Photovoltaic (PV) design

This factsheet promotes and provides the information needed to incorporate and make proper use of a robust micro-renewable technology that can significantly offset your electricity needs as well as reduce your environmental footprint – photovoltaics (PVs).

THE DEFINITION of a robust technology is one that can provide significant benefits to the majority of New Zealand homes while also being both easy and low cost to design, install, use and maintain.

PVs were shortlisted by BRANZ from a wider set of micro-renewable technologies, which included wind and water turbines. Of these three technologies investigated, only PVs made the robust shortlist.

PVs should be integrated into homes that have been designed to be very energy efficient. By reducing energy demand, the effectiveness of this micro-generation technology can be maximised. Ways of effectively reducing energy demand are outside the scope of this factsheet, but useful references are provided in 'Supporting information'.

A glossary of terms is provided at the end of this factsheet.

What is a photovoltaic system?

A photovoltaic array is made up of light-sensitive panels that contain solar cells (see Figure 1). The cells consist of layers of a semiconductor material – typically silicon. Sunlight striking the cells causes electrons to move between the semiconductor layers, generating direct current (DC) electricity. This DC electricity needs to be transformed into alternating current (AC) electricity for ordinary household needs. This transformation process is carried out by an inverter. From the inverter, electricity is fed into the household switchboard, where it is distributed directly to the outlets/appliances that need it immediately.

Electricity produced by the PV array that is surplus to household needs is redirected to the grid and bought by the energy retailer. In this situation, where no electricity is stored at the house, the PV system is called grid-tied or grid-connected.

The electricity generation capacity of PVs is measured in watts peak (Wp), which is the panel's power output rating under standardised test conditions. Panels come in output capacity sizes up to 350 Wp and can be connected together in any array size. An array of panels with a 2,000 Wp rating may produce between 4 kilowatt-hours (kWh) and 10 kWh per day on sunny days. New Zealand households use an average of 22 kWh of electricity per day, with most residential PV installations ranging between 1–5 kWp of output.

The focus of this factsheet is on a typical set-up: a grid-tied, 2–4 kW sized, fixed-roof mounted, crystalline system with no electricity storage ability, where the network buys back the excess electricity. This set-up represents the majority of installed systems in New Zealand. Other PV system variants – such as stand-alone systems with batteries for longer-term electricity storage – are not included here primarily because they are far costlier per unit of energy generated or have specialised application.

Several key considerations must be followed to ensure the success of PVs in the field. This factsheet includes the findings of four New Zealand examples and provides much of the information needed to successfully design-in PVs in New Zealand homes.

Why use this technology?

Grid-tied PVs are a winner – provided they are properly specified, installed and monitored. They are simple to install, quiet, reliable as the sun, non-polluting, require very little maintenance throughout their lifetime, reduce a home's carbon footprint, may be a good longer-term financial investment and may add resilience to a home's energy supply. Although

