BRANZ

ISSUE 609 BULLETIN

PHOTOVOLTAIC SYSTEMS FOR DWELLINGS

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- Photovoltaic systems for dwellings are typically small-scale systems that absorb sunlight and convert the energy into electricity.
- They are often grid connected, exporting surplus energy to the national electricity grid and allowing a dwelling to use grid energy as required.
- This bulletin describes the photovoltaic systems and grid connection and briefly addresses economic and sustainability issues.

1.0 INTRODUCTION

1.0.1 Photovoltaic (PV) systems connected to the national electricity grid are by far the most common type of domestic on-site electricity generation system in New Zealand.

1.0.2 Falling purchase costs of PV systems have led to a rapid increase in New Zealand's installed PV capacity. By the end of 2016, all PV generation (residential, commercial and industrial) totalled 48 megawatts (MW), up from just 8.2 MW at the end of 2013. While a significant increase, the contribution of PV generation to national energy demand remains very small at around 0.1% in 2016. Around 78% of installed capacity is in households.

1.0.3 Solar cells are the unit of generation. Multiple cells are encapsulated in solar panels or, much less commonly, in building elements such as roof tiles. A residential system is made up of panels on frames or solar roof tiles, cables and an inverter or controller. Grid-connected systems have one or two meters that record electricity imported and exported separately. Systems may or may not have batteries.

1.0.4 PV systems generate electricity from light, not heat, and perform better when thermally cooler in terms of generation. A 5 kilowatt (kW) system in Queenstown (July average temperature 4°C, February average 16°C) can generate as much energy per year as a similar system in Auckland (July average 11°C, February average 20°C) (Figure 1).

1.0.5 Higher solar intensity in summer and lower household electricity use mean that PV systems can generate surplus energy over summer. Reduced solar intensity in winter and typically higher electricity use mean a typical PV system will produce a smaller proportion of the electricity a household consumes in the middle of the year – perhaps a half or less.

1.0.6 However, a house can be optimised for PV generation by reducing electricity use such as:
- switching to other space-heating fuels such as gas, wood or wood pellets
- switching to solar thermal, gas or heat pump water heating.

1.0.7 To maximise the benefits of installing a PV system, building-related energy efficiency improvements should be made first. (Note that all the suggested interventions are sensible and worthwhile whether there is a PV system installed or not.) These may include:
- improving thermal insulation of the building envelope
- replacing single glazing with much higher-spec double glazing
- replacing very old electrical appliances with ENERGY STAR appliances
- replacing incandescent light bulbs with LED lighting
- where there is an electric storage water heater, ensuring it is insulated to the highest level.

1.0.8 As much as possible, PV electricity should be used on site when it is produced. Retailers' buy-back rates for surplus energy are considerably lower than the price of buying electricity from a retailer. The active management of household appliances to take advantage of generation times is called load shifting. However, the opportunities to load shift may be quite limited for some households.

2.0 REGULATORY REQUIREMENTS

2.0.1 Grid-connected PV systems must comply with AS/NZS 3000:2007 *Electrical installations* (known as the Australian/New Zealand Wiring Rules).

2.0.2 Solar panels and arrays (where panels are linked together) must comply with the following standards:
- AS/NZS 5033:2014 *Installation and safety requirements for photovoltaic (PV) arrays*. Designers and specifiers should not assume that all panels in the marketplace comply with this standard.
- AS/NZS 1170.2:2011 *Structural design actions – Part 2: Wind actions* (where the array is roof mounted), with a minimum 100 mm between panels and roof for ventilation.
- The international standard IEC 61730-1:2016 *Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction*. This demonstrates that a panel should meet electrical and mechanical operating safety requirements throughout its anticipated service life.

2.0.3 The inverter must comply with:
- AS/NZS 4777.1:2016 *Grid connection of energy systems via inverters – Part 1: Installation requirements*
- AS/NZS 4777.2:2015 *Grid connection of energy systems via inverters –Part 2: Inverter requirements*.

2.0.4 Grid-connected PV systems must meet the requirements in the Electricity Industry Participation Code 2010, in particular Part 6, which covers connection of distributed generation.

