Photovoltaic Solar Power Uptake in New Zealand

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Abstract

The GREEN Grid project is investigating the impact of solar power generation from photovoltaics (PV) connected to the low and medium voltage distribution networks. One of the goals of this research is to provide guidelines for adoption of PV in New Zealand, and modelling tools and techniques for distribution companies to better understand its impact on power quality within their networks. While collecting data from PV sites around New Zealand and considering how modelling in the distribution network should be conducted, the question of just how much PV is installed in New Zealand was asked. This paper presents the findings of a survey of 12 distribution company areas covering about 80% of New Zealand's population. It discusses the findings in the international context, and how PV might develop in the future in New Zealand. To obtain some idea of the adoption of PV in the future, and what the eventual installed capacity of PV might be, the Bass Diffusion Model, used to study new product diffusion, has been applied to the uptake data.

1. Introduction

Solar power generation from photovoltaics (PV) is receiving a lot of attention in New Zealand from many sectors. This includes local body and national politicians promoting clean renewable energy, PV suppliers and installers marketing PV heavily to homeowners, homeowners and businesses installing solar systems, and distribution companies who are keen to both understand the consequences of increasing distributed generation in the low voltage network, and embrace the technology. The GREEN Grid project is developing modelling tools to assess PV in the low and medium voltage networks. The aim of this is to better understand the impact of PV, and to feed into standards or guidelines for its adoption in New Zealand. In order to develop scenarios for modelling, the uptake of PV has been assessed per distribution company, and generalised to New Zealand regions. This paper reports the findings of the PV uptake assessment. It starts by summarising the methodology used in the study, followed by a discussion of PV sites in New Zealand to date. Various statistics of PV uptake are considered, and New Zealand's uptake is compared to that of other countries. The paper then considers what the ultimate uptake of PV in New Zealand might be, and considers the returns from PV in various parts of New Zealand. It is concluded with a discussion that includes the consequences of a large installed capacity of PV generation.

2. Study Methodology and Data

The PV uptake study was undertaken in October 2013 by obtaining data from distribution companies on all PV sites applied for in their networks from 2003 to date. The data covers the period January 2003 to December 2013. Two further distribution companies were added in 2014: Marlborough Lines and Network Tasman. The distribution companies include:

1. Vector
2. WEL Networks
3. Unison
4. PowerCo
5. Wellington Electricity
6. Marlborough Lines
7. Network Tasman
8. Orion
9. Aurora

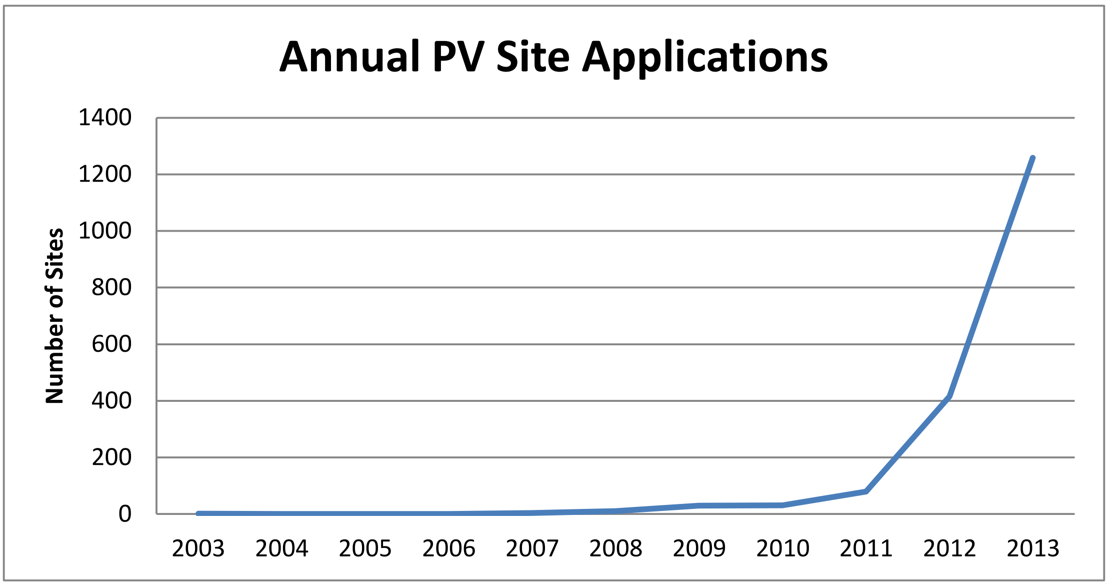
which covers about 80% of New Zealand's population. In order to annualise 2013's data, the applications in the last quarter of 2013 were assumed to be the average of the first three quarters of 2013. This assumption is conservative.