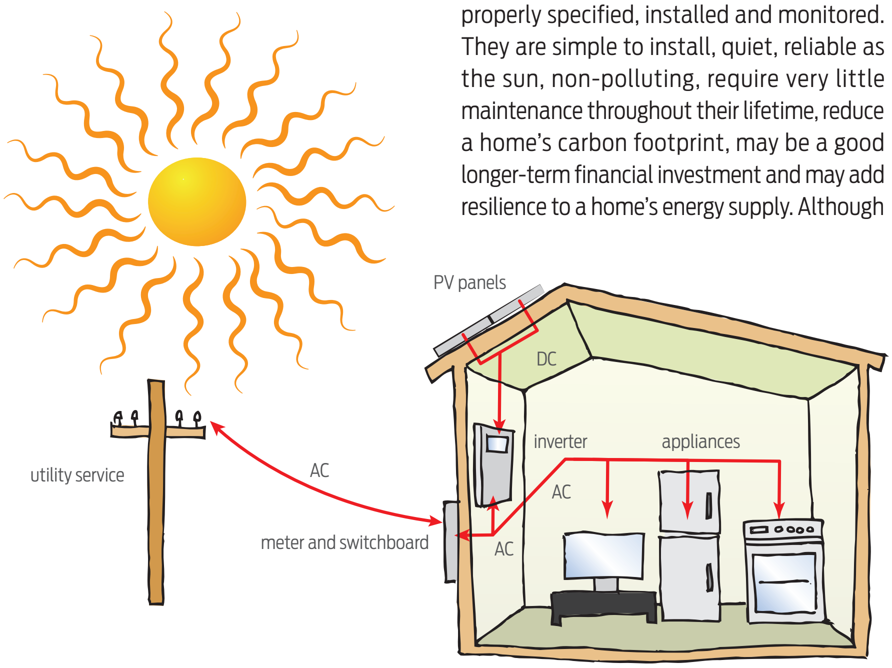

Figure 1. Schematic of typical grid-tied system showing key components and energy flows (red lines).

particularly well suited to sunny New Zealand climates that have few clouds, PVs are also feasible even in the most southern regions. Internationally, New Zealand stacks up very well in its solar potential, i.e. usability and intensity of sunshine hours.

The rapidly falling price of PV panels (less than New Zealand $1 per watt at the end of 2016, down from $1.25 at the end of 2012) mean that, for some situations, PVs are a good investment for domestic electricity generation. However, to ensure the best economic returns, a careful examination of the needs and expectations of the potential buyer as well as the solar potential of the site is strongly recommended.

User experiences

PV systems were recommended by all the New Zealand residential users surveyed by BRANZ. This quote is typical of their appreciation: "The panels provide energy reliably, silently, with little ongoing maintenance."

More survey responses from New Zealand users on key performance issues are found in Table 1.

All users were also asked about the initial installation cost of their PV system – the panels, inverter, wiring, consents, meters and substructure. This information has not been captured here, as the rapidly falling prices of the systems means historical prices are not useful.

Financial considerations (as at the end of 2016)

Determining the financial benefits of PV systems with any degree of accuracy is a challenging exercise, as some variables are important but are very difficult to predict. Assuming the PV goal is simply to maximise the financial returns of the system over its lifetime, the key variables become:

- any subsidies provided
- buy-back rate offered by the electricity retailer
- size, shading, orientation and slope of the panel set-up
- the amount of electricity the house uses during the day, which determines how much of the utility company's electricity can be displaced
- fault detection alert systems
- intended length of dwelling ownership
- to a lesser extent, type of panel used and inverter type.

It is strongly recommended that homeowners consider each of the variables above to gain a realistic appreciation of the issues associated with owning a PV system. Too often, the financial returns quoted by PV designers/installers are based on ideal conditions such as best possible orientation, no shading and high buy-back rates from retailers of electricity. This is usually not representative of reality and therefore overestimates the actual likely financial returns. The first four key variables above are examined in the following paragraphs.

Subsidies

In terms of financing options, Kiwibank offers a mortgage top-up and subsidy called Sustainable Energy Loan. This initiative provides up to $2,000 towards the cost of renewable systems such as PVs. Systems must be supplied and installed by a member of the Sustainable Electricity Association of New Zealand (SEANZ) or Solar Association of New Zealand (SANZ) and come with a 10-year warranty.

Buy-back rates

Typically, the more PV-generated electricity the residents make immediate use of, the greater the financial savings achieved and, therefore, the more cost-effective the PV system is. This is due to the utility pricing structure, which means that retailers typically pay less for the electricity you sell them than the electricity you buy from them.

Size, shading, orientation and slope of panel set-up

The size, shading, inclination (Figure 2) and orientation (Figure 3) of the panel set-up have a dramatic impact on the PV's output and, therefore, the resulting financial returns. In new homes where the renewables will be integral to the design process, it is likely that close to the ideal situation – where the panels are well sized, there is negligible shading and orientation is very close to true north – will be met fairly easily.

Utilisation rate

The utilisation rate describes how well electricity generated from the PV array matches electricity demanded by a particular house (Figure 4). In typical PV-equipped homes, there is a poor match between electricity generation and demand, since little electricity is needed around midday when the sun is shining brightest and PVs are producing the most electricity. Assuming that PVs are installed on more efficient homes with lower appliance loadings, there is less opportunity to reassign heavier appliance loadings to better match generation timings. Exceptions to this could be for time-delayed dishwasher and washing machine usage or where the site-generated electricity can be directly fed into the hot water cylinder element to top up hot water heating requirements.