2.0.5 Stand-alone power systems must comply with AS/NZS 4509.1:2009 *Stand-alone power systems – Safety and installation*. Battery installations must meet AS 4086 *Secondary batteries for use with stand-alone power systems*.

2.0.6 Because the installation of a PV system typically requires a penetration through the roof or building envelope, a building consent is likely to be required – check with the council/local authority.

2.0.7 Consumers considering PV should check with their council before going ahead. They should also advise their lines company that a PV system is going to be installed and preferably discuss this with the electricity retailer beforehand.

2.0.8 After installation is complete, the electrician must issue an electrical works certificate, which

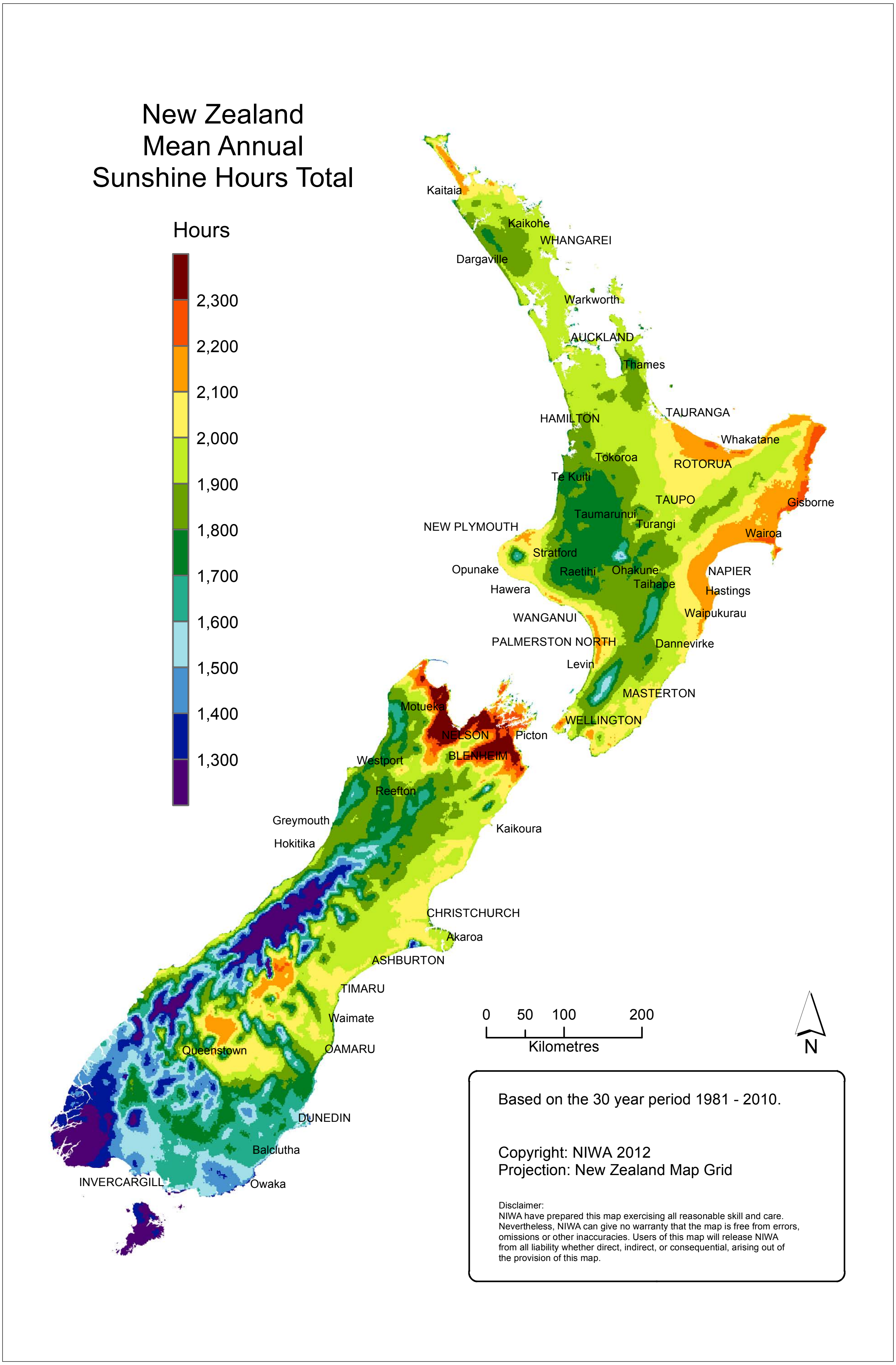

Figure 1. Solar intensity map of New Zealand. (Licensed under the NIWA Open Data Licence v1.0)

states that the work has been completed by a licensed electrician, meets legal requirements and has been tested for safety.

