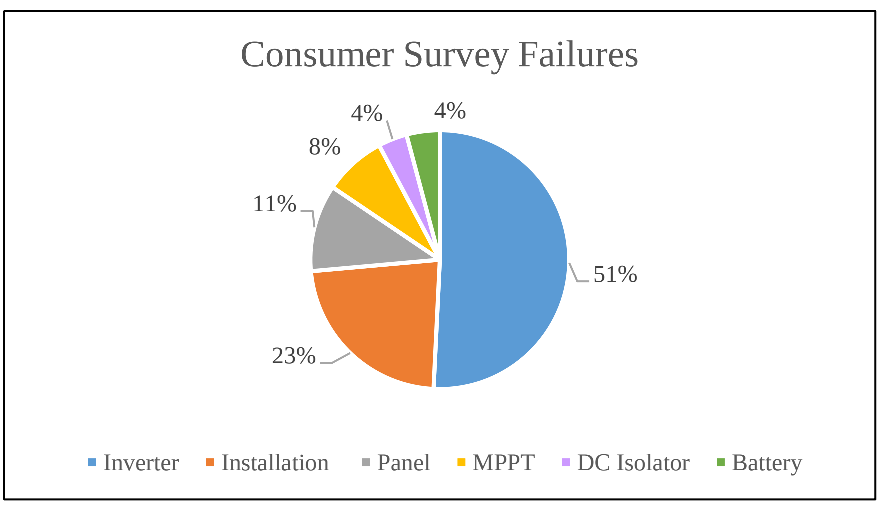


Figure 25: Consumer Failure Modes

4.3.2 Importance of Warranties

When consumers were asked to rank the most important factors when purchasing a solar photovoltaic system, warranty was most commonly ranked second behind quality. Warranties vary based upon the system component and type of failure. For example, inverter warranties typically range between 5 and 10 years, module product warranties are typically 10 years, module performance warranties are typically 20 to 25 years, and installation warranties are typically 5 years in length. When analyzing the most common failures as outlined in section 4.3.1, inverters and installation errors were the most common failures, both which fall under warranties.

Inverters are the most common failure mode according to consumers at 51% of failures. Therefore, it is vital when purchasing a solar PV system to select an inverter with a good warranty. The team analyzed the survey data regarding inverter failures to evaluate how soon an inverter is likely to fail, as depicted in Figure 26. As the graphic shows, 74% of inverter failures occur within the first three years of installation. Therefore, the majority of failures that occur are covered within the warranty period. However, 26% of inverter failures occur some time after 3 years of owning a solar PV system. Therefore, ensuring good quality in the inverter and a longer warranty provides more coverage, should any issues arise.

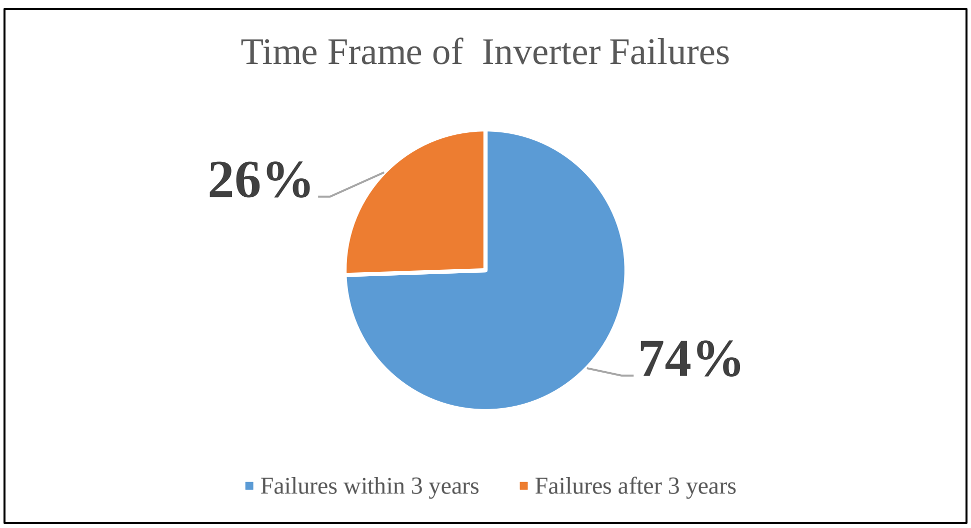


Figure 26: Timeframe of Inverter Failures

Installation failures were identified by industry leaders as the most common failure mode, and identified as the second most common failure mode by consumers. Installation warranties typically last 5 years and cover any issues in system performance as a result of poor installation.

The team conducted a failure timeframe analysis, identical to that of inverter failures, for installation failures, as depicted in Figure 27. As shown below, an overwhelming majority, 91%, of failures due to installation errors occur within the first 3 years of the system's life. Almost all failures due to installation errors occur within the warranty period, however it is still important when selecting an installer to consider the reputation and experience of the installer so that these issues do not arise.

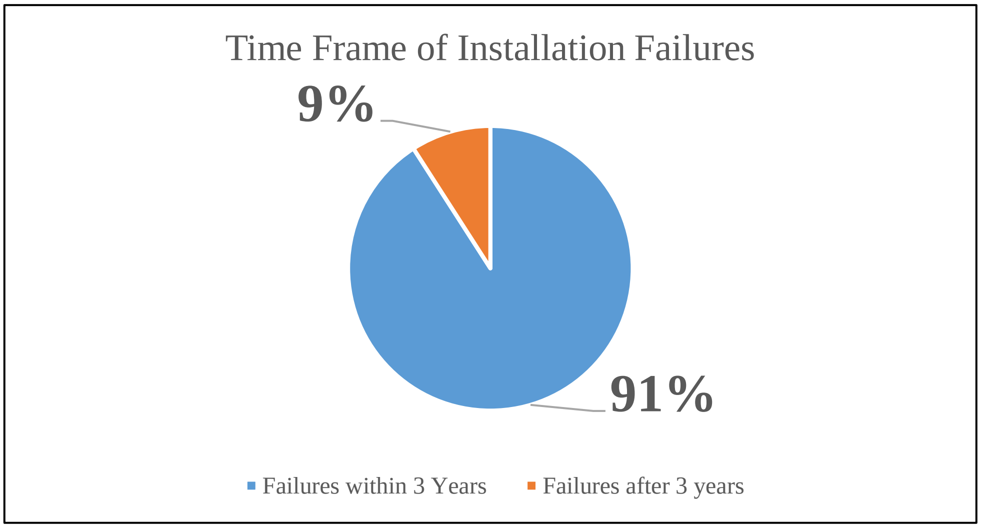


Figure 27: Timeframe of Failures due to Installation Errors

4.4 Design of a More Comprehensive Assessment Matrix

4.4.1 Importance of Application Context within Matrix

The team has identified the need to tailor assessments more closely to individual applications. Therefore, the enhanced matrix will include a tab containing various factors pertinent to a given application, and adjust the matrix in accordance with client needs.

An important factor in the design of solar photovoltaic systems is the ratio between the capacities of the module array and its inverters. One common practice is to undersize the inverter in relation to the capacity of the array. This configuration can be ideal because panels hardly ever produce their nameplate power, and a smaller inverter is more efficient converting smaller levels of power. Though, analysis of DKAAS data suggests that if there is a high level of solar irradiance, inverters should not be overloaded beyond their rated capacity. This unnecessarily taxes the system, and the reduction in initial cost would be rendered insignificant after just 4 years of capped performance. However, applications that do not receive the same quantity of irradiance and/or are partially shaded should consider overloading the inverter because it is highly unlikely that the array will operate at its peak capacity and limit power for a significant period of time.

In addition to the sizing ratio, the application specific tab will include geographic location pertaining to the amount of solar irradiance a system would be subject to, potential panel shading, various cost restrictions, and system types (off-grid vs. on-grid) that will affect the factors determining the most optimal components. Based on the needs of the client these values will alter the weighting both of the tabs themselves and within each respective tab.

Another factor to analyze when creating a client specific matrix is energy consumption by time of day. Typically, in the southern hemisphere, panels installed with a north facing orientation generate the most electricity during the peak hours of the day (Energy Matters, 2017a). However, during peak sunlight hours in the middle of the day most people are at school or work and therefore not using their solar PV system. In an on-grid system, any unused power generated will be exported to the grid and in turn lost. Therefore, panel orientation should reflect peak hours of use for the consumer (Morris G., 2017). In most Australian households, this is a west facing orientation. Most households utilize most electricity in the evening hours, and west facing panel orientation generates electricity mostly during the evening hours when the sun is setting. This provides optimal coverage for the consumer, allows for less export to the grid, and more personal usage. This is an important consideration for specific applications and is factored into the application specific tab.

While this project focuses primarily on grid-connected systems, the application specific tab must provide considerations for both on and off grid applications. On-grid systems are solar PV systems that utilize solar energy to reduce usage and cost of on grid power for a homeowner. Off-grid systems are completely dependent upon solar energy for power, utilizing batteries to store excess energy and back-up generators in the case of a lack of energy generation. As mentioned previously, panel orientation is important to consider. In on-grid applications, west facing orientation is optimal to reflect peak hours of use. However, for off-grid applications, north facing orientation is optimal to collect the most electricity throughout the day for battery storage. Another major factor to consider for off-grid applications is customer service. If an issue should arise, it is important that the company responds quickly and provides assistance to the consumer’s needs. (Morris, G. 2017) Without reliable customer service, off-grid systems could lose power and be without electricity for a long time as their system’s problem goes unresolved.

4.4.2 Tabular Weighting Factors in Assessment Matrix

After assessing the current state of the Australian solar energy market and the Alternative Technology Association's methodology, the study determined that customer priority was not appropriately taken into account in the previous assessment process. Therefore, the team conducted a survey to better gauge the current needs of Australian solar consumers. Making use of the mechanism established in Section 3.4, the consumer survey data was compiled and analyzed to create a more tailored tabular weighting mechanism, the results of which are shown in Figure 28.

$$Customer\ Service: (45 * 5) + (109 * 4) + (194 * 3) + (229 * 2) + (233 * 1) = \mathbf{1,934}$$

$$Warranty: (43 * 5) + (221 * 4) + (213 * 3) + (200 * 2) + (133 * 1) = \mathbf{2,271}$$

$$Quality: (572 * 5) + (147 * 4) + (64 * 3) + (17 * 2) + (10 * 1) = \mathbf{3,684}$$

$$Company\ Experience: (71 * 5) + (159 * 4) + (152 * 3) + (202 * 2) + (226 * 1) = \mathbf{2,077}$$

$$Price: (79 * 5) + (174 * 4) + (187 * 3) + (162 * 2) + (208 * 1) = \mathbf{2,184}$$

Figure 28: Tabular weighting calculations

This methodology for assigning weights and the accompanying data provides a more industry representative weighting mechanism. Previously, weights were established subjectively and had little quantitative data for justification. While the assessment was sufficient, it lacked the supporting data to allow the ATA to fully justify their recommendations. Table 4 displays the previous tabular weightings. The largest shift in weighting is the decrease in the importance of price. This shows that solar consumers are more concerned with purchasing a quality system that will operate consistently and efficiently for a long period of time, rather than minimizing initial cost. The importance of quality over cost was also emphasized through a questing asking if consumers would prefer to spend more on solar panels to guarantee they would not need repairs within the first 25 years. Approximately 50% of the respondents stated that they would be willing to spend more than 10% extra on a system of higher quality. In a similar fashion, the importance of both quality and warranty were increased to better represent this shift toward higher quality systems. These enhanced weightings display a trend towards higher quality systems and customer experience. Based upon the calculated scores, shown in Table 5, the enhanced tabular weighting percentages were established. These weights will be able to be shifted based on the given needs of an application, through the application specific tab, making the enhanced matrix even more representative of consumer and application needs.

Table 4: Previous matrix tabular weightings

	Customer Service	Warranty	Quality	Company Experience	Price
Weight	10%	25%	25%	10%	30%

Table 5: Enhanced matrix tabular weightings

	Customer Service	Warranty	Quality	Company Experience	Price
Score	1,934	2,271	3,684	2,077	2,184
Weight	15.9%	18.7%	30.3%	17.1%	18.0%

It should be noted that the survey was distributed to Alternative Technology Association members. These are members of the Australian community that are extremely passionate and knowledgeable about solar photovoltaic energy. This passion for solar power has the potential to skew the consumer data because not all Australians will be so well-informed regarding the importance of PV quality. However, their industry knowledge makes the ATA members an extremely useful source of information regarding solar PV and a potentially more credible population for sampling. In addition, the previously discussed application specific tab will have the capability to alter weighting based upon specific consumer and application needs. Therefore, the matrix will have the flexibility to properly account for the necessary consumer groups.

4.4.3 Alterations to the Decision Matrix

The price section of the decision matrix has been altered to include columns for the size of the inverter as well as the module array. The previous assessment matrix recorded the power capacity as the smaller size of either the inverter or the array. This was restrictive as there are many situations where it is ideal to have inverter and array sizes that are not matched. The price per kilowatt will still be calculated as the overall indication of cost, but it will be dependent upon the size of the array as opposed to the smaller of the two. The matrix also has calculations tailored by the application specific tab to guarantee that the ratio in size between the inverter and array is within standards and not a sub-optimal configuration. This safeguard checks the capacity relationship between inverter and array against inverter maximum DC input and parameters set in the application tab. If the inverter size is found to be below the recommend limit, the system is flagged on the summary page.