This study required data from distribution companies on their customers' applications for PV system connection to the distribution network (the Application). The most reliable data available is the Application; information about commissioned sites is not as easily available, because not all customers inform their distribution company once a site has been commissioned. Hence Application data is used in this study to give the date and size of the installation. This assumes that all Applications become commissioned and operational sites. A study of available data by the author showed that the large majority of sites are commissioned (over 95%), and the average time between application and commissioning for most sites is between two and three months. In order to examine PV uptake by population and number of connections (ICPs), the regional centres' populations were obtained from Statistics New Zealand [1], and the ICP connections were obtained from the distribution companies.

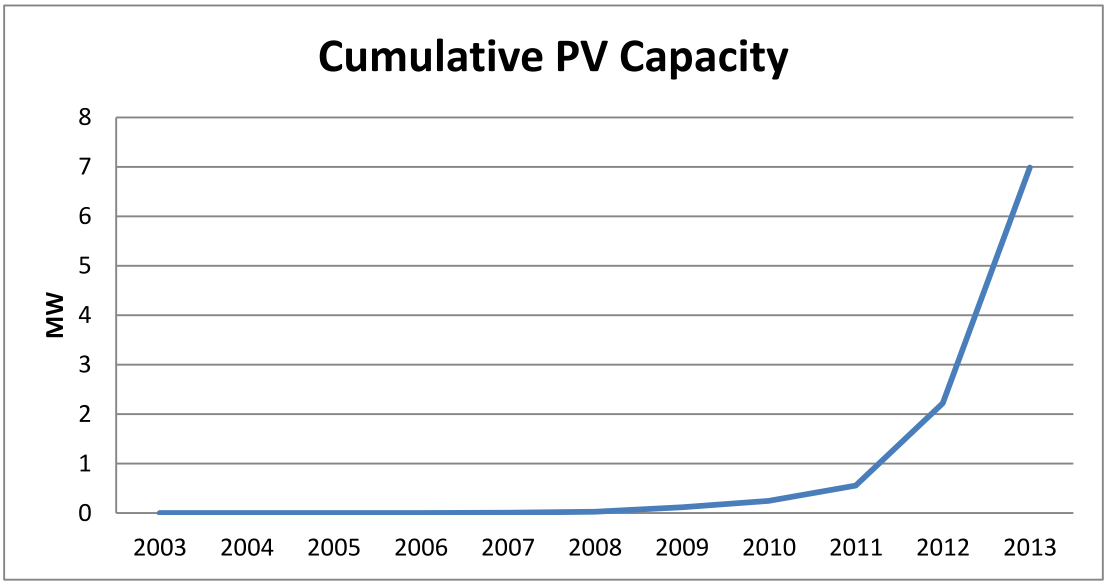
The above provided the data for the core of the uptake study. It also enabled the authors to examine the trends and extrapolate them to future potential uptake. An update of costs of PV systems was made from data available from manufacturers, and the cost savings from PV in the various main centres was determined from the model developed for reference [2].

3. PV Sites in NZ to date

For the distribution companies who provided data, the number of PV site applications and cumulative capacity is shown in Figure 1. The number of applications is clearly increasing dramatically, by a factor of three to four per year, with a corresponding increase in cumulative capacity. The average size of a PV system across New Zealand is given in Table 1. This shows an increase over time up to 2010, where it appears to have stabilised at around 3.8 to 4kW. The average PV size for a household will be slightly smaller than this, as the Applications contain a small number of large Applications, ranging from 10kW to 99kW. However the vast majority of Applications are from households.



(a)



(b)

Figure 1: PV in New Zealand: (a) Annual PV applications, (b) Capacity of cumulative PV applications.

Table 1: Average PV application size.