3.0 SOLAR PANELS AND ARRAY FRAMES AND SOLAR TILES

3.0.1 There are two main types of solar panel/module:

- Crystalline silicon solar cells have a solid silicon wafer as the semiconductor. The cells are sandwiched between tempered glass or plastic and a backing plate. There are two types – monocrystalline (which is more efficient) and polycrystalline.
- Amorphous silicon thin film solar cells have silicon in a thin film as the semiconductor on a substrate such as glass or a thin metal foil. The coating on top may be a flexible material (as opposed to glass), and they may use a flexible mounting system. These cells are being developed for integration with materials so they can be part of the building fabric.

3.0.2 Solar cells that produce energy have traditionally been installed in large flat panels. Individual panels are rated by their direct current (DC) output power, which typically ranges from 100 watts to over 300 watts. The panels are then installed in array frames, typically mounted on a north-facing roof, but they can be sited on the ground, a bank or a garage.

3.0.3 Tracking array frames can be used to provide more electrical energy throughout every day of the year by turning the panels to maximise solar exposure. The power used for tracking will normally be less than the additional power output obtained. Tracking works better in dry desert climates than in New Zealand's wetter and cloudier climates. These systems are more expensive and require more maintenance. Tracking frames are rarely worth it for micro-generation and are rarely specified. It is almost always more economical to fit more modules on to increase power output.

3.0.4 Solar cells are now available that are built into roof tiles that are fixed to battens in the same way as ordinary roof tiles. The old array frames that sit on top of a roof are not required. These new building-integrated photovoltaic (BIPV) options can potentially include many different types of building elements exposed to sunlight. At the time of the introduction of this technology into New Zealand, a 3 kW PV tile system cost around twice the price of a typical 3 kW system of solar panels, but costs are likely to fall over time.

4.0 INVERTERS

4.0.1 An inverter converts DC electricity from PV generation or battery storage to alternating current (AC) electricity, which is the form of electricity provided by the grid. Inverters can work with a stand-alone system or can be designed to work with a grid-tied system.

4.0.2 A grid-connected inverter is designed to disconnect the system from the grid when there is a utility power cut. This is so that no energy is fed into the grid, which would be a hazard for lines workers repairing the outage. Thus, in the event of a grid power cut, grid-tied PV homes will not have any power available from either electricity source.

4.0.3 Inverters are sized for the amount of power they can deal with. To allow for future expansion of a PV system, it is important not to undersize the inverter.

4.0.4 Alternatively, prospective PV owners can size the system to meet self-consumption, so as little as possible electricity is exported. Although larger PV systems are cheaper than smaller systems (in $/W terms), larger systems result in the exportation of more electricity due to oversizing. It is suggested that a careful evaluation of different-sized systems is carried out before purchase.

4.0.5 Inverters monitor energy generation and typically have displays showing how much electricity is being produced. Almost all can connect to a home Wi-Fi system, allowing performance to be checked remotely with a smartphone or computer.

4.0.6 A PV system will work with one of two types of inverter:

- A string inverter is a single unit that serves the whole solar array. It is typically mounted on a wall where it will be accessible.
- Micro-inverters are connected to each panel in the array.

4.0.7 There are strict technical requirements that inverters must meet – see section 2.0.3.

5.0 SYSTEM SIZE AND GENERATION CAPACITY

5.0.1 The choice of system size depends on:

- the amount of electricity a household consumes daily and peak loading requirements
- whether the system will be grid connected or include batteries
- the reduction required in purchased electricity
- the size and orientation of the area available for the panels to be located
- budget.