The warranty section of the matrix has been altered to include the actual figures covered for each warranty. The warranty has been reorganized to display the information pertinent to the three major system warranties covering installation, the inverter, and panels. The matrix has also been updated with new equations to analyze both the years and coverage of each specific warranty. This eliminates the need to have a ranking key on the tab. All of the data is clearly displayed with the scores for each warranty. Each of the three types of warranties is weighted to be equal and contribute evenly to the entire warranty analysis. The panel warranty is unique because it is made up from two different warranties. Modules are covered by product warranties and performance warranties. The product warranty contributes more to the panel score (66%) than the performance warranty (33%) because the coverage is much stronger, replacing panels in the event of failure.

The quality section of the decision matrix includes information relating to reliability and performance of solar modules and inverters. This section of the matrix has been altered to separate quality into different categories reflecting this. Both the specific panel and inverter are individually assessed when observing quality of the system. The metrics included for panel performance are efficiency, temperature coefficient, PTC value, and yield performance ration. The factors considered for panel reliability are junction box protection, glass type, and company reputation. There were many more metrics assessed while building the decision matrix, but these key items were recognized as the most commonly discussed by industry leaders, the most widely available, and with the most distinguishable benefits amongst other panels. Assessment of inverter performance was characterized by efficiency, number of Power Point Tracking inputs, and maximum DC inputs. Reliability was assessed within the matrix using protection class, operating temperature range, and company reputation. These were all identified in interviews and research as crucial considerations when determining which type of inverter to purchase. The values associated with each performance metric contribute equally to the performance score, but the reliability score places greater emphasis on company reputation because interviews with industry professionals found company reputation to be a decisive indication of component quality. The final score for the quality of each combination was found by valuing both components at 50% each.

The installer experience tab within the matrix was altered to include columns considering installer accreditation and shipping practices of the company. Interviews with solar providers and manufacturers as well as failure data collected from the survey indicated that system failures can occur with poor installation, and that accreditation through the Clean Energy Council provides greater confidence that the installer is knowledgeable about proper procedures. Issues caused by faulty shipping were also identified as a common theme in interviews, and thus were included in the matrix. The tender document was revised to include shipping information, which can be directly imported to the matrix column. The experience tab was also adjusted to accommodate direct insertion of numerical values. The previous matrix relied upon a rating system to describe the amount of years and generation capacity installed by the company. The rating keys were eliminated and equations were developed to more easily enter, present, and accurately calculate information regarding installer experience.

Lastly, the customer service tab was changed to eliminate qualitative assessment. The Queenscliffe assessment had a customer service score assigned based off information included in a notes column. All companies received the same score, except for one which lacked specific information. In order to differentiate between companies and quantitatively assess customer service, the notes section was encoded and the common services were identified. Four major customer service offerings were found, and included as the new column headers. If the solar providers offered the specific services, then they received credit. Each of the four columns was equally weighted to contribute to the overall calculation of customer service.

4.4.4 Revised Matrix Comparative Analysis

A comparative analysis was conducted to determine how the new matrix performed in relation to the prior assessment methodology. The Queenscliffe consultation was used as the example case and the matrix was filled with information relating to the specific tenders and system components. The analysis was conducted similarly to the original bulk buy assessment. The new matrix had several alterations, mainly relating to additional metrics more indicative of system quality. This data was acquired through component data sheets and information from the prior assessment. Application parameters were completed with specific information characteristic of Queenscliffe to produce a more robust report.

The analysis was completed and final rankings of tenders were calculated and displayed within the Matrix. The overall rankings had been significantly reordered from the original analysis conducted by the ATA in 2015. However, the top two offers as identified by the original decision matrix remained unchanged. These two offers were still identified as significantly better than the other systems. The only other offer that did not change in rank was the lowest ranked system because it was much worse than all the other tender requests. Table 6 below shows the rankings as determined by revised decision matrix and the rank change when compared to the original.

Table 6: Comparison of tender rank to prior methodology

Rank Change	Solar Provider	Percentage
--	Sustainable Solar Services B	78.2
--	Green Energy Options A	76.8
▲3	City to Surf Solar Plus A	74.7
▲1	Sustainable Solar Services A	73.5
▼2	Efficient Energy A	72.9
▲7	City to Surf Solar Plus B	71.7
▲4	Efficient Energy B	70.6
▲4	Green Energy Options B	69.7
▼5	Radiant Energy Systems A	68.3
▼3	Massive Solar A	68.2
▼1	Radiant Energy Systems B	66.0
▼3	Aus1Energis A	62.2
▼5	Massive Solar B	61.3
▲1	Aus1Energis B	58.5
▼1	New Generation Solar A	58.3
--	New Generation Solar B	57.2

As indicated by Table 6, many photovoltaic system offers had major changes in rank. Both tenders submitted by City to Surf Solar Plus performed significantly better in the new matrix, and rose many positions. This is due, in part, to both offers delivering high quality products, albeit at a high cost. The new matrix placed greater emphasis on high quality systems while reducing the importance of price. Additionally, the new metrics and weightings introduced to the quality tab of the matrix reorganized the top systems, and identified City to Surf Solar Plus B as having the system of highest quality. Improved quality and installer experience scores caused it to rise seven spots. Radiant Energy Systems A and Massive Solar B both dropped in the rankings because their quality score decreased and they earned a lower customer service score because of the amount of services provided. The revised matrix relies more heavily on quantitative values indicative of quality and other factors, granting greater confidence in the decisions generated by the matrix.

5. Deliverables

Based upon our objectives, our team provided the ATA with five deliverables in addition to this final report. First, the team provided the ATA with a more comprehensive, enhanced decision-making matrix. Along with the decision-making matrix, an updated tender request document was provided to ensure the ATA receives all information needed when making an assessment. The team also provided the ATA with registries of both solar modules and solar inverters relevant to the Australian market. Accompanied with the team's reliability analysis methodology, the team provided a survey for the ATA to use on their website to continuously gather reliability data. Lastly, the team provided the ATA with a 30 page summary of this report, providing a briefer overview of the project and key findings.

5.1 Enhanced Assessment Matrix

The team made several changes to the existing assessment matrix. The tabs were reweighted to be tailored more towards consumer priorities. The tabs were also renamed to be more descriptive of the factors they are considering. Each tab was modified to provide more quantifiable data for a more justifiable assessment. The data was then weighted accordingly. Photos of the updated matrix can be found in Appendix K.

5.2 Tender Request Document

With the addition of quantifiable data for a more justifiable assessment, the need for an updated tender document arose. This tender document now requests all data needed for the assessment matrix from solar retailers. This allows the ATA to spend less time searching for the required product data, and more time comparing and assessing the different tenders submitted. Photos of the new tender request document can be found in Appendix L.

5.3 Solar Module and Inverter Registries

Through gathering information for the enhanced assessment matrix, the team came across information valuable for the ATA to have, but not necessarily pertinent for use in the matrix. Previously, in issues of the ATA's *ReNew* Magazine (134 and 137 specifically), the ATA provided subscribers with a buyer's guide for solar modules and solar inverters, respectively. These buyer's guides provided general information regarding panels and inverters. Using the information the team found during research, the buyer's guides were updated with more columns, providing additional information valuable to assessing the quality of products not previously included. Photos of the updated module and inverter buyer's guides can be found in Appendices M and N, respectively.

5.4 Continuous Reliability Survey & Database

After conducting a reliability analysis based upon the survey results received during this project, the team has made a recommendation for the ATA to conduct these analyses on a regular basis. To provide the ATA with easily accessible reliability data to conduct these analyses, the team created a survey for the ATA to either send out quarterly, or leave on their website for continuous data collection. It is up to the discretion of the ATA as to how they distribute the survey. Utilizing the reliability analysis procedure outlined in Section 4.2.5 and the data provided in the new survey, the ATA can use reliability data to estimate lifespans of products and provide data driven consultations. Images of the survey can be found in Appendix P.

5.5 Summarizing Report

To allow the ATA greater ease in providing quick consultations, the team has created a 30-page summarizing report. This report includes a brief executive summary, background regarding material data and common failures, a brief summary of the methodology, and the key findings of this project. It also provides a brief conclusion and recommendations, providing recommendations for future ATA projects or considerations. The concise nature of this report will help the ATA in efficiently providing consultations to their members and clients.

6. Conclusions & Recommendations

Given the current state of the Australian energy market, solar photovoltaic systems have the potential to play a primary role in the country's energy generation. However, in order for this to occur it is necessary to optimize the balance between cost and quality to provide consumers with a cost-effective product that will function properly over time. This chapter provides recommendations to provide more comprehensive solar PV quality assessments and a concluding project summary.

6.1 Recommendations

Based upon the data and information collected through the methods described in the previous section, we have developed the following recommendations. These recommendations are directed towards the Alternative Technology Association and Australian consumers. In addition, this section includes recommendations for potential future projects.

6.1.1 Recommendations to Australian consumers

The consultations that the ATA provides are aimed to provide consumers with the most optimal solar PV system for their application. This section includes recommendations to Australian consumers to further enhance the long-term quality of the systems they purchase.

We recommend that consumers only hire installers that are accredited by the Clean Energy Council.

This study identified installation as one of the most common causes of failure within solar photovoltaic systems. Therefore, to improve the reliability and performance of PV systems, it is critical that they are installed correctly. Poor quality of installation can result in microfractures, faulty connections, and sub-optimal module positioning and shading. In an effort to mitigate the risk of these improper installations, we suggest consumers only make use of CEC accredited solar installers. To become a CEC accredited installer the company must have employees who fully complete required installation training courses, up-to-date electrical and working at heights licenses, and public liability insurance. In addition, companies are required to submit a case study of one of their installation to prove that they fully understand the proper techniques for installing solar PV systems. Companies must also re-apply for accreditation every two years and complete required training and professional development, which help to ensure installers are informed regarding the ever-changing Australian solar industry. This guarantees that a company that maintains CEC accreditation has been successfully installing products for an extended time period.

We recommend that consumers solicit post-installation inspections of their systems to ensure the quality of shipping and installation and perform regular maintenance on their systems.

While making use of CEC accredited installer will help to mitigate failures caused by installation errors, we recommend that consumers have inspections performed on their systems following installation. Consumers can solicit these inspections from a CEC accredited installer or from their state government. By conducting these inspections consumers will be able to determine the quality of the installation work. Using Maximum Power Point Tracking the inspector will be able to determine the initial functionality of the system compared to its manufacturer rating. This comparison makes it possible to identify any defects in installation, and correct them before they become more serious post-warranty problems. These inspections should be performed regularly following installation to ensure optimal system functionality.

In addition to regular inspections, consumers should be sure to perform the necessary maintenance required by the system. While it is important to purchase a high-quality system, it is equally important to properly maintain each component. This maintenance includes cleaning of the module glass, removing dust and dirt from the inverter, and ensuring the safety of all electrical connections. An accredited installer should be contracted for all maintenance, as these professionals have the ability and knowledge to perform the work safely. We also recommend that consumers keep a log of all inspections and maintenance done on the system to make potential warranty claims simpler when issues do arise.

We recommend that consumers purchase panels from a manufacturer that has conducted electroluminescence (EL) testing.

As mentioned earlier on in the report, electroluminescence testing conducted by a manufacturer can detect early microfractures prior to shipping and therefore ensure products leaving the factories are of good quality. This extra step in the manufacturing process can save countless panels from early microfractures and help ensure a healthy system life. Therefore, we recommend that consumers seek to purchase panels from a manufacturer that conducts EL testing on their products.

We recommend that consumers consider the following factors when purchasing solar photovoltaic systems and consult the ATA for further guidance.

When purchasing a solar photovoltaic system there are numerous things to consider, however this study has identified some critical factors affecting long-term performance and reliability. The first factor being the design of their system. There are a wide variety of design options for both modules and inverters, and purchasing the proper construction type for the given application is crucial to quality of the system. An additional design consideration when purchasing a system is the module/inverter sizing ratio. By oversizing the array to the inverter consumers can expect increased generation when the array is not operating at its maximum capacity, but will lose the excess power when the maximum is reached. For this reason, it is important for consumers to consider the amount of solar irradiance and shading their system will experience, the potential safety risk of overloading the inverter, and the potential financial benefits. However, it should be noted that consumers should never exceed the CEC specification of the inverter being rated to least 75% of the array's capacity.

In the case that a system does experience a failure, it crucial that the products purchased have proper warranties and that consumers understand the difference between the various warranties offered. Warranties offered for modules and inverters differ slightly in both coverage and length. Therefore, it is important to research the full extent of each warranty, which can be done by contacting the company directly or by consulting the ATA. Warranties are often representative product quality, and therefore a longer warranty is important in ensuring the quality of the system purchased and the installation. Although, warranty length alone should not be used to determine the value of the warranty, and in turn the product.