Year	Average Size (kW)
2007	1.3
2008	2.0
2009	3.0
2010	4.2
2011	3.9
2012	4.0
2013	3.8

Finally an indication of per capita installed PV capacity and per ICP capacity is given in Table 2. This shows a tripling of per capita PV in each of the last three years, which is not surprising given the rapid uptake of PV. As shown in Table 3 there is some variation between New Zealand's regions. Most of the regions fall in the range of 1.5 to 2.0 Watts per inhabitant, Wellington is lower at 0.7 Watts per inhabitant, and all exceeded by Marlborough at 7.1 and Tasman at 9.2 Watts per inhabitant in 2013. Contrasting this is the installed PV capacity in other parts of the world, obtained from [3], and summarised in Table 4. This shows that New Zealand is a long way behind many other parts of the world with PV uptake. The reason why some parts of the world are so far ahead is heavy subsidies for PV, generally through attractive feed-in tariffs.

Table 2: New Zealand’s per capita and ICP installed PV capacity.

Year	Watts per Inhabitant	Watts per ICP
2008	0.0	0.0
2009	0.0	0.1
2010	0.1	0.2
2011	0.2	0.4
2012	0.6	1.5
2013	1.9	4.6

Table 3: 2013 per capita and ICP installed PV capacity by region.

<table>
<tr><td>Area</td><td>Watts per Inhabitant</td><td>Watts per ICP</td></tr>
<tr><td>Auckland</td><td>1.5</td><td>0.7</td></tr>
<tr><td>Waikato</td><td>1.9</td><td>1.1</td></tr>
<tr><td>Hawkes Bay</td><td>1.5</td><td rowspan="2">0.7</td></tr>
<tr><td>Taupo Area</td><td>1.1</td></tr>
<tr><td>Wellington</td><td>0.7</td><td>0.5</td></tr>
<tr><td>Tasman</td><td>9.2</td><td>3.0</td></tr>
<tr><td>Marlborough</td><td>7.1</td><td>1.9</td></tr>
<tr><td>Canterbury</td><td>1.7</td><td>1.0</td></tr>
</table>

Table 4: Per capita installed PV capacity in other countries [3].

Country	Watts per Inhabitant (2013)
Germany	440
Italy	293
Belgium	267
Bulgaria	140
Australia	139
Spain	119
Japan	107
Denmark	95
Switzerland	91
France	70
Austria	68
Israel	51
UK	46
Netherlands	39
USA	38
Canada	34
South Korea	29
Portugal	27
Taiwan	16
China	13
Thailand	11
Sweden	4
Malaysia	2
Norway	2
India	2
Mexico	1
Turkey	0

4. What might the future uptake of PV be?

The previous section looked at PV applications and their capacity to date. They show a dramatic increase in the number of PV sites installed, and therefore the capacity. This raises the question: how long will this rate of uptake continue, and what will the eventual installed capacity be? The GREEN Grid project has attempted to answer this question in three ways:

1. A simple exponential fit to the existing data, with an extrapolation into the future – the results of which must be interpreted very carefully;
2. Examination of New Zealand's housing stock to ascertain the potential for PV installation, from such parameters as house location, orientation, and roof area. This work is still underway and will be published at a later date; and
3. Application of the Bass diffusion model, to model the diffusion of a new technology (PV in this case) into a market.

The GREEN Grid project has used a variety of ways to gain an indication of the likely range of PV uptake, and to attempt to validate any estimates.

The exponential extrapolation of the known uptake data to date, as cumulative capacity, is shown in Figure 2. The extrapolation was stopped at 2018, as this represents 372 watts per inhabitant (at today's population), and about 43% of houses with PV. This seems unrealistic, certainly in the space of a year. Hence 2017 might be more realistic, at 116 Watts per inhabitant and 13% of houses with PV, giving a total of 753MW of PV. The data in Table 4 suggests that either of these capacities is possible, although the rate of uptake may be slower with the lack of subsidised feed-in tariffs – so the capacity of almost 1GW may be reached later.