Fault detection alert systems

The system's owner/user should be able to

Table 1. Key performance indicators of PV systems – from BRANZ interviews in 2011–2012.

House location	Q. What do you really like about the system?	Q. What is the annual maintenance cost?	Q. How reliable is the system?	Q. Would you recommend the system to others?
Auckland	For this set-up, it is amazing how little this system needs in terms of repairs. Although the inverter is a sophisticated system, there are no moving parts ... (being) solid state ... technology. Brilliant.	The new modules don't require any maintenance – due to its improved build quality.	Extremely reliable over 5 years. The reliability is further enhanced with the very good sunshine hours that Auckland experiences year round.	Absolutely. Mono-crystal is cheap as chips. As long as you follow some sensible guidelines in its installation, you will be able to get your maximum output.
Wellington	Silent, no hassle, no moving parts, low maintenance. ... Users become very aware of how to use energy effectively. Very important to look at the energy balance.	Battery water top-up twice yearly. Voltage drop check almost daily. However, the batteries will need replacement after several more years.	Very: haven't done any maintenance on the system apart from checking water and volt levels on the batteries.	Yes – PV is a good choice for micro-renewables, as it is a solid performer and very easy to live with.
Blenheim	It produces a lot of power – was surprised at how much and for how long they produced power. Installer very competent.	Installer comes around once a quarter for 15 minutes to have a check as part of his continued (free) service.	Very reliable as far as owners know.	PVs are a very simple technology – good for the average punter. Not much you have to do. No moving parts. Easy because it's simple.

manage the fault detection systems easily as a result of advances in technology and the user friendliness of the PV controls, monitoring and inverter provided as part of the PV generation package. Almost all systems now provide smartphone alerts.

Financial returns

An example case study of the estimated energy and financial returns of a typical grid-tied set-up in five cities has been provided here to give an idea of what conservative returns on investment might look like. All calculations were conducted using the highly customisable EnergyWise online calculator, freely available at www.energywise.govt.nz.

In the case study, the set-up had the following properties: 3 kW of panels costing a total of $9,500 to install. The panels are placed under ideal conditions: no shading, oriented dead north and on a 30º pitch roof. The electricity tariff is assumed to be close to the national average of 28c/kWh (including GST). The funding for the system comes from savings, with the buy-back rate for surplus electricity at 8c/kWh. The all-electric case study house uses approximately 13,600 kWh annually, independent of its location. In terms of user behaviour, electricity requirements are high for more than 5 days a week.

Three metrics are used to assess the viability of this set-up for each of the five locations presented here. However, in the online tool, many other metrics are displayed such as the solar energy generated versus that used on site. The three metrics are:

- simple pay-back – how long it would take to recoup the cost of solar through electricity cost savings if bank interest was ignored
- pay-back – how long it would take to recoup the cost of solar through electricity cost savings including bank interest
- the estimated total earnings over 25 years expressed in today's dollars (assuming no equipment replacement needed).

As can be seen in Table 2, the simple pay-back for each of these scenarios is at least a decade. For many potential homeowners, this is too long. This is all the more telling given that the panels are installed under ideal solar access conditions and most of the energy generated is self-consumed by the occupants.

However, it should be remembered that this is a simple tool, and it doesn't account for the ever-lowering cost of set-up, the rise