A warranty is useless if a company is no longer in operation or does not have the capability of handling a warranty claim. Therefore, the location and reputation of companies should also be taken into account when purchasing solar PV systems. Through interviews with industry leaders, it was identified that when they are purchasing solar systems this is the most important factor influencing their decision. It is important that companies chosen by the consumer have offices located in Australia. This will make maintenance, warranty claims, and general customer service far easier. Maintaining an Australian office also shows a commitment to providing the Australian people with a quality product. Failure to use a company with a domestic facility has the potential to lead to decreased long-term system quality due to lack of available support. Location also affects the reputation of the company. It is critical that consumers research online forums, investigate company information, and consult the ATA regarding the most reputable manufacturers, installers, and suppliers.

6.1.2 Recommendations to the Alternative Technology Association

The ATA provides Australian consumers with the knowledge necessary to live as sustainably as possible. This section contains recommendations for the Alternative Technology Association to help them enhance the services they offer to their members.

We recommend that the ATA solicit consumer failure data and compile it into a running database of system failures.

This study identified the lack of available reliability data regarding solar photovoltaic products that are currently on the market. With the industry constantly changing, it is extremely difficult to produce valid product failure data and manufacturers are highly reluctant to provide this information to the public. For this reason, we recommend that that the ATA begin compiling information regarding the failures of its consumer's solar PV systems. This data will, with time, allow them to generate their own reliability metrics We also recommend that they make use of the reliability calculation detailed in Section 4.2.5. Using this methodology will provide the ATA with the probability that the project will still be operating properly after a given amount of time based upon the previously recorded failures. This analysis will allow the ATA to make comparisons and provide more informed consultations to their members in lieu of the unavailable published data.

We recommend that the ATA solicit failure rate data from solar PV manufacturers.

In addition to gathering consumer failure data, we also recommend that the ATA request manufacturer failure data. Whether this data be from accelerated life testing or warranty claims, this data will increase the amount of reliability data available to the ATA and enhance the certainty to which they can make their assessments. The team was only successful in soliciting failure rate information from one solar manufacturer. If the ATA use their leverage to request this data it will greatly enhance their assessments. This failure data could also be included in their published buyer's guides for personal use by their subscribers, assuming the ATA does not need to sign a Nondisclosure Agreement to acquire the data.

We recommend that the ATA solicit technical information regarding the thickness of solar cells.

Through our research, we have discovered that the thickness of a solar cell makes the cell more or less susceptible to microfractures. Therefore, it is important to take solar cell thickness into consideration when providing consultations. However, this data is currently unavailable to the public. The team recommends that the ATA should contact manufacturers to solicit information regarding solar cell thickness. In doing this, the ATA will be able to provide more knowledgeable consultations and reduce failures for consumers participating in these consultations.

We recommend that the ATA make use of the ENF Solar database when performing system assessments.

In our research of the most important factors and metrics used to determine solar system performance and reliability, we discovered the ENF Solar database. This database is operated and maintained by a private company who has staff members solely dedicated to ensuring the database is up to date and as comprehensive as possible. This has resulted in a constantly updating database with information regarding thousands of PV components and companies. We recommend that the ATA make use of the statistics available in this database when making consultations, updating their buyer's guides, and performing bulk-buy assessments. The website contains data regarding material composition, performance, test certifications, and third party test information. When this is combined with the analysis provided within this report, the ATA will be able to provide enhanced consultations to its clients.

We recommend that the ATA work in conjunction with the Clean Energy Council to develop industry guidelines regarding the shipping of solar PV system components.

Our study has discovered a major gap in the regulation of shipping solar PV system components. There are currently Australian regulations regarding both the manufacturing and installation of solar PV components, but there are no such regulations for shipping. Through our interviews and research it was identified that microfractures and other damages are often caused by poor shipping methods such as stacking panels or insufficient protective packaging. This is often because the shipping protocols are currently established by the manufacturers themselves and can be minimized to reduce costs to the companies. For this reason, we recommend that the ATA work with the Clean Energy Council to develop a set of guidelines for the proper transport solar PV components, especially solar modules. A set of guidelines similar to their current installation guidelines would increase the quality of the shipping process and reduce the presence of microfractures within solar modules. "CEC accredited shippers" would be subject to similar training courses and reporting practices as installers, which would provide greater product quality assurance for an aspect that is currently overlooked.

6.1.3 Recommendations for future projects

Working with the Alternative Technology Association provides amazing opportunities for combining students' technical knowledge and the social science requirement of the Interactive Qualifying Project. This section provides recommendations for future projects that will benefit not only the Alternative Technology Association and students, but the community as a whole.

We recommend a project be completed analyzing the quality of off-grid system components and expanding the ATA's assessment methodology for these systems.

The current ATA assessment methodology is primarily focused on the evaluation of grid-connected photovoltaic systems. However, as the Australian energy market continues to change many consumers are making the switch to off-grid and hybrid systems. These systems require additional technology such as batteries and charge controllers. As these two system types become prevalent within the Australian market it will be crucial for the Alternative Technology Association to have the capacity to provide justifiable recommendations to its members regarding these technologies.

We recommend a project be completed to develop an educational program providing the public with the knowledge necessary to make informed solar photovoltaic system purchases.

This study has identified numerous factors affecting solar PV system quality and has provided the ATA with this information for use within their own assessments and consultations. However, it is highly important that the public is properly informed because they will actually be implementing these systems on their properties. We recommend a project be completed to develop an educational program that can be presented to ATA members and the general public to increase their knowledge regarding the quality of the solar PV systems they are purchasing. Given the ATA's experience with creating educational publications and holding these types of workshops, this project has the potential to greatly improve the Australian solar community.

6.2 Conclusion

As solar photovoltaic systems become more frequently used in Australia, the overall quality of these systems has come into question. The purpose of this project was to develop a methodology to better assess the quality of these systems. This was accomplished by conducting interviews with industry leaders, surveying consumer priorities, and independent research.

Suppliers, installers, and manufacturers of solar photovoltaics systems were interviewed to determine what factors are most important when assessing the quality of PV systems. This was done in conjunction with interviews of key Alternative Technology Association employees. The factors that were identified include: the design of PV systems, the sizing ratio between modules and inverters, installation and shipping, and company reputation. In addition to the information gathered from interviews, surveys were conducted to take consumer priority into account when assessing what truly makes a quality PV system. Through this survey the team was able to establish that quality is the most important factor when purchasing solar PV systems and gather data regarding the failure of systems that have been used in the field for an extended period of time. This data could be used to calculate the probability of product failure and other reliability metrics. Lastly, independent research was performed to identify metrics capable of quantifying the long-term performance and reliability of these systems. The resulted in recommendations for the use of the ENF Solar database, certification testing, performance metrics, and a methodology for creating reliability data for solar PV products.

In order to make full use of the information collected, the project provided several deliverables for use by the ATA. These deliverables include: module and inverter product registries, a more comprehensive quality assessment methodology, a concise report detailing our findings, and recommendations for further improving the assessment of quality within PV systems. The product registries build upon the ATA's previously established buyer's guides and compile important quality information for the most common products on the Australian market. The assessment methodology was worked into a decision-making matrix that will allow for the comparison of various tenders for large scale applications. Lastly, the concise report and recommendations provide direction for furthering the research conducted by this study and how to best assess the quality of solar photovoltaic systems.

The work performed by the project team and the final deliverables provided to the Alternative Technology Association have great potential to affect the Australian solar industry. Up until this point the industry lacked a methodology for assessing the quality of solar photovoltaic systems. This project provides both a methodology and instructions to make further improvements. The implementation of this methodology will inform the Australian public of what factors have the greatest impact on the quality of their solar PV system. This will eventually lead to a market that appropriately rewards high quality solar PV systems that operate properly for the long-term. Given the uncertainties about energy security and high energy prices in the Australian market, consumers operating reliable, high-performance solar photovoltaic systems will be able to be confident that their energy will remain consistent, cost-effective, and capable of supporting the lifestyle all Australians are deserving of.

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Appendix A: Renewable Incentive Programs

There are a number of incentive programs that exist in Australia to promote the adoption of solar and other renewable resources. The major federal incentive program is the Australian Renewable Energy Target (RET) scheme. This program, initiated in 2001, created a credit system imposing charges on electricity generation from non-renewable sources and granting reimbursements to systems that produce electricity from renewables. A variety of incentive programs such as feed-in tariffs or bulk-buy promotions are also managed at the state or city level.

The Renewable Energy (Electricity) Act 2000 and the Renewable Energy (Electricity) Regulations 2001 built an incentive program to encourage the adoption of clean and renewable energy sources. The original Renewable Energy Target was to create 9,500 gigawatt hours of new electricity generation from renewable resources by 2010. The scheme had early success and the goal was extended to reach 33,000 gigawatt hours of new power by 2020 (Clean Energy Regulator, 2016). The program was designed to place emphasis on both large and small scale renewable ventures. New requirements were introduced stipulating that liable entities must purchase and submit a set number of credits annually. Liable entities are companies or individuals (predominately electricity retailers) who first acquire electricity after generation and in excess of 100MWh annually. These credits take the form of large-scale generation certificates (LGCs) and small-scale technology certificates (STCs) (Clean Energy Regulator, 2016). These certificates are treated as a form of currency in the Australian Energy industry, and are created, registered, audited, and traded in an online platform called the Renewable Energy Certificate (REC) Registry. The certificate model allows renewable technology to be more affordable because profits from non-renewable sources are subsidizing them. This serves to balance the competitive energy sector and encourage the slow integration of renewable power stations.

Small-scale technology certificates are earned by companies and individuals involved with implementing renewable technologies for residential or small commercial applications (systems smaller than 100kW). Small-scale technology certificates are created at the time of installation, and the number of certificates earned corresponds to the projected power generation over the ensuing fifteen years. Solar installation companies often accept STCs to offset the cost of PV or solar water heater systems. STCs are backed with a minimal value of 40 AUD by the

Australian Clean Energy Regulator. Alternatively, STCs can be traded on the REC Registry for a negotiated price (Clean Energy Regulator, 2016). Liable entities are required to submit a certain number of STCs quarterly, and will purchase STCs off the REC Registry.

Large-scale generation certificates are earned by renewable energy power stations and match the amount of power produced from sources such as hydroelectric, wind, or solar. Similar to STCs, one LGC is equivalent to one megawatt hour of power produced from a renewable source (Clean Energy Regulator, 2016). The value of these certificates is variable, and affected by the supply and demand factors surrounding the LGC market. There is no guaranteed value backing LGCs. These certificates are exchanged on the REC Registry as well, and LGCs are typically sold to liable entities who must surrender a certain amount each year to avoid incompliance penalties.

The Renewable Energy Target program has been successful to varying degrees. In the early years of the RET, the original goal of 9,500 GWh of new capacity was easily attainable, predominantly because of major technological developments. The Progress and Status of the Renewable Energy Target created by the Clean Energy Council in 2016 states that currently Australia is 15,200 GWh above 1997 RET baseline levels for renewable fuels. Clean Energy Council Chief Executive Kane Thornton has said that large-scale construction projects currently underway have inspired strong momentum and confidence in the renewable industry, though major developments must occur in 2017 to instigate the amount of growth still required (Zahedi, 2016). The Clean Energy Council explains that 6000 MW of new generation capacity must still be added to reach the 2020 target (Zahedi, 2016). While there are less than three years remaining in the program, and the target has yet to reach even 50% of the mark, the Clean Energy Council is confident that the target can be attained. Projects amounting to 11,000 MW of renewable electricity generation have already completed the planning approval process, and an additional 6000 MW worth of power generation stations are in the planning approval process (Zahedi, 2016). If these projects begin making serious progress in 2017 that target could be surpassed and help to severely cut greenhouse gas emissions.

A few other types of financial incentives for solar energy exist in Australia, yet are not necessarily adopted nationwide. Feed-in Tariffs (FiTs), for example, offer additional revenue for small-scale renewable energy producers. FiTs are not available in every Australian territory, and the compensation level varies. In Victoria, any excess power generated from a renewable source is reimbursed by electricity retailers at 0.05 AUD per kilowatt hour (Energy Matter, 2017a). This is a competitive rate as the wholesale cost of electricity ranges between 0.03 and 0.055 AUD per kilowatt hour. Many city councils throughout Australia have also been establishing solar bulk-buy programs for their residents. For example, the city of Melbourne, along with a number of other city councils in the metropolitan area, has been supporting a solar bulk-buy program in conjunction with Positive Charge. Positive Charge is a non-profit enterprise focused on reducing carbon emissions through implementation of renewable generators. This bulk-buy program is targeted at providing affordable PV systems to homeowners. Positive Charge worked with the Alternative Technology Association (ATA) to identify ideal rooftop PV systems based on product quality, warranty length, and cost. The solar bulk-buy program combines modules manufactured by JA solar, Sungrow inverters, and Australian-made mounting systems from Sunlock (Positive Charge, 2016). These bulk purchases aim to deliver premium systems at highly discounted rates.