5.0.2 The unit used to measure electricity generation capacity of PV panels is the watt-peak (Wp), which is the panel's power output rating under standard test conditions.

5.0.3 Panels for home systems come in output capacity sizes up to 300 Wp and can be configured in any array size. An array of panels with a 2000 Wp rating may produce 4–10 kWh per day on sunny days with good solar gain. (Non-solar New Zealand households use an average of 22 kWh of electricity per day (but this can vary hugely). Energy-efficient houses that are optimised for PV generation should use considerably less. Most residential installations range from 1.5–5 kWp.

5.0.4 An indication of generation capability for a particular region can be found using an online calculator such as:

- EECA's Solar Calculator (www.energywise.govt.nz/tools/solar-calculator)
- BRANZ's Photovoltaic Generation Calculator, to estimate the output of a system (www.branz.co.nz/PVcalculator)
- NIWA's SolarView calculator, to work out the available solar energy at a particular location (https://solarview.niwa.co.nz/)
- NREL's PVWatts Calculator (http://pvwatts.nrel.gov/).

6.0 INSTALLATION

6.0.1 Installation must be carried out by a licensed electrician.

6.0.2 The site for the solar panels or tiles should ideally be northerly facing and not shaded by hills, chimneys, trees or neighbouring buildings.

6.0.3 Specifying the optimum year-round tilt angle can boost the generation capability of a PV system. The angle depends on latitude – it is around 20° above horizontal for Auckland and around 30° for Queenstown, for example.

6.0.4 Overproduction in summer and underproduction in winter may be countered by installing the panel at a greater angle closer to the incident angle of winter sun. This will reduce the solar production in summer but increase it in winter. The total yearly production will be reduced but potentially will allow better utilisation of the captured solar energy.

6.0.5 PV systems must have DC isolator switches between solar collectors (panels/tiles) and the inverter. These DC switches are specialised equipment and need to safely interrupt potentially large currents. Systems must also have AC isolator switches between the inverter and meter (Figure 2).

7.0 SUPPLYING THE GRID

7.0.1 With distributed generation (DG) systems, property owners generate their own electricity using a system that is also connected to the grid (Figure 2). Energy produced by the PV system that is not immediately used in the house is exported. Systems are typically around 3 kW for a single-phase installation and up to 10 kW for a three-phase domestic dwelling.

7.0.2 DG systems require an inverter that can be grid connected with correct voltage, correct frequency and a good waveform. The connection of the inverter is the concern of the lines company. Some lines companies have lists of compliant inverters on their websites.