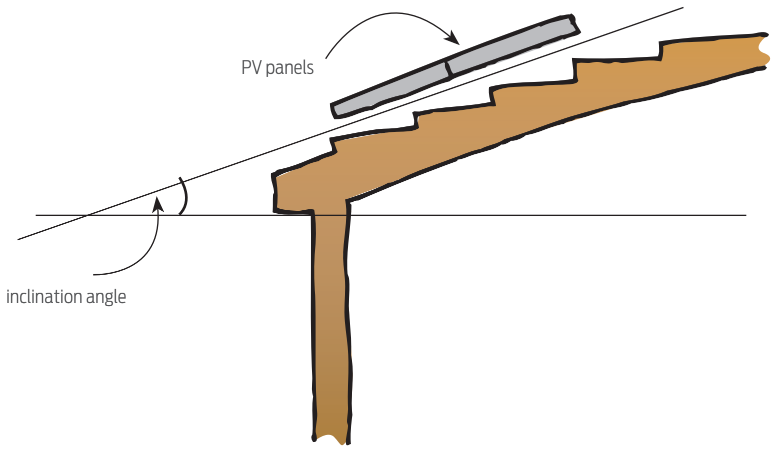

Figure 2. Cross-section of house showing inclination angle.

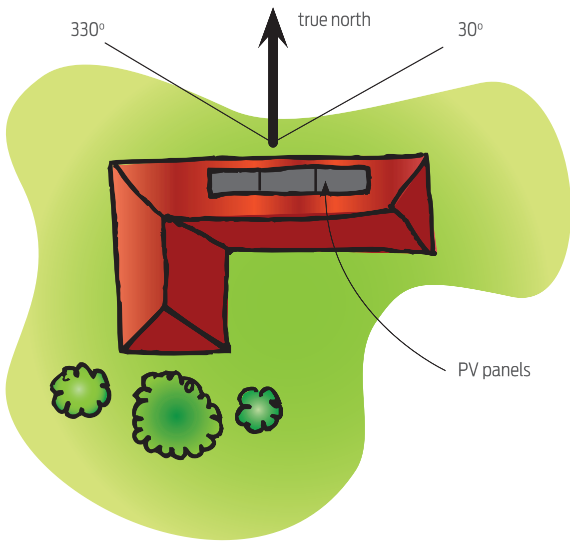

Figure 3. Plan view of house showing PV panel orientation.

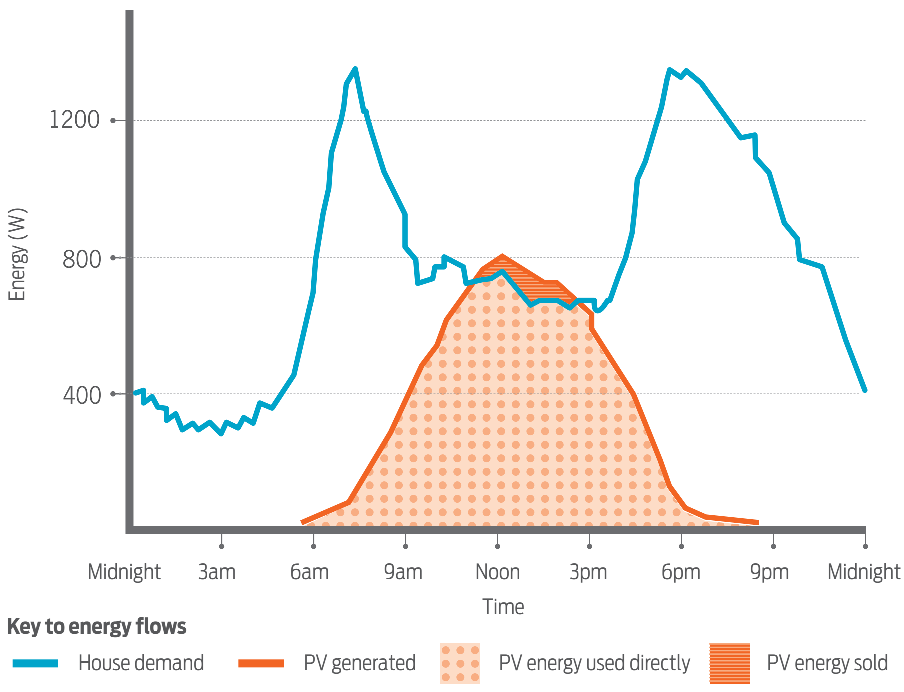

Figure 4. Typical grid-tied home's electricity flows and use.

of energy costs and the $2,000 Kiwibank subsidy, all of which would reduce the return on investment.