Appendix B: Interview for ATA Employees

Name:
Date:
Time:
Location of Interview:
Job Title:
Interviewer:

1. How many bulk-buy assessments have you participated in?

2. How does the process begin? Are you approached by a town, do you approach them, etc.?

3. Once you have the client, how do you gather information for the assessment matrix?

4. How do you decide the weighting scale of your current assessment matrix?

5. Do weighting systems change based on the needs of the municipality?

6. In your opinion what is the most important characteristic of the solar PV system? (Price, Warranty, Experience, Customer Service, Quality)

7. In regards to the Quality tab, where do you gather the information provided in the "Fail Notes" section?

8. Do you currently see any issues or gaps of information in the existing matrix?

9. If you were to change anything about the assessment matrix, what would it be?

Appendix C: Interview for Bulk-Buy Government Officials

Name:
Date:
Time:
Location of Interview:
Municipality:
Job Title:
Interviewer:

1. What role did you play in the bulk-buy program?

2. Did the ATA solicit your input in the final PV system selection process?

3. Have you received any complaints regarding the PV systems since the program's conclusion?

4. If so, how would you describe the quality of the customer support you received?

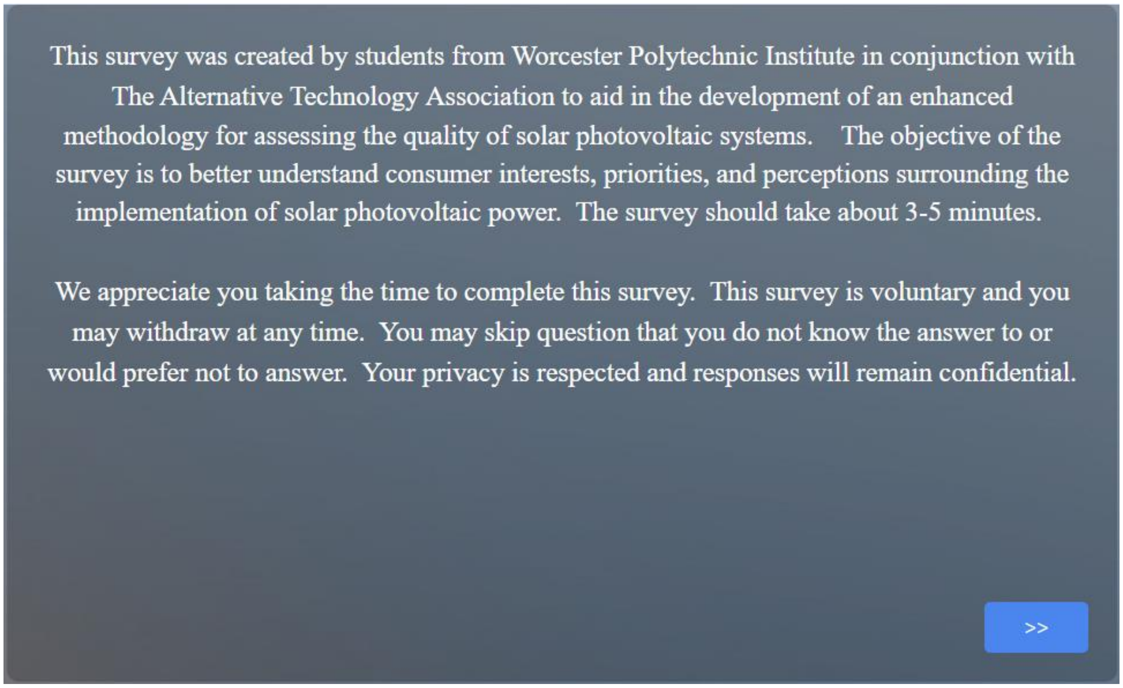
5. What is most important attribute to you when looking for a solar PV system?

6. Do you feel that your community received the best panels possible? If not, why?

7. What do you see as areas of improvement for the ATA and the bulk-buy program?

Appendix D: Survey for Consumers on ATA Mailing List

Below is the Qualtrics Survey given to subscribers to the ATA newsletters and magazines. We have included screenshots of each step. There are a few routes the survey can take, these routes will be highlighted below.



In which state do you currently reside?

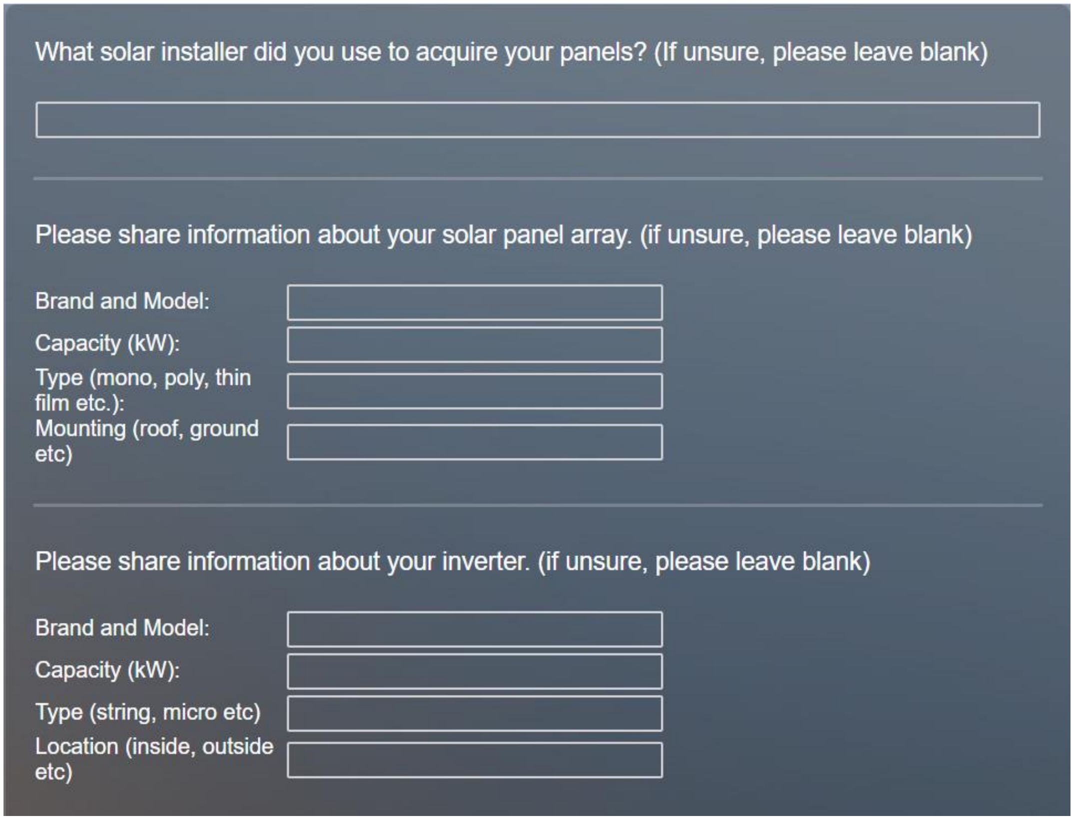
- Victoria
- Queensland
- New South Wales
- South Australia
- Western Australia
- Tasmania
- Northern Territory

Have you had a solar photovoltaic system system installed on your property?

- Yes
- No

>>

If yes is selected for "Have you had a solar photovoltaic system installed on your property?" several questions regarding their personal system will be asked (as seen on the following page). If no is selected, the respondent will skip this section of the survey.



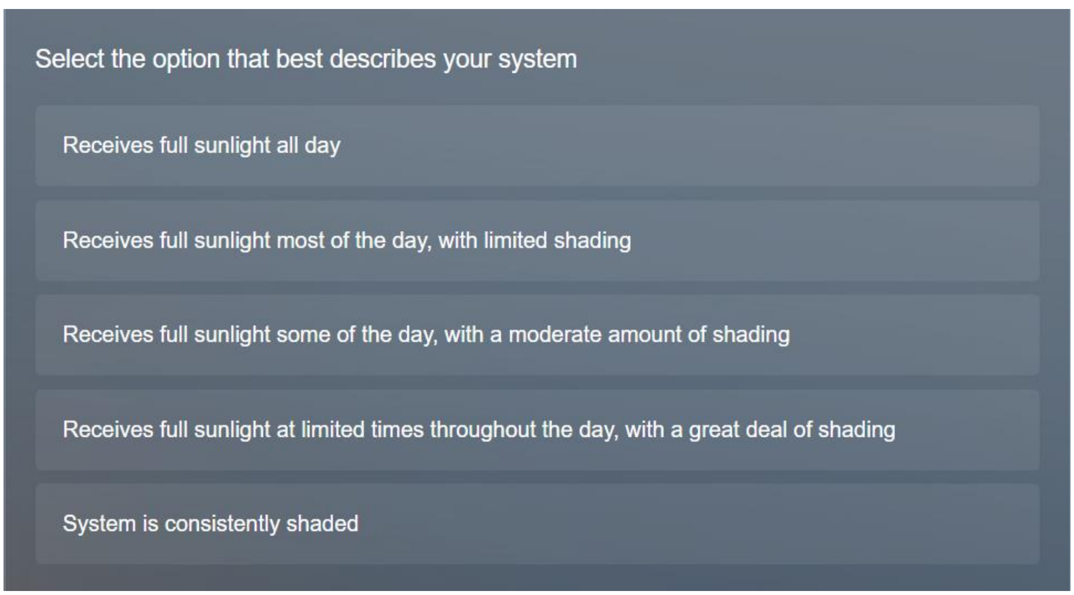
What solar installer did you use to acquire your panels? (If unsure, please leave blank)

Please share information about your solar panel array. (if unsure, please leave blank)

Brand and Model:
Capacity (kW):
Type (mono, poly, thin film etc.):
Mounting (roof, ground etc)

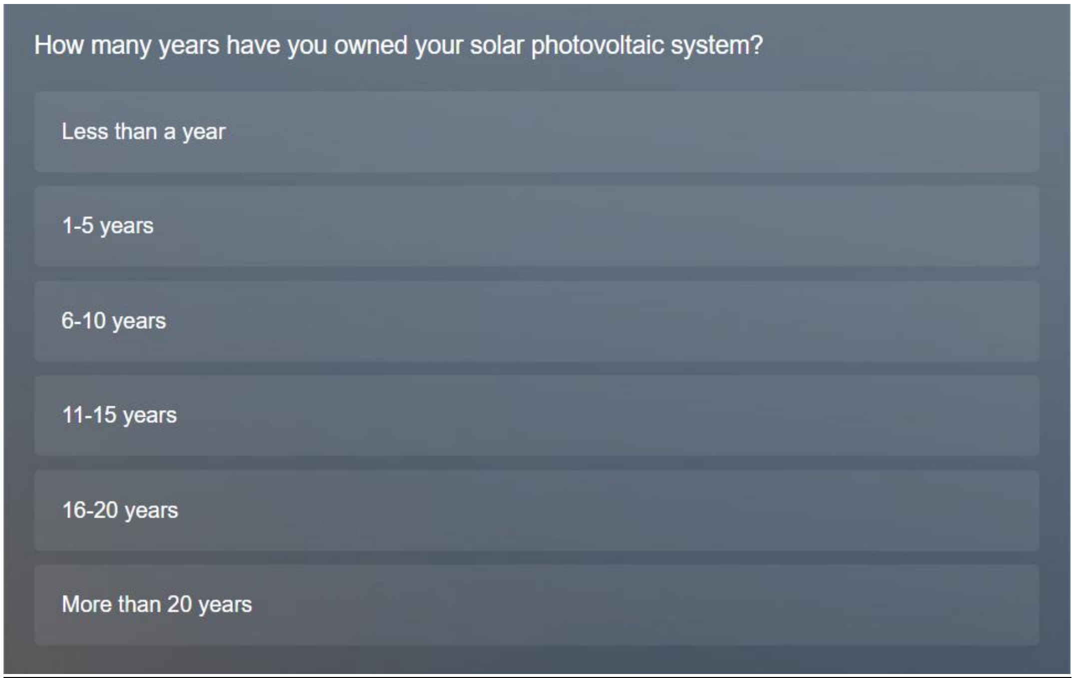
Please share information about your inverter. (if unsure, please leave blank)

Brand and Model:
Capacity (kW):
Type (string, micro etc)
Location (inside, outside etc)



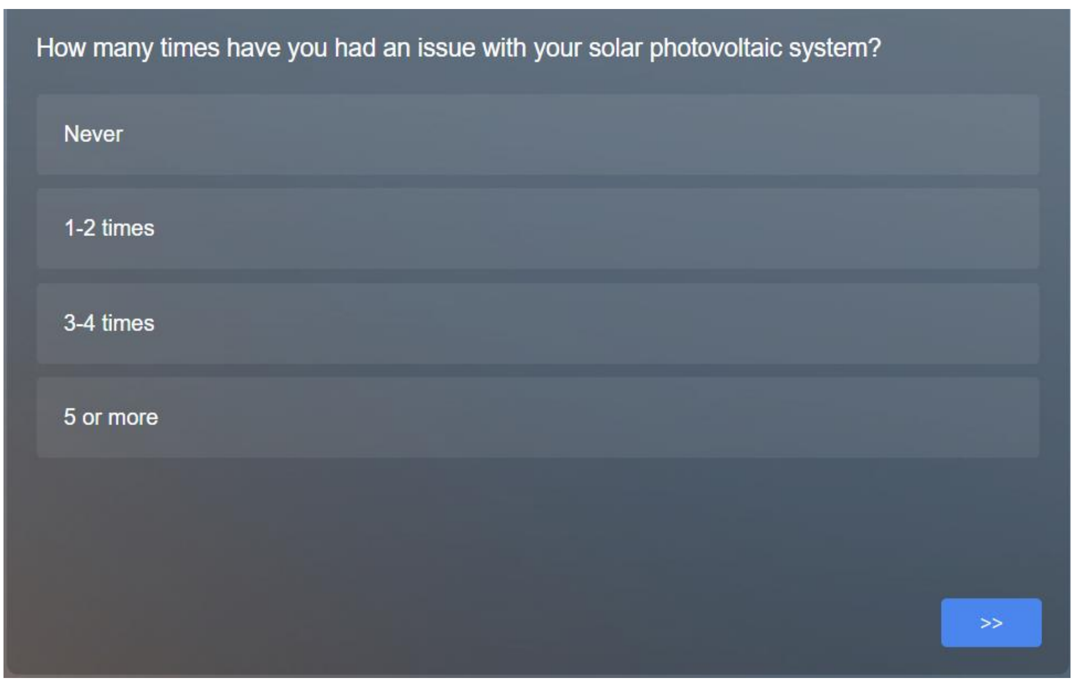
Select the option that best describes your system

- Receives full sunlight all day
- Receives full sunlight most of the day, with limited shading
- Receives full sunlight some of the day, with a moderate amount of shading
- Receives full sunlight at limited times throughout the day, with a great deal of shading
- System is consistently shaded



How many years have you owned your solar photovoltaic system?