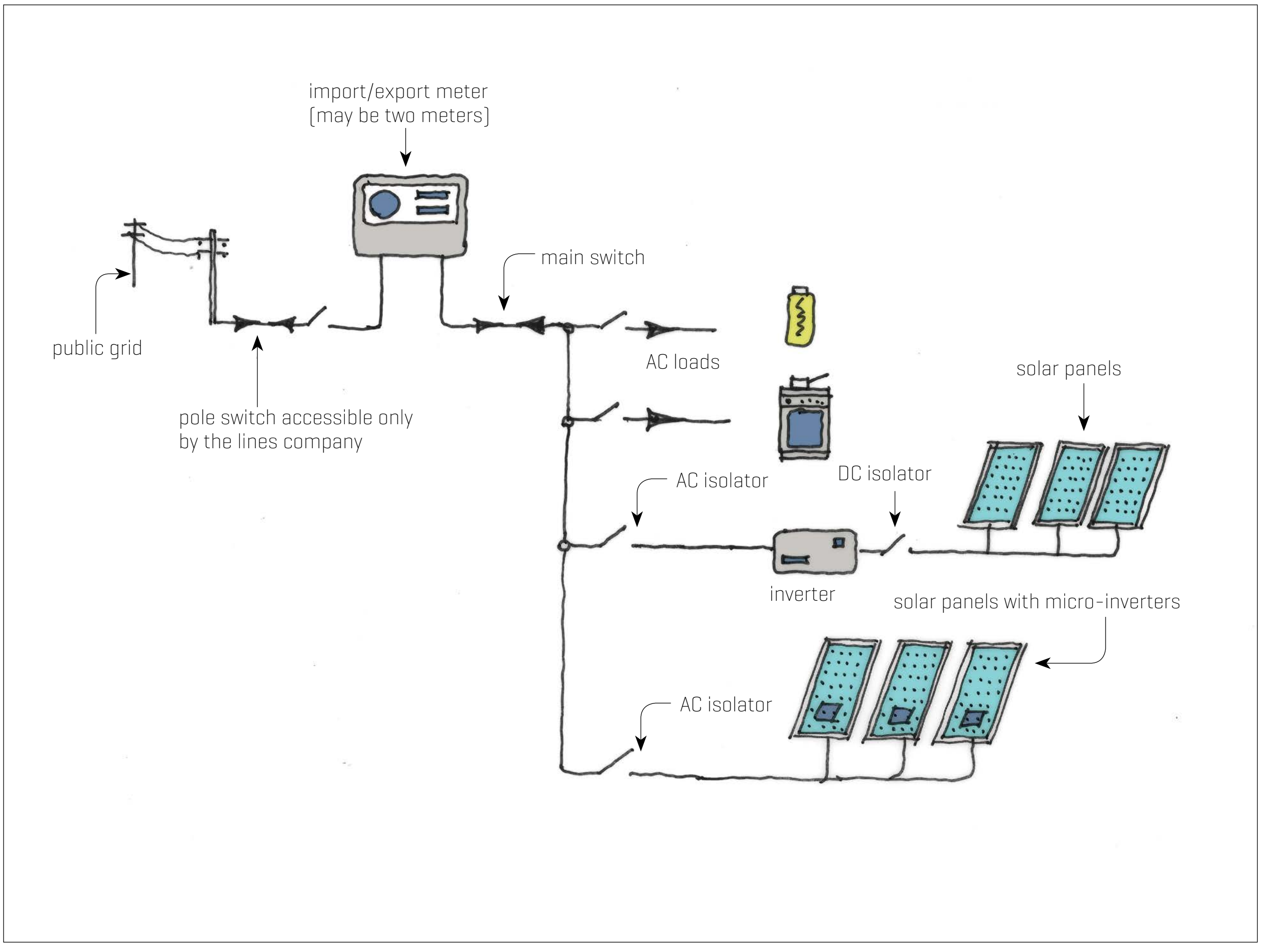

Figure 2. Schematic of typical grid-tied PV system. The main switch in the house is downstream from the meter.

However, under current rules, AS 4777-compliant inverters can still be used. This is likely to change in mid-2017 with an updated standard being released. DG systems also need one or two meters that separately measure the energy imported and exported. While some houses may have existing smart meters that can do this, others may need their electricity retailer to install a new meter. It is the electricity retailer that buys and sells the electricity.

7.0.3 A disadvantage of almost all DG systems is that the self-generated power supply stops if the grid fails. The self-generated system must disconnect from the grid so it does not cause lines somewhere else from becoming live during a grid failure. A solution is to incorporate a control system that activates the grid connection when the mains power is available but provides power from a battery bank via the inverter when the grid fails. However, this type of system will be more expensive and is much more viable for commercial applications where an uninterruptable power supply is required. Alternatively, there are some systems that can provide a small amount of power to the house for emergency purposes, even though the grid has failed.

7.0.4 Solar PV systems with battery storage are becoming more popular as battery costs fall. Electricity is still available when the grid fails. The size of the battery bank and loads on it determine the length of time electricity is available.

7.1 BUY-BACK ARRANGEMENTS

7.1.1 Householders wanting to sell surplus electricity will need agreements with both a power distribution (lines) company and an electricity retailer. The requirements are slightly different for systems with capacity of 10 kWh or less and those that are larger. The vast majority of residential installations will be in the smaller bracket.

7.1.2 Retailers are not compelled by law to buy electricity from any particular supplier, and they do not have to provide a fixed-term contract. There is no New Zealand standard regulating small-scale buy-back of electricity, and each retailer sets its own rules. As it is a competitive market, a PV owner can approach any retailer in a bid to sell their electricity. The retailer can choose whether or not they want to purchase it from them.

7.1.3 Retailers quote their buy-back rates in cents/kWh, the same as the selling price. It is common for retailers to reserve the right to change the price with 1 month's notice.