As a bare minimum, this calculator should be used by the potential investor in these energy generation systems.

If wider implications such as environmental issues (e.g. carbon dioxide) or the social implications of these systems are a concern, the very detailed Concept Consulting new technologies reports written in 2016 and 2017 should be read. (See 'Supporting information'.) These call into question preconceived notions about the environmental and social benefits of investing in solar PV – both with and without storage capability – for a variety of scenarios.

Table 2. Implications of a 3 kW array in five New Zealand cities.

	Pay-back (yr)		Estimated earnings over 25 years
	excluding interest	including interest	
Auckland	10	11	$9,800
Tauranga	10	11	$9,900
Wellington	11	13	$7,900
Christchurch	10	12	$8,700
Dunedin	12	14	$5,800

Strategies

The following strategies are for those interested in establishing households that generate their own electricity via a small-scale grid-tied PV system connected to a network that buys back the excess power.

Planning

To quickly estimate the annual PV electricity yield for any New Zealand location, the BRANZ Photovoltaic Generation Calculator should be used (see www.branz.co.nz/PVcalculator). The only details needed are solar panel type, location, orientation and roof slope. This estimation assumes no shading. To calculate the return on investment for your specific system, refer to www.pvcalc.org/pvcalc or www.energywise.govt.nz/tools/solar-calculator/.

Having an unshaded roof area for the PVs, of a suitable size, pitch and orientation, is the basic requirement for any PV set-up. If a suitable nearby roof is not available, a ground-based array may suffice. If the house/extension has yet to be built, orienting the house to maximise its solar exposure and installing a roof with the correct solar pitch can simplify the process considerably.

At the very start of the investigation, the current grid pricing for exporting renewables should be explored and realistic financial returns calculated. Any grid-tied photovoltaic system needs to be agreed to by both the lines company (for the connection) and the electricity retailer (for pricing arrangements).

Design

In terms of the area required for a PV array, about 6 m² is needed per kW installed for the crystalline modules, and module size is usually 1–4 kWp in capacity.

The positioning of the solar array is also critical – both in terms of the inclination (the slope should be latitude minus 10°) and orientation (the degrees away from true north). Table 3 shows the drop-off in performance from non-ideal situations (the green-shaded cells are the ideal).

Although it is possible to install PV modules on all roof types, generally, corrugated and trapezoidal long-run metal are the easiest, with timber shingles and tile roofs being more challenging and membrane-types being the most problematic. In retrofits, if the roof needs replacing within 10 years, it is suggested it is replaced at the time the PV system is installed to avoid the cost of removing and reinstalling the PV system.

The placement of a PV array to ensure minimal year-round shading between 9am and 3pm is critical for viable PV operation. This is especially true in winter when the sun is lower in the sky and objects such as trees, power poles, dormer windows, chimneys and TV aerials cast longer shadows.

Solar panels and their supporting structure must be installed to meet the requirements of wind and seismic loading, electrochemical corrosion with the different metals in the components and electrical safety issues and also allow for a cooling airflow of at least 100 mm behind the panels. Details of these issues are outside the scope of this factsheet but will be addressed by the accredited SEANZ installer.

In newbuild homes, wires from the PV panels to the inverter can be installed before interior walls are enclosed, reducing installation time and damage to plasterwork and hiding unsightly conduits. Also, the distances of wire runs can be minimised, reducing costs and increasing system efficiency. In existing buildings, installation is more challenging.

Establish and promote good relationships with the various contractors associated with the installation, such as PV consultants, roofers and electricians. Encouraging the PV installers to work closely with the other trade contractors helps successful project delivery. Good communication between trades results in better allocation of tasks and more economical construction.

Adequate indoor wall space to mount the inverter and other associated components is also required in the utility room or next to the electrical panel. Allow at least 1 m² of wall space for inverter and switch gear. The mounting area can be on a shelf or wall above the floor at a height that the unit can be easily read, with no direct sunlight on the unit and in a position that can be easily accessed in an emergency.