- Less than a year
- 1-5 years
- 6-10 years
- 11-15 years
- 16-20 years
- More than 20 years

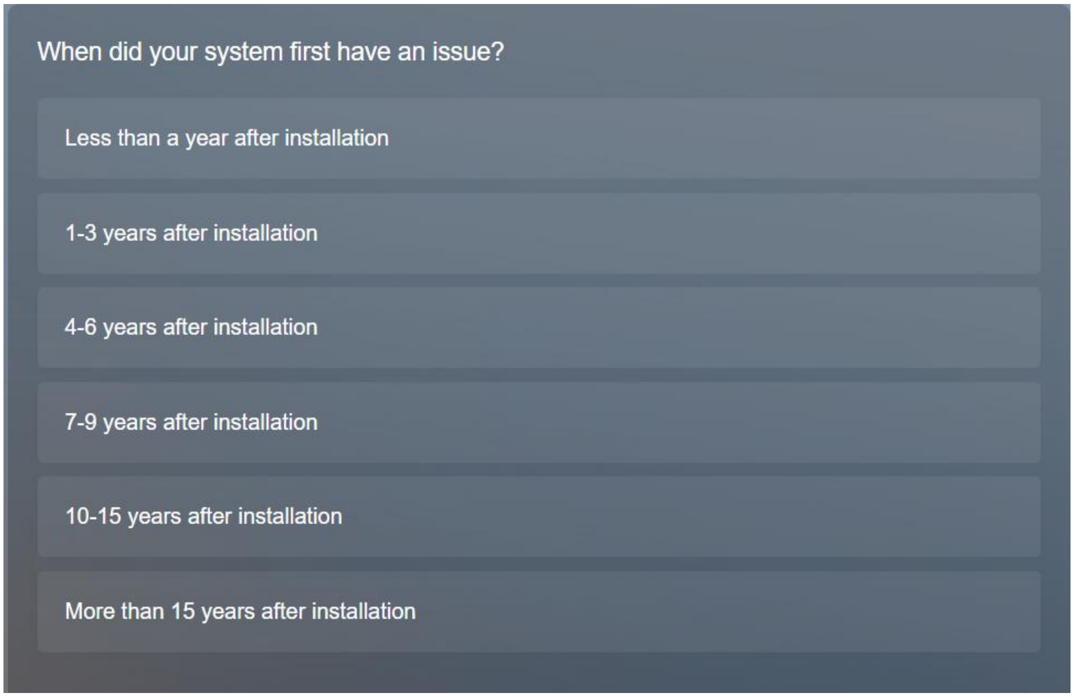


How many times have you had an issue with your solar photovoltaic system?

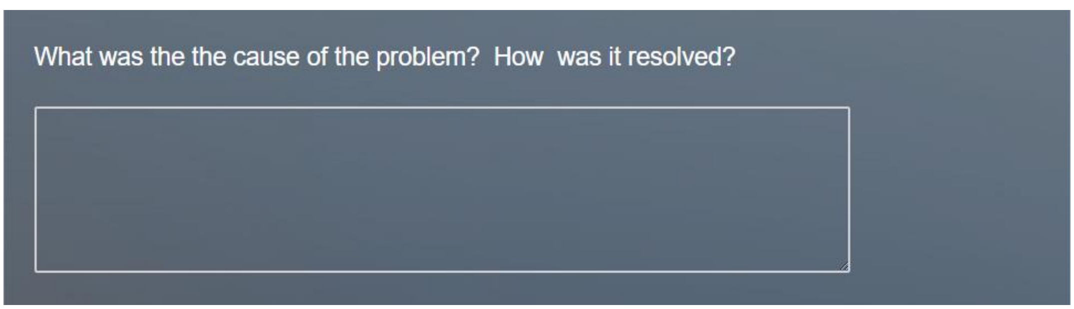
- Never
- 1-2 times
- 3-4 times
- 5 or more

>>

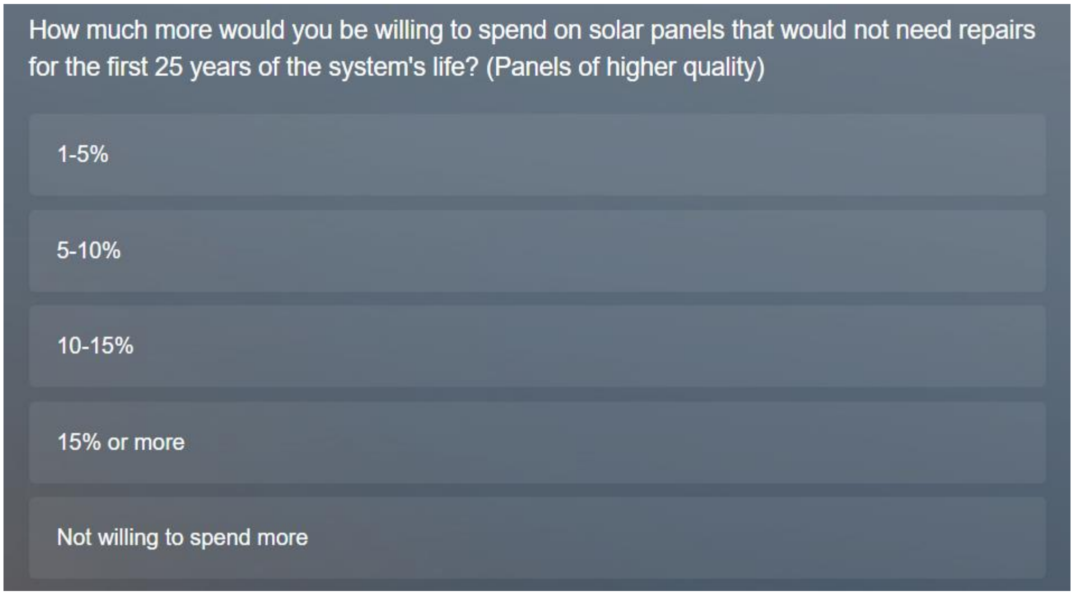
The questions shown below will appear if the respondent answers “1-2 times,” “3-4 times,” or “5 or more times” from the above question regarding issues with the systems.


When did your system first have an issue?

- Less than a year after installation
- 1-3 years after installation
- 4-6 years after installation
- 7-9 years after installation
- 10-15 years after installation
- More than 15 years after installation


What was the the cause of the problem? How was it resolved?

The respondents that selected “No” to owning a solar photovoltaic system would be directed to this point in the survey from the beginning. The respondents that selected “Yes” also continue to this section of the survey once the above section is completed.



How much more would you be willing to spend on solar panels that would not need repairs for the first 25 years of the system's life? (Panels of higher quality)

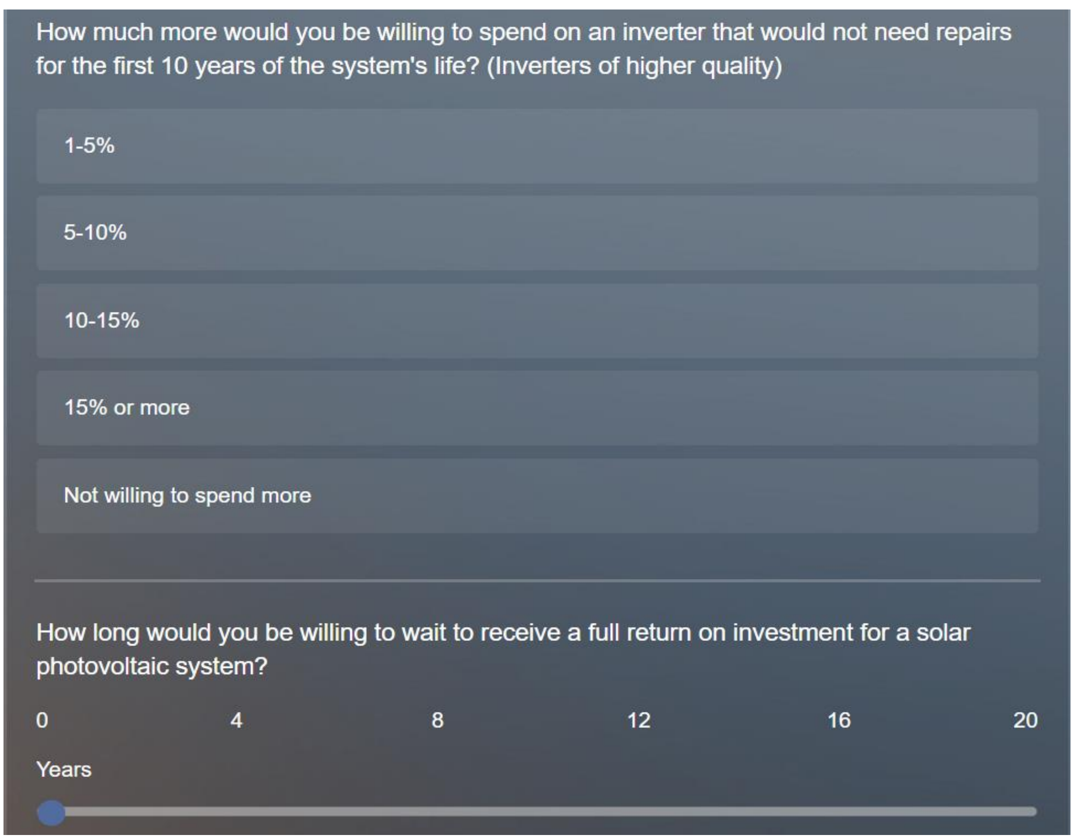
1-5%

5-10%

10-15%

15% or more

Not willing to spend more



How much more would you be willing to spend on an inverter that would not need repairs for the first 10 years of the system's life? (Inverters of higher quality)

1-5%

5-10%

10-15%

15% or more

Not willing to spend more

How long would you be willing to wait to receive a full return on investment for a solar photovoltaic system?

0 4 8 12 16 20

Years

How important are the following categories when considering to purchase a solar photovoltaic system.

	Extremely important	Very important	Moderately important	Slightly important	Not at all important
Warranty	○	○	○	○	○
Company Reputation	○	○	○	○	○
Cost	○	○	○	○	○
Customer Service	○	○	○	○	○
Performance and Reliability	○	○	○	○	○

What is most important to you when purchasing a photovoltaic system? (Please click and drag to rank)

Price

Warranty

Company Experience

Customer Service

Quality

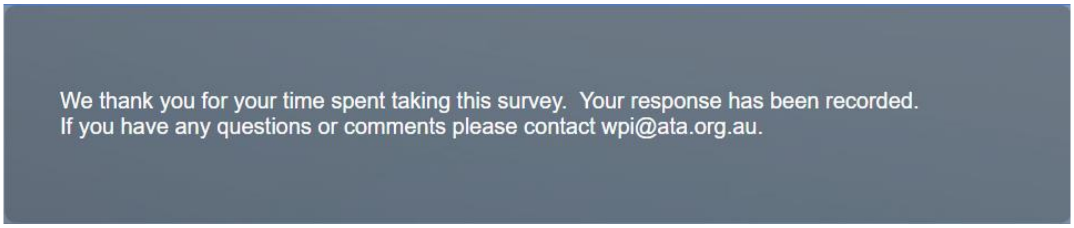
If you would be willing to conduct a follow up interview about solar photovoltaics, please include your name and contact information below. Thank you.

Name: __________

Contact: __________

>>

The final survey page thanks the participants for providing the team with useful data and provides contact information for any comments of questions.