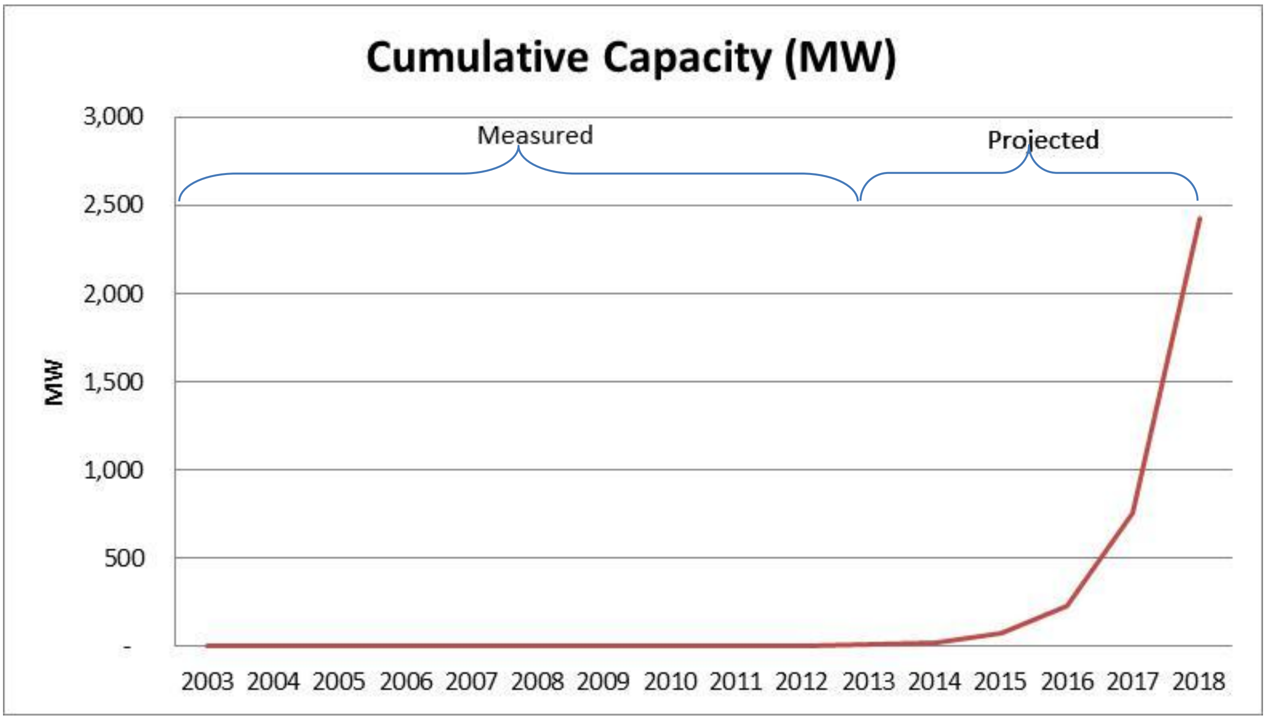


Figure 2: Exponential projection of cumulative PV capacity.

4.1 Bass Diffusion Modelling

PV is a relatively new innovation in society, and in this section we have attempted to model the spread of PV through the population, based on the uptake data to date (as PV units installed). In general the spread of a new innovation starts slowly, and then increases rapidly, as shown in the PV uptake in New Zealand to date. After this the acceleration decreases, and slows to zero when the market is fully penetrated.

The Bass Diffusion Model (BDM) was first proposed by Frank Bass in 1969 [4]. The basic BDM uses a differential equation to model uptake of new technology, with a coefficient of innovation influenced primarily by information from non-personal sources (such as advertising) and a coefficient of imitation, which relates to those whose decision to adopt is based on observation of whether others have adopted the innovation ("word of mouth" or vicarious learning).

In this section we are concerned with applying the BDM to the PV uptake data collected to date. Monthly uptake data is used, as the annual data contains insufficient information for the numerical methods of integration used for parameter estimation to work. Using a non-linear regression method the diffusion model fit to the PV uptake data is shown in Figure 3, which shows the actual and predicted sales (i.e. applications) per month (top panel) and cumulative sales to date (bottom panel). This shows full market penetration of 8,000 PV units. Based on an average size of 3.8kW per PV unit, this equates to about 30MW of installed PV capacity. Also the coefficient of innovation is near zero, implying the sales growth is driven largely by personal sources ("word of mouth" and direct observation) rather than institutional sources (e.g. advertising).