7.1.4 Contrary to popular belief, selling surplus electricity is not the best way to enhance the financial return on an investment in PV. This is chiefly because buy-back rates are relatively low. A study by IT Power calculated that, on average, during the 4 years ending 2016, households with PV saw a benefit of just $182 per year for electricity exported to the grid (Passey, Ngo, Watt & Henricksen, 2016).

7.1.5 To maximise financial benefits, electricity should be used in situ as it is generated as much as possible. This reduces the grid electricity that has to be bought at a comparatively high price. It would be opportune to operate storage water heaters, washing machines, dishwashers and other appliances and equipment when there is capacity in the PV system. There are controllers that can be installed as part of the system to manage these operations.

8.0 BATTERIES AND STAND-ALONE SYSTEMS

8.0.1 PV systems can be designed without batteries. Batteries are an expensive component and require maintenance. However, batteries provide resilience and ongoing electricity in the event of grid failure. A PV system without batteries can be connected to the grid, exporting unused electricity and importing energy from the grid as required, effectively using the grid as a battery.

8.0.2 Battery options include:
- vented and sealed lead acid – a common type of battery in existing systems
- absorbent glass mat (AGM) – a type of sealed dry-cell battery
- gel – the electrolyte is suspended in a thick paste
- lead-carbon
- lithium-ion – a newer and high-profile option (the early 2017 cost of a 14 kWh storage capacity household system, including installation, built-in inverter and GST, was around $10,500).

8.0.3 Battery systems or inverters for battery systems typically include a solar controller to modify the energy going from the solar panels into the batteries to maximise efficiency and reduce the risk of damage. Most newer controllers and inverters include maximum power point tracker (MPPT) circuits that can improve charging system efficiency by up to 30%. The MPPT converts the DC solar panel output to high-frequency AC, then converts it back to a DC voltage and current that better matches the panels to batteries.

8.1 STAND-ALONE ENERGY SYSTEM SIZING

8.1.1 The sizing of stand-alone systems is critical to a successful outcome. The calculation must be completed in detail. The household's current as well as expected power usage and habits must be analysed to calculate a daily or weekly power consumption figure and a peak demand requirement. This is best done by an experienced professional.

9.0 PV DEDICATED TO A STORAGE WATER HEATER

9.0.1 There are smaller PV systems available that do not make electricity available to the whole house but just to an electric storage water heater. With some systems, the connection is made at the switchboard.

Others use a simple controller only between the PV panels and the heating element itself. Electricity from the grid provides a heating boost when the PV energy is insufficient, but the PV system itself is not tied to the grid.

9.0.2 There are a few control systems for PV systems on the market that divert surplus power to the hot water cylinder element. These may, in some instances, increase the cost-effectiveness of PV (but not necessarily). More analysis is needed to investigate the claims made for these products.

10.0 MAINTENANCE

10.0.1 Solar panels/tiles should be checked for dirt or debris occasionally and washed gently with a hose or warm soapy water and a soft cloth or brush at least once a year. This should be done in the morning or late in the day when the panels/tiles are cool and the system is turned off.

11.0 THE ECONOMICS OF PV GENERATION

11.0.1 The 2016 purchase and installation cost of a 3 kW conventional PV panel/array system was around $9,000–10,000.

11.0.2 The IT Power study (Passey et al., 2016) calculated that, on average, during the 4 years ending 2016, households with installed solar PV reduced their electricity bills by around $647 per year. Solar systems are a long-term investment for most households that will generally break even at around 20–25 years, according to EECA estimations. Given this timeframe, the time value of money becomes important, and solar competes with alternative investments

11.0.3 A 2015 University of Canterbury study found that economic benefits exist for households that consume a lot of electricity and those that make substantial use of the energy during the day. Their ability to use more of the energy they produce reduces the amount of energy they have to purchase.

11.0.4 The University's EPECentre developed an online calculator through the GREEN Grid research programme, using data from NIWA's SolarView. The calculator estimates whether installing a PV system will be cost-effective for a consumer, based on their inputs into the tool. It considers geographic region, roof slope, current electricity use, the cost of a PV system and other factors. It then gives an estimate of the years it would take for the cost of a PV system to be repaid and the earnings or losses that would be incurred. The calculator is designed for typical New Zealand homes and is not applicable for commercial buildings or off-grid installations. It can be found at www.energywise.govt.nz/tools/solar-calculator.