Appendix E: Interview for Solar Industry Leaders

Name:
Date:
Time:
Location of Interview:
Job Title:
Interviewer:

1. How many years of experience do you have working with solar photovoltaic systems?

2. What do you see as the most common failure mode in these systems? What causes this?

3. Are there any components in particular that are primarily responsible for these failures?

4. What do you look for in a high quality solar PV system? Are there specific materials or designs that you think provide the best overall system? Are there any that you avoid?

5. What metrics do you utilize to rate a system's quality?

6. Do manufacturers provide you with reliability data?

7. What do you base your warranty numbers off of?

8. Do these metrics differ between modules and inverters?

9. What is the most important factor, to you, when you are selecting the proper panel for an application?

10. Is this factor the same in the case of inverters? If not, what is?

11. What are some challenges you face in ensuring the quality of your work?

Appendix F: Interview for Solar Manufacturers

Name:
Date:
Time:
Location of Interview:
Job Title:
Interviewer:

1. How many years of experience do you have working with solar photovoltaic systems?

2. What types of manufacturing methods do you utilize when making your modules/inverters? Do you use multiple methods? Are these methods standard across the industry or do they vary?

3. In your opinion, what defines a high quality solar PV system? Are there specific materials or designs that you think provide the best overall system? Are there any that you would avoid?

4. What are some challenges you face in ensuring the quality of your work?

5. What do you see as the most common failure mode in these systems? What causes this?

6. Are there any components in particular that are primarily responsible for these failures?

7. What metrics do you utilize to rate a system's quality?

8. What sort of reliability data do you publish for your systems?

9. What do base your warranty numbers off of?

10. Do these metrics differ between modules and inverters?

11. What is the most important factor, to you, when you are selecting the proper panel for an application?

12. Is this factor the same in the case of inverters? If not, what is?

Appendix G: Oral Consent Form for Interviewees

Hello, our names are ______. We are American students at Worcester Polytechnic Institute. We are collecting information regarding quality of solar components in an attempt to provide a quantifiable assessment of qualitative metrics. This interview/survey should take no longer than ____ minutes.

We appreciate you taking the time to meet with us today. We would like to remind you that this interview/survey is completely voluntary and you may withdraw at any time. We respect your privacy and therefore if you request to remain anonymous, your responses will stay confidential.

Are you willing to allow us to use quotations taken from this interview in our final report?

Appendix H: Interview Coding Mechanism

This coding methodology will successfully allow for qualitative data gathered from interviews with Australian solar photovoltaic industry leaders to be turned into quantitative data useful for establishing findings and making recommendations.

Study purpose:

To interview solar industry leaders in order to gain knowledge regarding what aspects affect solar system quality (materials, manufacturing, and installation)

Keyword Coding Mechanisms:

Panels:

- Manufacturing
  - Methods
  - Metrics
  - Location
- Installation
- Materials
- Warranty
- Reputation

Inverters

- Manufacturing
  - Methods
  - Metrics
  - Location
- Installation
- Manufacturing
- Warranty
- Reputation

Question-Specific Coding:

1. Years of experience
   a. Use numerical analysis (average together all the years of experience, sum together the years of experience in the industry)
2. What do you see as the most common failure in systems/what are some failures in systems?
   a. DC Isolators
   b. Installation errors
   c. Inverters
   d. Water damage
   e. Other

3. How do you determine good quality?
   a. Company Reputations
   b. Reliability data

4. Does the manufacturer provide you with reliability data
   a. Yes
   b. No

5. Challenges faced to ensure quality
   a. Installation
   b. Reputation
   c. Price
   d. Bad batches of panels

Appendix J: Survey Response Data

Quantitative data collected from consumer survey:

1. In which state do you currently reside?

#	Field	Choice Count	
1	Victoria	44.87%	385
2	Queensland	9.56%	82
3	New South Wales	22.61%	194
4	South Australia	8.16%	70
5	Western Australia	6.41%	55
6	Tasmania	5.36%	46
7	Northern Territory	0.35%	3
8	Australian Capital Territory	2.68%	23
			858

2. Have you had a solar photovoltaic system installed on your property?

#	Field	Choice Count	
1	Yes	70.66%	607
2	No	29.34%	252
			859

6. Select the option that best describes your system.

#	Field	Choice Count	
1	Receives full sunlight all day	56.04%	334
2	Receives full sunlight most of the day, with limited shading	36.41%	217
3	Receives full sunlight some of the day, with a moderate amount of shading	6.88%	41
4	Receives full sunlight at limited times throughout the day, with a great deal of shading	0.67%	4
5	System is consistently shaded	0.00%	0
			596

7. How many years have you owned your solar photovoltaic system?

#	Field	Choice Count	
1	Less than a year	8.22%	49
2	1-5 years	40.27%	240
3	6-10 years	42.45%	253
4	11-15 years	5.03%	30
5	16-20 years	1.85%	11
6	More than 20 years	2.18%	13
			596

8. How many times have you had an issue with your solar photovoltaic system?

#	Field	Choice Count	
1	Never	65.55%	390
2	1-2 times	29.08%	173
3	3-4 times	3.87%	23
4	5 or more	1.51%	9
			595

9. When did your system first have an issue?

#	Field	Choice Count	
1	Less than a year after installation	33.50%	66
2	1-3 years after installation	36.55%	72
3	4-6 years after installation	22.84%	45
4	7-9 years after installation	3.55%	7
5	10-15 years after installation	3.55%	7
6	More than 15 years after installation	0.00%	0
			197

11. How much more would you be willing to spend on solar panels that would not need repairs for the first 25 years of the system's life? (Panels of higher quality)

#	Field	Choice Count	
1	1-5%	10.34%	86
2	5-10%	24.28%	202
3	10-15%	24.64%	205
4	15% or more	24.76%	206
5	Not willing to spend more	15.99%	133
			832

12. How much more would you be willing to spend on an inverter that would not need repairs for the first 10 years of the system's life? (Inverters of higher quality)

#	Field	Choice Count	
1	1-5%	9.74%	81
2	5-10%	26.08%	217
3	10-15%	23.92%	199
4	15% or more	22.84%	190
5	Not willing to spend more	17.43%	145
			832

13. How long would you be willing to wait to receive a full return on investment for a solar photovoltaic system?

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Years	0.00	20.00	8.56	4.17	17.39	820

14. How important are the following categories when considering to purchase a solar photovoltaic system?

#	Field	Extremely important		Very important		Moderately important		Slightly important		Not at all important		Total
1	Cost	17.06%	144	40.17%	339	38.51%	325	4.03%	34	0.24%	2	844
2	Warranty	47.75%	403	39.45%	333	10.90%	92	1.54%	13	0.36%	3	844
3	Customer Service	39.69%	335	40.76%	344	16.59%	140	2.37%	20	0.59%	5	844
4	Performance and Reliability	77.24%	655	22.17%	188	0.59%	5	0.00%	0	0.00%	0	848
5	Company Reputation	35.95%	302	42.98%	361	18.57%	156	2.26%	19	0.24%	2	840

15. What is most important to you when purchasing a photovoltaic system? (Please click and drag to rank)

#	Field	1		2		3		4		5		Total
1	Customer Service	5.56%	45	13.46%	109	23.95%	194	28.27%	229	28.77%	233	810
2	Warranty	5.31%	43	27.28%	221	26.30%	213	24.69%	200	16.42%	133	810
3	Quality	70.62%	572	18.15%	147	7.90%	64	2.10%	17	1.23%	10	810
4	Company Experience	8.77%	71	19.63%	159	18.77%	152	24.94%	202	27.90%	226	810
5	Price	9.75%	79	21.48%	174	23.09%	187	20.00%	162	25.68%	208	810

Qualitative data collected from consumer survey:

The following questions supplied qualitative consumer data. These responses can be found in an accompanying Microsoft Excel document.

3. What solar installer did you use to acquire your panels? (If unsure, please leave blank)

4. Please share information about your solar panel array. (If unsure, please leave blank)

5. Please share information about your inverter. (If unsure, please leave blank)

10. What was the cause of the problem? How was it resolved?

Appendix K: Images of Enhanced Assessment Matrix

Summary Page

SUMMARY		Highlight Top	1						
Sub	Supplier	System components	Rank	Final Score 100%	Price 18%	Warranty 19%	Quality 30%	Experience 17%	Cust Serv 16%
1	Aus1Energis	Risen/Goodwe	12	62.2%	18.0%	10.1%	19.1%	7.0%	8.0%
2	Aus1Energis	Risen/SolarEdge	14	58.5%	13.6%	10.1%	19.8%	7.0%	8.0%
3	City to Surf Solar Plus	Sunpower E327/Fronius	3	74.7%	13.4%	15.8%	22.6%	14.9%	8.0%
4	City to Surf Solar Plus	Sunpower P340/Enphase	6	71.7%	8.4%	15.5%	25.0%	14.9%	8.0%
5	Efficient Energy	Jinko/Fronius	5	72.9%	17.3%	12.9%	22.1%	8.6%	12.0%
6	Efficient Energy	Jinko/Enphase	7	70.6%	12.0%	12.9%	25.0%	8.6%	12.0%
7	Green Energy Options	JA Solar/Fronius	2	76.8%	15.6%	16.4%	22.5%	10.3%	12.0%
8	Green Energy Options	REC/Enphase	8	69.7%	6.2%	16.4%	24.8%	10.3%	12.0%
9	Massive Solar	Jinko/SMA	10	68.2%	14.4%	12.9%	21.4%	7.5%	12.0%
10	Massive Solar	Dortmund/Zeversolar	13	61.3%	17.9%	12.9%	11.0%	7.5%	12.0%
11	New Generation Solar	Risen/Growatt	15	58.3%	14.8%	10.1%	19.9%	9.5%	4.0%
12	New Generation Solar	JA Solar/Schneider	16	57.2%	12.7%	9.8%	21.2%	9.5%	4.0%
13	Radiant Energy Systems	Trina/Fronius	9	68.3%	15.6%	12.9%	19.9%	11.9%	8.0%
14	Radiant Energy Systems	Trina/Enphase	11	66.0%	10.4%	12.9%	22.8%	11.9%	8.0%
15	Sustainable Solar Services	ET/Zeversolar	4	73.5%	18.0%	12.9%	19.2%	11.4%	12.0%
16	Sustainable Solar Services	ET/Fronius	1	78.2%	17.0%	16.1%	21.7%	11.4%	12.0%

Application Specific Tab

Application Parameters		
	Enter Values	Equations
Average Global Horizontal Irradiance (kW/m^2):	1600.0	
Average High Temperature in Summer (°C):	22.5	
Average Low Temperature in Winter (°C):	6.7	
Average Annual Rainfall (mL):	60.7	
Within 25 km from Seashore (Yes or No):	Yes	
High Cost Constraints (Yes or No):	No	
Rooftop Space Constraints (Yes or No):	No	
Rooftops Affected by Shading (Yes or No):	No	
Inverter Preferance (String, Micro, None):	None	
Max Inverter to Array Capacity Ratio:	0.75	

Price Analysis Tab

Price Analysis

	A	B	C	D	E	F	G	H	I
4					Score	Array Capaci	Inverter Capacit	Price	Metric
5	Sub	Supplier	System Components	Notes		kW	kW	$	$/W
6	1	Aus1Energis	Risen/Goodwe		10.0	4.00	4.00	$3,699	$0.92
7	2	Aus1Energis	Risen/SolarEdge		6.5	4.00	4.00	$5,896	$1.47
8	3	City to Surf Solar Plus	Sunpower E327/Fronius		6.4	4.00	4.00	$5,980	$1.50
9	4	City to Surf Solar Plus	Sunpower P340/Enphase		3.5	3.24	3.24	$6,300	$1.94
10	5	Efficient Energy	Jinko/Fronius		8.6	4.00	4.00	$4,590	$1.15
11	6	Efficient Energy	Jinko/Enphase		5.6	3.68	3.68	$5,967	$1.62
12	7	Green Energy Options	JA Solar/Fronius		7.6	4.00	4.00	$5,190	$1.30
13	8	Green Energy Options	REC/Enphase		2.3	3.22	3.22	$6,890	$2.14
14	9	Massive Solar	Jinko/SMA		6.9	4.00	4.00	$5,625	$1.41
15	10	Massive Solar	Dortmund/Zeversolar		8.9	4.00	4.00	$4,370	$1.09
16	11	New Generation Solar	Risen/Growatt		7.2	4.00	4.00	$5,471	$1.37
17	12	New Generation Solar	JA Solar/Schneider		6.0	4.16	4.16	$6,473	$1.56
18	13	Radiant Energy Systems	Trina/Fronius		7.6	4.00	4.00	$5,200	$1.30
19	14	Radiant Energy Systems	Trina/Enphase		4.6	3.68	3.68	$6,512	$1.77
20	15	Sustainable Solar Service	ET/Zeversolar		9.6	4.00	4.00	$3,943	$0.99
21	16	Sustainable Solar Service	ET/Fronius		8.4	4.00	4.00	$4,694	$1.17