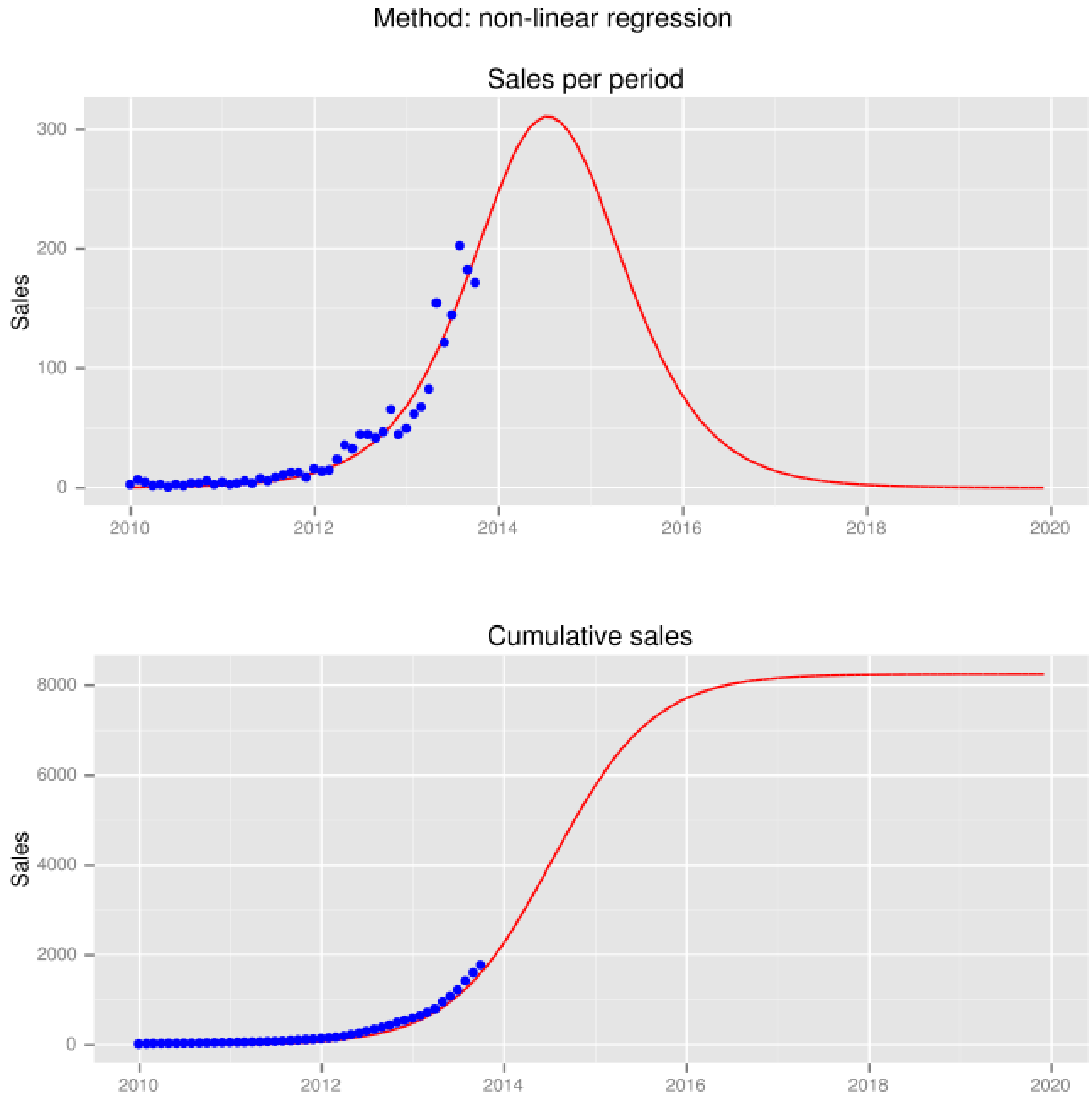


Figure 3: Bass diffusion of PV uptake.

The fit of the model to the data is very good: the R^2 for cumulative applications is over 99%. However it is important to note that the BDM models the data at hand, reflecting the conditions under which the data were collected. Consequently it cannot take into account expected future conditions, especially increasing economic incentives due to, in particular, technological improvements and increasing opportunity costs (i.e. relative cost of alternative energy sources). Also, many innovations undergo step-changes when they reach a critical mass, for example when penetration reaches a level such that on a typical commute to work most people would be guaranteed of seeing at least one or two solar arrays. It is for these reasons that the BDM forecasts are lower than what might be expected. However the forecast is almost certainly more realistic than a simple exponential fit, which assumes monotonic increase, asymptotically approaching infinite sales per period. This is why it has been essential to truncate the exponential series by examining the implications of its results, such as per capita capacity and percentage of houses with PV.