Installation

Installing PV systems presents a number of dangers to the installers and the building itself. Only appropriately qualified people should install PV systems. There are a number of technical standards relating to the design and installation of PV systems, which are mandated by the Electricity (Safety) Regulations 2010. PV suppliers (designers and installers) should be SEANZ accredited to ensure that outcomes are safe and energy efficient and that work meets the requirements of AS/NZS 4777 series *Grid connection of energy systems via inverters* and AS/NZS 5033:2014 *Installation and safety requirements for photovoltaic (PV) arrays*. Consent may be required for photovoltaic systems that penetrate the roof or are considered by neighbours to affect their property. This is at the discretion of the local council.

Proper roof mounting can be labour intensive, depending on the type of roof, accessibility, its angle of inclination and how the mounting brackets are installed and sealed to avoid water penetration and galvanic corrosion. Ask the PV supplier to ensure the best

Table 3. Performance of PV panels in non-optimum positions (after NZS 4614:1986 *Installation of domestic solar water heating systems*).

		Inclination angle					
	Direction	0°	20°	40°	60°	80°	90°
West	270°	0.85	0.85	0.80	0.72	0.60	0.53
	300°	0.85	0.92	0.92	0.86	0.73	0.65
	330°	0.85	0.98	0.99	0.93	0.80	0.71
True north	0°	0.85	0.97	1.00	0.94	0.80	0.70
	30°	0.85	0.94	0.95	0.88	0.74	0.65
	60°	0.85	0.88	0.86	0.77	0.65	0.57
East	90°	0.85	0.80	0.73	0.64	0.52	0.46

Ideal orientation Good orientation Poor orientation

racking system, based on the above factors and the PV panel manufacturer's support requirements. If installing a PV system on a new roof that is covered under warranty, the installer should ensure that adding a racking system with roof penetrations will not void the warranty.

A solar-ready kit, provided by some PV component suppliers and volume home builders, is the easiest way for a new house to be PV ready while minimising upfront costs. Typically, this service installs the cabling (from inverter to rooftop), inverter backing and essential switching for a minimal fee. When the owner is ready, it is a very simple task to finish off the system installation for the house's PVs to start generating electricity.

Maintenance and monitoring

Very little maintenance is required – just wiping panels with a clean, soft cloth when necessary. From time to time, the trimming of nearby trees may also be needed.

The option to have the inverter equipped with continuous PV system monitoring to provide instant feedback on performance and to provide alerts if something goes wrong is highly recommended for fast remediation. Monitoring now is comparatively easy, low or no cost and can be integrated with various smart devices such as smartphones, tablet computers and PCs. Usually, the monitoring systems rely on wifi and broadband.

Some PV retailers/installers will provide monitoring services as part of an ongoing contract. This depends on how engaged the owner wants to be. The type of inverter purchased has implications for the extent of monitoring service possible, so this needs some consideration.

Questions for the homeowner, architect and PV consultant to discuss

A variety of issues can have significant impacts on the financial viability of a PV system. Here are some key issues that need discussing to maximise a system's performance.

- What implications does the placement of a PV array have to ensure minimal year-round shading from landscaping and vegetation over the next 10 years or even 20+ years? What is the risk from neighbouring buildings (or gardens) causing obstructions during this time, and how can the risks be successfully managed?
- Does the ideal slope of the new house/garage roof have implications for the house/garage design?
- If the homeowner's needs or budget increase, how easy is it to increase the number of panels adjacent to the existing ones? Is it worth investing in oversized cabling and controls to make upgrades easy? Usually, this is as simple as seeing what the next biggest 1 kWp system requires.
- Some PV arrays might almost completely cover the roofing. If the roofing is metal, this has implications for the way the roof gets rain-washed. In coastal environments, what implications does this have on its longer-term durability and its manufacturer's warranty?
- Given the panels are likely to be highly exposed, what implications does their placement have on the aesthetics of the whole house?
- Inverters, which are usually located indoors, can produce a noticeable (rather than noisy) electrical hum. Therefore, they should be installed in a location where this will not disturb people. What restriction does this place on its indoor positioning?
- In terms of maintenance, most PV systems can get away with a half-yearly wiping down of their arrays with a soft cloth. How easy is it for the homeowner to access them safely?