Warranty Analysis Tab

Warranty Analysis

	A	B	C	D	E	F	G	H	I	J	K	L	M
4					Total	Installation		Inverter		Panels			
5	Sub	Supplier	Product	Notes	out of 10	Years	Score (Out of 10)	Product (Years)	Score (Out of 10)	Product (Years)	Performance (Years)	Performance (% Level)	Score (Out of 10)
6	1	Aus1Energis	Risen/Goodwe		5.3	5	5.0	5	5.0	12	25	80	6.0
7	2	Aus1Energis	Risen/SolarEdge		5.3	5	5.0	5	5.0	12	25	80	6.0
8	3	City to Surf Solar Plus	Sunpower E327/Fronius		8.3	5	5.0	10	10.0	25	25	85	10.0
9	4	City to Surf Solar Plus	Sunpower P340/Enphase		8.1	5	5.0	10	10.0	25	25	80	9.4
10	5	Efficient Energy	Jinko/Fronius		6.8	5	5.0	10	10.0	10	25	80	5.4
11	6	Efficient Energy	Jinko/Enphase		6.8	5	5.0	10	10.0	10	25	80	5.4
12	7	Green Energy Options	JA Solar/Fronius		8.6	10	10.0	10	10.0	12	25	80	6.0
13	8	Green Energy Options	REC/Enphase		8.6	10	10.0	10	10.0	12	25	80	6.0
14	9	Massive Solar	Jinko/SMA		6.8	10	10.0	5	5.0	10	25	80	5.4
15	10	Massive Solar	Dortmund/Zeversolar		6.8	10	10.0	5	5.0	10	25	80	5.4
16	11	New Generation Solar	Risen/Growatt		5.3	5	5.0	5	5.0	12	25	80	6.0
17	12	New Generation Solar	JA Solar/Schneider		5.1	5	5.0	5	5.0	10	25	80	5.4

Quality Analysis Tab (First image: Panel Quality, Second Image: Inverter Quality)

Quality Analysis

1.666666667

			Total Out of 10	Panel: Brand, Model	Performance: Efficiency	Performance: Temp Coefficient	Performance: PTC Ratio (Model)	Performance: Yield / Perform Ratio (Brand)	Performance: Score (out of 10)	Reliability: Junction Box Protection IP___	Reliability: Glass Type: Tempered/ Thoughed	Reliability: Glass Type: High Transmit	Reliability: Glass Type: Anti-Reflection Coating	Reliability: Glass Type: Low Iron	Reliability: Company Reputation (out of 10)	Reliability: Reputation Notes	Reliability: Score (out of 10)
1	Aus1Energis	Risen/Goodwe	6.4	RSM60-6-260P	16.0%	-0.39%	89.12%	93.40%	7.5	67	Yes	Yes	Yes	Yes	6	No reports of failures.	8.1
2	Aus1Energis	Risen/SolarEdge	6.6	RSM60-6-260P	16.0%	-0.39%	89.12%	93.40%	7.5	67	Yes	Yes	Yes	Yes	6	No reports of failures.	8.1
3	City to Surf Solar Plus	Sunpower E327/Fronius	7.5	Sunpower E327	20.4%	-0.38%	92.17%	92.30%	9.3	65	Yes	Yes	Yes	No	8	Excellent panel	7.0
4	City to Surf Solar Plus	Sunpower P340/Enphase	8.3	Sunpower P340	16.5%	-0.37%	89.85%	92.30%	8.2	65	Yes	Yes	Yes	No	8	Excellent panel	7.0
5	Efficient Energy	Jinko/Fronius	7.4	Jinko JKM 260P -60	15.9%	-0.41%	91.62%	93.90%	7.5	67	Yes	Yes	No	Yes	7.5	Still fairly new panel	8.2
6	Efficient Energy	Jinko/Enphase	8.3	Jinko JKM 260P -60	15.9%	-0.41%	91.62%	93.90%	7.5	67	Yes	Yes	No	Yes	7.5	Still fairly new panel	8.2
7	Green Energy Options	JA Solar/Fronius	7.5	JA Solar JAM(L) 60 290	17.7%	-0.40%	91.90%	92.30%	8.0	67	Yes	Yes	No	Yes	7.5	Very good test results	8.2
8	Green Energy Options	REC/Enphase	8.3	REC 280TP Twin Peak	17.3%	-0.39%	92.64%	90.60%	8.0	67	No	No	Yes	No	8	Very good reputation	7.3
9	Massive Solar	Jinko/SMA	7.1	Jinko Solar Eagle 60P JKM280M-60	15.6%	-0.40%	91.86%	93.90%	7.7	67	Yes	Yes	Yes	Yes	7.5	A good midrange	8.8
10	Massive Solar	Dortmund/Zeversolar	3.7	Dortmund Energy DM-60	15.9%	-0.42%			2.4						4	New panel on the	1.9

Quality Analysis

			Inverter: Brand, Model	Performance: Efficiency	Performance: String or Micro	Performance: Number of PPT Strings	Performance: Max DC Input: Power (W)	Performance: Max DC Input: Voltage (V)	Performance: Max DC Input: Current (A)	Performance: Score (out of 10)	Reliability: Protection Class IP__	Reliability: Operating: Min (°C)	Reliability: Operating: Max (°C)	Reliability: Company Reputation (out of 10)	Reliability: Reputation Notes	Reliability: Score (out of 10)
1	Aus1Energis	Risen/Goodwe	GoodWe GW4000-NS	96.0%	String	1	5460	580	22	5.7	0	-25	60	7	No major reports of	4.2
2	Aus1Energis	Risen/SolarEdge	SolarEdge SE4000	97.5%	String	1	5400	350	15.5	5.9	65	-20	50	8	Premium inverter	4.9
3	City to Surf Solar Plus	Sunpower E327/Fronius	Fronius Primo 4.0-1	97.0%	String	2	6000	1000	12	7.2	65	-40	55	7.5	High end inverter	6.6
4	City to Surf Solar Plus	Sunpower P340/Enphase	Enphase, S-270	95.6%	micro	2	350	60	15	9.0	67	-40	65	8	No negative	9.0
5	Efficient Energy	Jinko/Fronius	Fronius Primo 4	97.0%	String	2	6000	1000	12	7.2	65	-40	55	7.5	High end inverter	6.6
6	Efficient Energy	Jinko/Enphase	Enphase s230	95.8%	micro	2	285	48	15	8.7	67	-40	65	8	No negative	9.0
7	Green Energy Options	JA Solar/Fronius	Fronius Primo 4.0-1	97.0%	String	2	6000	1000	12	7.2	65	-40	55	7.5	High end inverter	6.6
8	Green Energy Options	REC/Enphase	Enphase S230	95.8%	micro	2	285	48	15	8.7	67	-40	65	8	No negative	9.0
9	Massive Solar	Jinko/SMA	SMA Sunnyboy	96.4%	String	2	4200	750	15	6.5	65	-25	60	7	A good midrange	5.6
10	Massive Solar	Dortmund/Zeversolar	Zeversolar Zeverlution	96.5%	String	2	4650	600	11	6.3	65	-25	60	4	High failure rate	4.1

Installation Experience Tab

	A	B	C	D	E	F	G	H	I	J	K	L
1												
2												
3	***Sub***	***Supplier***	***Product***	***Total***	*CEC Accredited* ***(Yes or No)***		*Number of installs* ***(either number or capcacity)***		*Years experience of company*	*Use in-house installers* ***(Yes, No, or Sometimes)***	*Positive customer feedback* ***(out of 5)***	*Shipping Practices* ***(out of 5)***
4				out of 10	*Retailer*	*Installers*	*Amount*	*MW p.a.*				
5	**1**	**Aus1Energis**	**Risen/Goodwe**	**4.1**	**Yes**	**Yes**	**400**		**7**	**No**	**1**	**3**
6	**2**	**Aus1Energis**	**Risen/SolarEdge**	**4.1**	**Yes**	**Yes**	**400**		**7**	**No**	**1**	**3**
7	**3**	**City to Surf Solar Plus**	**Sunpower E327/Fronius**	**8.8**	**Yes**	**Yes**	**600**		**7**	**Yes**	**5**	**3**
8	**4**	**City to Surf Solar Plus**	**Sunpower P340/Enphase**	**8.8**	**Yes**	**Yes**	**600**		**7**	**Yes**	**5**	**3**
9	**5**	**Efficient Energy**	**Jinko/Fronius**	**5.1**	**No**	**Yes**	**1000**		**3**	**No**	**3**	**3**
10	**6**	**Efficient Energy**	**Jinko/Enphase**	**5.1**	**No**	**Yes**	**1000**		**3**	**No**	**3**	**3**
11	**7**	**Green Energy Options**	**JA Solar/Fronius**	**6.1**	**No**	**Yes**		**3**	**2**	**Yes**	**1**	**3**

	F	G	H	I	J	K	L	M	N
1									
2									
3	*redited* ***r No)***	*Number of installs* ***(either number or capcacity)***		*Years experience of company*	*Use in-house installers* ***(Yes, No, or Sometimes)***	*Positive customer feedback* ***(out of 5)***	*Shipping Practices* ***(out of 5)***	***Notes***	***Total***
4	*Installers*	*Amount*	*MW p.a.*						out of 10
5	**Yes**	**400**		**7**	**No**	**1**	**3**	Limited customer reviews available online. No information on history or number of installs available via their site or the tender documentation. Trades as "Energis" not Aus1 Energis.	**10.0**
6	**Yes**	**400**		**7**	**No**	**1**	**3**	Limited customer reviews available online. No information on history or number of installs available via their site or the tender documentation. Trades as "Energis" not Aus1 Energis.	**10.0**
7	**Yes**	**600**		**7**	**Yes**	**5**	**3**	10 reviews on SolarQuotes, all either 4 or 5 stars. Previously traded as Pritchett Electrical. Founded in 2008, over 1100 installs in greater Geelong area.	**10.0**
8	**Yes**	**600**		**7**	**Yes**	**5**	**3**	10 reviews on SolarQuotes, all either 4 or 5 stars. Previously traded as Pritchett Electrical. Founded in 2008, over 1100 installs in greater Geelong area.	**10.0**
9	**Yes**	**1000**		**3**	**No**	**3**	**3**	Very good online reviews from customers. Limited website with no information about installers, company history or installs per annum. Online customer reviews suggest they outsource to independant installers but the few customer responses were positive.	**10.0**
10	**Yes**	**1000**		**3**	**No**	**3**	**3**	Very good online reviews from customers. Limited website with no information about installers, company history or installs per annum. Online customer reviews suggest they outsource to independant installers but the few customer responses were positive.	**10.0**
11	**Yes**		**3**	**2**	**Yes**	**1**	**3**	Small local retailer. Good level of experience with over 500 installs between the small staff. Small number of customer reviews, all positive.	**9.0**

Customer Service Tab

	A	B	C	D	E	F	G	H
1								
2								
3–4	***Sub***	***Supplier***	***Product***	***Total*** out of 10	*Installation Warranty Covers Full Duration of Manufacturer Warranties* ***(Yes or No)***	*Manufacturer Takes Carrige of Warranty Claim* ***(Yes or No)***	*No Fee to Customer* ***(Yes or No)***	*Installer will Monitor Performance to Detect Fault* ***(Yes or No)***
5	**1**	**Aus1Energis**	**Risen/Goodwe**	**5.0**	**No**	**Yes**	**Yes**	**No**
6	**2**	**Aus1Energis**	**Risen/SolarEdge**	**5.0**	**No**	**Yes**	**Yes**	**No**
7	**3**	**City to Surf Solar Plus**	**Sunpower E327/Fronius**	**5.0**	**No**	**Yes**	**Yes**	**No**
8	**4**	**City to Surf Solar Plus**	**Sunpower P340/Enphase**	**5.0**	**No**	**Yes**	**Yes**	**No**
9	**5**	**Efficient Energy**	**Jinko/Fronius**	**7.5**	**No**	**Yes**	**Yes**	**Yes**
10	**6**	**Efficient Energy**	**Jinko/Enphase**	**7.5**	**No**	**Yes**	**Yes**	**Yes**
11	**7**	**Green Energy Options**	**JA Solar/Fronius**	**7.5**	**No**	**Yes**	**Yes**	**Yes**

	Notes	Comments
3–4	***Notes***	***Comments***
5	For manufacturer claims which fall outside of the installation warranty period, the customer should contact Aus1 Energis who will take carriage of the claim and liaise with the manufacturer on behalf of the customer.	This is about best practice. No fee to customer, Aus1 Energis will manage the process and seek re-compense from the manufacturer.
6	For manufacturer claims which fall outside of the installation warranty period, the customer should contact Aus1 Energis who will take carriage of the claim and liaise with the manufacturer on behalf of the customer.	This is about best practice. No fee to customer, Aus1 Energis will manage the process and seek re-compense from the manufacturer.
7	For manufacturer claims which fall outside of the installation warranty period, the customer should contact City 2 Surf who will take carriage of the claim and liaise with the manufacturer on behalf of the customer.	This is about best practice. No fee to customer, City to Surf Solar Plus will manage the process and seek re-compense from the manufacturer.
8	For manufacturer claims which fall outside of the installation warranty period, the customer should contact City 2 Surf who will take carriage of the claim and liaise with the manufacturer on behalf of the customer.	This is about best practice. No fee to customer, City to Surf Solar Plus will manage the process and seek re-compense from the manufacturer.
9	The customer can contact Clean Energy Solar who will enact a warranty claim on behalf of the club with the manufacturer if fault occurs outside of the installer warranty period. Clean Energy Solar will continue monitoring system's performance to detect if fault occurs.	This is about best practice. No fee to customer, Efficient Energy will manage the process and seek re-compense from the manufacturer.
10	The customer can contact Clean Energy Solar who will enact a warranty claim on behalf of the club with the manufacturer if fault occurs outside of the installer warranty period. Clean Energy Solar will continue monitoring system's performance to detect if fault occurs.	This is about best practice. No fee to customer, Efficient Energy will manage the process and seek re-compense from the manufacturer.
11	The customer can contact Green Energy Options who will enact a warranty claim on behalf of the club with the manufacturer if fault occurs outside of the installer warranty period. Clean Energy Solar will continue monitoring system's performance to detect if fault occurs.	This is about best practice. No fee to customer, Green Energy Options will manage the process and seek re-compense from the manufacturer.
	The customer can contact Green Energy Options who will enact a warranty claim on behalf of the club with the manufacturer if fault occurs outside of the installer warranty period. Clean Energy Solar will continue monitoring	This is about best practice. No fee to customer, Green Energy Options will manage the process and seek re-compense from the manufacturer.