4.2 PV Uptake Discussion

The two models applied show a substantial difference between potential uptakes of PV. The simple exponential model, with some thought applied in terms of when to stop it, shows that the ultimate uptake could be about 753MW, representing about 13% of houses, and giving 118 Watts per inhabitant. The BDM model suggests an uptake of 30MW, which gives about 7 Watts per inhabitant. Data from Europe suggests it will be higher than this. Furthermore, there is evidence of commercial operations, such as wineries in the Marlborough region, installing large PV arrays in the order of 50 to 100kW. Once commercial operations begin installing PV in large volumes, basing the market penetration on housing stock alone is less reliable, suggesting that PV capacity could go beyond the 753MW predicted by the exponential graph. It is extremely difficult to forecast, and fraught with dangers. What we do know is that PV uptake is growing rapidly at present.

5. PV System Returns

The cost of PV systems appears to be declining, although this is very difficult to ascertain accurately. In 2013 we reported an install cost in excess of $4 per Watt [2], and some anecdotal evidence shows that has dropped to about $3 per Watt. Given the large regional variation in uptake, discussed previously, the cost savings by region are of interest. The model used to derive results for [2] was used to give cost savings for houses in each of the cities listed in Table 5. In order to enable comparison between each of these results, all other variables here held constant between the centres. These include: an average daytime household load of 600 Watts, a PV system size of 3kW, a daytime electricity price of $25 c/kWh, a panel tilt of 30^{o}, and for a true north facing site. As shown in Table 5 there is quite a variation between cities, up to 25%. This is entirely due to the difference in insolation (which varies with latitude) and average cloud cover between those cities, as obtained from the NIWA data discussed in [2].

Table 5: Difference in savings for the same 3kW PV system and house (600 Watts average daytime load) across New Zealand. The Watts per inhabitant is taken from Table 3 to enable comparison of annual savings with PV uptake.

City	Annual Savings	Watts per Inhabitant (surrounding region)
Auckland	$800	1.5
Hamilton	$790	1.9
Tauranga	$790	
Masterton	$780	
Taupo	$780	1.1
Hastings	$800	1.5
Wellington	$750	0.7
Blenheim	$850	7.1
Nelson	$850	9.2
Christchurch	$750	1.7
Dunedin	$675	
Invercargill	$675	

6. Discussion and Conclusion

We can only give bounds for future PV uptake at present, which may be between 30MW and 1GW. It is far too early to tell this reliably, which is why GREEN Grid intends to repeat this exercise annually. A simple exponential mode of uptake (assuming growth without end) gives forecasts that are evidently too high, while a more realistic model (the BDM) gives predictions which appear too low. It is very difficult to apply the BDM, as New Zealand is at too early a stage of adoption, and we may not be near the point of inflection. (i.e when the rate of increase of sales per period starts to decline). The parameters of the BDM can be either estimated directly from the data (as we have done here), or simply specified by the analyst. In such cases, likely values of the parameters can be sourced from "similar" products. In our case that would be PV adoption in comparable economies. However identifying such similar cases is difficult, and work is not complete at the time of writing.

The 2013 New Zealand Census included a question about heating of peoples' dwellings, which included "solar heating equipment" as an option [7]. About 0.5% of respondents (roughly 8,000 homes) ticked this option, however solar may include solar hot water, passive solar, and photovoltaics. Therefore this does not provide validation of the PV uptake results, or information able to project them.

Costs of PV are reducing each year; hence PV is only likely to increase in popularity. Results show an uneven uptake of PV around NZ, skewed towards areas with high sunshine hours and active promotion such as through economic incentives. This is not surprising given that the returns from PV in those areas is as much as 25% higher than areas with fewer sunshine hours. If PV in New Zealand does grow to 1GW, this represents about 10% of today's installed generation capacity. However, with a capacity factor of about 15%, PV is only likely to generate 2-3% of NZ's electrical energy needs. In turn this will increase the variability of electricity supply as the sun shines, or is shaded by clouds. GREEN Grid sets out to understand the potential variability and to determine ways to deal with it.

GREEN Grid also sets out to find ways of modelling PV, and other distributed renewable generation, in the low and medium voltage networks. Work in this area to date has involved a working group comprising researchers from the University of Canterbury, University of Auckland, and distribution company technical representatives, as well as the development of modelling tools.

7. Acknowledgement

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