Minimum criteria checklist for designers

For this technology to provide the best results for a typical New Zealand micro-generation set-up – a grid-tied, static, roof-mounted system with no electricity storage capability – some key design issues need to be addressed. These issues are set out below.

PVs should be integrated into homes that have been designed to be very energy efficient so that their effectiveness can be maximised.

Estimating the financial benefits of PV systems is challenging, as the most significant variable – the buy-back rate of the retailer – is also the most difficult one to predict into the future. If the installation is being carried out for non-financial reasons, there is a great deal of certainty around performance.

Consideration should be given to the following issues:

- Any subsidies provided, which might be provided by either the government or banks.
- The physical aspects of the installation, such as the size, slope, strength, potential for being shaded and orientation of the roof on which the panels are being installed; the potential to install the main cabling within the wall during the new-build process; and the size of the wall space needed to mount the inverter and other associated components.
- The predicted electricity demand of the house. Ideally, user demand should be minimised through behaviour change, more efficient appliance substitution or whole-house thermal improvements. Consequently, the micro-generation capacity would not need to be so substantial or expensive.
- The monitoring and alert features within the inverter chosen so that system checks can be easily made and problems quickly rectified over its lifetime.
- The flexibility of the system so that it is easy to add a panel or two to the existing system. Aspects such as practicality, cost and aesthetics need to be considered for this type of future addition.

These issues should all be discussed at length with your local SEANZ-accredited PV supplier.

Supporting information

These references are specifically chosen to ensure that the designer and user can gain unbiased, independent and relevant information on PVs.

- The BRANZ Level website for independent information: www.level.org.nz has a general introduction to micro-renewables and covers both grid-tied and off-grid systems.
- SEANZ (the Sustainable Electricity Association New Zealand): www.seanz.org.nz has resources on training, accreditation, standards and codes of conduct. Their *Small scale renewable energy standards guide* provides essential information on the design and installation of small-scale renewable energy systems.
- The BRANZ Photovoltaic Generation Calculator (www.branz.co.nz/PVcalculator) provides a fast and easy method of estimating the annual PV electricity yield for any New Zealand location.
- Jaques, R. 2013. *Uncommon energy technologies in NZ homes.* Conference paper for 4th International ASA Conference, Hong Kong, November 2013.
- Great 3D shading tools: SketchUp www.sketchup.com.
- Critical standards for industry: AS/NZS 5033:2016 *Installation and safety requirements for photovoltaic (PV) arrays* and AS/NZS 4777 series *Grid connection of energy systems via inverters*.
- EECA. 2010. *Power from the people: A guide to micro-generation.* Downloadable from www.eeca.govt.nz.
- Environmental, economic and social impacts of new technologies: Concept Consulting's new technologies reports can be downloaded for free on www.concept.co.nz/publications.html.

Glossary of terms

AC (alternating current)
An electric current that periodically reverses its direction. Most household electricity supply is AC.

array
A group of solar panels wired together.

base load power
The lowest continuous power demand that must be met by the network. It includes standby power (power drawn by an appliance when it is not in operation, such as to power clocks in microwave ovens) and appliances that operate continuously such as phone chargers and security systems.

DC (direct current)
Electric current that moves in one direction only. DC current is the current produced by PV cells.

grid-tied or grid-connected
A generation system that is connected to the local electricity network and can export excess electricity into the network.

inverter
The electrical device that converts DC electricity from generation sources such as photovoltaics into AC electricity that can be used by modern appliances.

kilowatt-hour (kWh)
The accumulated amount of energy used or produced. A PV array that has a rated capacity of 1 kilowatt will produce 1 kilowatt-hour of electricity in 1 hour of operation (under standard conditions).

panel
A group of photovoltaic cells wired together as one unit as a sheet.

watt (W)
A standard measure of power. Used to rate the production capacity of PVs and also the electricity requirements (or demand) of appliances.

watts peak (Wp)
The power output generated by a PV module under standardised test conditions.

This factsheet is part of a BRANZ series on the best-performing, unusual space-conditioning and micro-renewables technologies for the New Zealand situation.

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