Summary | Application Parameters | Price | Warranty | Quality | Installer Experience | CustSer

Appendix L: Images of Tender Request Document

Tender Request Form

Solar PV Submission Document

Instructions:

Please complete the pages for your submission and submit with your Request for Quotation.

PV Scenario 1 System Size Option 1

Contents | System Size Option 1

System Size Option 1

Please only submit no more than two (2) different X kW systems.

Please include all relevant data specification sheets for both panels and inverters with tender documentation.

Company name:		
Contact person name:		
	SYSTEM 1	SYSTEM 2
Panels		
Panel brand and model:		
Panel Manufacturer Location:		
Nearest Manufacturer Support Office:		
Size of each panel (Watts):		
Number of panels:		
Panel Certifications:		
Have the panels been subject to Electroluminescent (EL) testing? (Yes/No):		
If Yes, please provide the results of the testing (if available):		

19	**Inverter**		
20	**Inverter brand and model:**		
21	**Inverter Manufacturer Location:**		
22	**Nearest Manufacturer Support Office:**		
23	**Inverter capacity (kilowatts):**		
24	**Inverter Certifications:**		
25	**Is this a string inverter system or a microinverter system?**		
26	**If a string inverter system, does the system make use of optimisers?:**		
27			
28	**Cost (GST Inclusive)**		
29	**Total installed cost after discounts (incl STCs):**		
30	**Extra cost for tilt frames:**		
31	**Extra cost installation on 2nd storey:**		
32	**Please indicate additional costs here:**		
33	**Safety Switch**		
34	**Tiled roofs**		
35	**Other**		
36	**Other**		
37	**Other**		

39	**Warranty**		
40	**Panel 'Performance' Warranty (% at Year 10):**		
41	**Panel 'Performance' Warranty (% at Year 15):**		
42	**Panel 'Performance' Warranty (% at Year 25):**		
43	**Panel 'Product' Warranty (if applicable):**		
44	**Inverter 'Product' Warranty (years):**		
45	**Installation/Workmanship Warranty (years):**		
46			
47	**Please explain in detail the process for the consumer to enact the Panel or Inverter Warranty after the Installation Warranty has expired:**		

49	**Shipping**	
50	**Please explain in detail your company's shipping protocol (transportation, stacking of panels, number of panels per pallette, etc.):**	

Appendix M: Images of Solar Module Registry

	A	B	C	D	E	F	G	H	I	J
1			Electrical Data at STC						Thermal Ratings	
2	Brand (made in)	Model	Rated power (watts)	Voltage at max power	Current at max power	AC or DC output	Power tolerance	Panel efficiency (%)	Cell temp at which panel is	Power temp coefficient (%/°C)
3	AUO AC Solar Warehouse ph:1300 55 44 67 info@acsolarwarehouse.com www.acsolarwarehouse.com	PM060PW0	250-265	30.6-31.6	8.17-8.36	DC	0 +3%	15.4-16.3%	25	-0.39
4		PM072PW0	300-315 (310 to 320)	36.62-37.61	8.19-8.38	DC		16-16.5%	25	-0.43 (-0.41)
5		PM096B00	325-335	54.7	5.94-6.13	DC		19.90% - 20.40%	25	-0.33
6	Axitec (Asia)									

Solar Panel Buyers Guide ReNew | Contact info

	A	AB	AC	AD	AE	AF
1		Certifications				
2	Brand (made in)	IEC 61215 and 61730	UL 1703	Manufacturer Data Sheet	Australian Presence (HQ)	General Comments
3	AUO AC Solar Warehouse ph:1300 55 44 67 info@acsolarwarehouse.com www.acsolarwarehouse.com	1	1	http://solar.auo.com/download.php?file=..%2Fupload%2Fmedia%2FASFile%2Fbrochure%2FPM060PW0_EN.pdf		AUO was established in 1996and is a diversified technology manufacturer. In partnership with Sunpower, AUO produce the highest efficiency solar modules available on the market (20.3%).
4		1	1	http://www.auosolar.com/download.php?file=..%2Fupload%2Fmedia%2FASFile%2Fbrochure%2FPM072PW0_EN_TW.pdf		
5		1	1	https://cdn.enfsolar.com/Product/pdf/Crystalline/575e1fc1e8629.pdf		
6	Axitec (Asia)			http://krannich.com.au/w		

Solar Panel Buyers Guide ReNew | Contact info

Brand (made in)	Material Data							
	Cell type	Size in mm (L x W x T)	Weight (kg)	Cell Number	Glass Type	Glass Thickness	Frame Type	Junction Box Protection Class
AUO AC Solar Warehouse ph:1300 55 44 67 info@acsolarwarehouse.com www.acsolarwarehouse.com	Polycrystalline	1640 x 992 x 40	19	60	Highly transparent solar glass (hardened)	3.2 mm	Anodized Aluminium Alloy	IP67
		1956 x 992 x 40	22.5 (22.7)	72	Highly transparent solar glass (tempered)	3.2 mm	Anodized Aluminium Alloy	IP67
	Monocrystalline	1559 x 1046 x 46	18.6	96	High transmission tempered glass with AR-Tech	3.2 mm	Anodized Aluminium Alloy	IP67
Axitec (Asia)								

Brand (made in)	Warranty			Cost			Performance Data		
	Product Warranty (years)	Power Warranty (years)	Rated lifetime (years)	RRP Inc GST ($)	Cost per Watt ($)	Embodied energy (yrs)	Photon 2014 Ranking	California PTC	Choice Performance Ratio
AUO AC Solar Warehouse ph:1300 55 44 67 info@acsolarwarehouse.com www.acsolarwarehouse.com	10 years for materials and workmanship	10 Years of 90% Output Power, 25 Years of 80% Output Power	25	Prices will flunctuate with exchange rate. For most up-to-date pricing please contact AC Solar Warehouse				0.909615	
			25					0.894516	
			25					0.915455	
Axitec (Asia)		15 years manufacturer's							

Appendix N: Images of Inverter Registry

Manufacturer/supplier	Diversion capability	Efficiency (%)	Operating temperature range/derating	Display	Comms/connectability	Size (mm) W x H x D
Genius Power / Altronics www.altronics.com.au		>80	0-40°C	LCD		400 x 300 x 150
						450 x 300 x 190
						450 x 300 x 190
						600 x 415 x 260
Delta Energy Systems (Australia) ph:(03) 9543 3720 sales.australia@solar-inverter.com www.solar-inverter.com		97.0	-25°C - 60°C	LCD Interactive Display with push buttons	RS485	475 x 415 x 157
		97.5				475 x 415 x 155
		98.3				510 x 445 x 177

Grid interactive | Hybrid | Inverter chargers | Stand-alone | Contacts

Manufacturer/supplier	Model	Solar input voltage range	Operating voltage range	Power output (watts) Continuous	Power output (watts) Maximum	Oversizing capability
Genius Power / Altronics www.altronics.com.au	M 8139	120-275	120-275	800	-	
	M 8144			1600		
	M 8145			2400		
	M 8148			4000		
Delta Energy Systems (Australia) ph:(03) 9543 3720 sales.australia@solar-inverter.com www.solar-inverter.com	H3	125 - 550	125 - 500 (550)	3000	3000	3780
	H3A	100 - 550	100 - 500 (550)	3000	3000	3780
	H4A		100 - 500 (550)	4000	4000	5000
	H5A		100 - 500 (550)	5000	5000	6300
	M6A	200 - 1000	200 - 800	6300	6300	7500
	M10A		200 - 800	10500	10500	12500

Grid interactive | Hybrid | Inverter chargers | Stand-alone | Contacts

Manufacturer/supplier	Weight (Kg)	# phases	# PPT strings	Maximum DC input current	Protection Class	Cooling system	RRP ($)
Genius Power / Altronics www.altronics.com.au	14		1	>40A			$1,299
	24		1	>50A			$1,349
	32		1	>50A			$2,299
	49		1	>60A			$2,999
Delta Energy Systems (Australia) ph:(03) 9543 3720 sales.australia@solar-inverter.com www.solar-inverter.com	15	1	1	10A	IP65	Natural convection	POA
	21	1	2	20A			
		1	2	24A			
		1	2	24A			
	25	3	2	20A			
	26	3	2	25A			

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Manufacturer/supplier	Warranty	Manufacturer's PDF	Australian Presence	Comments
Genius Power / Altronics www.altronics.com.au	1 Year	http://download.altronics.com.au/files/docs_225.pdf		Pure Sine Wave, Standalone remote power inverter for 12/24V battery banks (no grid connection).
Delta Energy Systems (Australia) ph:(03) 9543 3720 sales.australia@solar-inverter.com www.solar-inverter.com	5 years	http://www.delta-es.com.au/solutions/renewable-energy-solutions/rpi-h32-5kw-pl-2/	20-21/45 Normanby Road Notting Hill, VIC 3168, Australia Tel: 1300 335 823	Transformerless 1 Phase Inverter, IP65 Built in AC/DC isolation
		http://www.delta-es.com.au/solutions/renewable-energy-solutions/rpi-h3a-2-5kw-pl/		Transformerless Single Phase Inverter, Dual MPP trackers, IP65 Protection, Built in AC/DC isolation switch and Power Limiting Options available, asymmetricsl loading, < 3% HD, Diecast Casing,
		http://www.delta-es.com.au/solutions/renewable-energy-		Transformerless 3 Phase Inverter, Dual MPPT IP65 Protection, Built in AC/DC isolation switch and Power Limiting, asymmetricsl loading, <

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Appendix P: Images of Continuous Reliability Survey

Solar Module and Inverter Failure Data Gathering Survey

1. Where is your solar photovoltaic system currently located?

- Victoria
- New South Wales
- Tasmania
- Northern Territory
- Australian Capital Territory
- South Australia
- Western Australia
- Queensland
- Prefer not to specify

Other (please specify)

2. What solar Installer did you use to acquire your panels? (If unsure leave blank)

3. Please share information about your solar panel array (if unsure please leave blank)

Brand and Model

Capacity (kW)

Mounting (roof, ground, etc)

4. Please share information about your solar inverter (if unsure please leave blank)

Brand and Model

Capacity (kW)

Type (String, micro, etc)

Location (inside, outside, etc)

5. Select the option that best describes your system

- ◯ Receives full sunlight all day
- ◯ Receives full sunlight most of the day, with limited shading
- ◯ Receives full sunlight some of the day, with a moderate amount of shading
- ◯ Receives full sunlight at limited times throughout the day
- ◯ System is consistently shaded

6. How many years have you owned your current solar photovoltaic system?

0 ——————————————— 30 [ ]

7. Have you had more than one issue with your system?

- ◯ Yes
- ◯ No

Next

If this question is answered "Yes", respondents are sent to the second set of questions 8-10

If the question is answered "No", they are sent to the first set of questions 8-11

Solar Module and Inverter Failure Data Gathering Survey

For respondents that answered "No" to Question 7

8. What part of your system failed?

- ◯ Inverter
- ◯ Module
- ◯ Other (please specify)

[ ]

9. When did your system failure occur? (in years after installation)

0 ——————————————— 30 [ ]

10. What was the cause of the problem? How was it resolved?

11. What parts of your system have failed?

- [ ] Inverter
- [ ] Module
- [ ] Other (please specify)

Prev Next

Survey ends here.

Solar Module and Inverter Failure Data Gathering Survey

For respondents that answered “Yes” to Question 7

8. When did these system failures occur? (in years after installation)

First Failure

Second Failure

Third Failure

Fourth Failure

Fifth Failure

9. What was the cause of the problem? How was it resolved?

First Failure:

Second Failure:

Third Failure:

Fourth Failure:

Fifth Failure:

10. Additional Comments:

Prev Done

Survey ends here.