11.0.5 SEANZ, representing the solar industry, is releasing a Solar PV Optimiser tool that provides up-to-date calculations but also real-time information on how to optimise self-generation to maximise the financial benefits of solar PV. The Optimiser is being released in early 2017 (see www.seanz.org.nz).

11.0.6 A Concept Consulting Group study in 2016 found that the cost-effectiveness of PV is very sensitive to amount and pattern of power use, panel size and house location. An analysis of over 1,000 potential combinations of these factors indicated that solar PV systems were unlikely to provide consumer cost savings in most situations under existing 2016 electricity tariff structures. However, they are likely to become increasingly attractive as panel prices decline further.

11.0.7 The study also considered batteries and found that they are unlikely to save consumers money based on existing prices but may become attractive in some situations as prices come down over time. It is difficult to gauge when that will be, but SEANZ expects battery uptake to increase exponentially as prices continue to reduce.

11.0.8 A PV system may give a small enhancement to property value. A BRANZ survey of real estate agents found that around half believed a PV system added value to a property but by an average of only $3,200, well below cost. A study of valuers found that around half believed the presence of solar panels would encourage a house purchase. Valuers believed that a PV system added $4,300–6,500 to the value of a house (Jaques, Norman & Page, 2015).

12.0 SUSTAINABILITY CONSIDERATIONS

12.0.1 To determine the environmental impacts a product or system has on the environment, comprehensive life cycle-based studies have to be carried out by independent agencies. In addition, societal and economic impacts must also be addressed and factored in to the overall sustainability equation. Although some informative studies have been made on solar micro-PV systems, the situation is complicated, and more studies are required to provide more definitive New Zealand-specific answers.

12.0.2 Much of New Zealand's electricity is already sustainably produced. Approximately 80% of electricity currently comes from renewable sources, including hydro, geothermal and wind. The government has a target of increasing this to 90% by 2025.

12.0.3 There is debate over PV's potential benefits to the sustainability of New Zealand's energy sector, reflecting the issue's complexity. The Concept Consulting Group study found that PV has limited potential to reduce greenhouse gas emissions. This is because electricity generation makes up little of New Zealand's total emissions, and PV's contribution to the reduction in electricity generation emissions would be small. However, the IT Power study found that, as PV uptake increases and battery uptake follows, households will contribute to reducing evening electricity consumption peaks and reducing greenhouse gas emissions. The authors stated, "These households will also be helping New Zealand to meet its renewable energy target." (p. 24)

12.0.4 Consumer surveys indicate that environmental concerns are not the primary driver for people installing PV systems. More people are seeking some control over their power supply, more independence from power companies and protection against possible future rises in the price of electricity. Conversely, a strong argument could be made that owners of grid-tied systems are less independent after installing PV, as they have no bargaining in terms of a buy-back rate in the competitive marketplace.

13.0 REFERENCES AND RESOURCES

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- Schwartfeger, L. & Miller, A. (2015). *Environmental aspects of photovoltaic solar power: The New Zealand context.* EEA Conference & Exhibition, 24–26 June, Wellington.

ONLINE RESOURCES

- BRANZ – www.branz.co.nz/PVcalculator and www.level.org.nz (the BRANZ sustainable building website)
- Consumer New Zealand – www.consumer.org.nz/articles/grid-tied-pv-systems
- Electricity Authority – Electricity Industry Participation Code 2010 https://www.ea.govt.nz/code-and-compliance/the-code
- Energywise – www.energywise.govt.nz/tools/solar-calculator
- NIWA – https://solarview.niwa.co.nz
- NREL – http://pvwatts.nrel.gov
- Sustainable Electricity Association of New Zealand (SEANZ) – www.seanz.org.nz
- University of Canterbury EPECentre (Electric Power Engineering Centre) – www.epecentre.ac.nz
- University of Otago Centre for Sustainability – www.otago.ac.nz/centre-sustainability/index.html

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