The Economics and Potential Uptake of PV Solar Power by Region and PV System Cost

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In 2015 the GREEN Grid project examined the economics of Photovoltaic solar power (PV) to residential users, commercial users, and utility companies. They found that for a certain number of residential households, PV was already financially viable. They also found that the financial viability was highly dependent on local irradiation, nature of the household load, access to capital, and cost of the PV system. Given that people are more likely to install solar when it becomes financial viable to do so, by exploring the factors affecting financial viability, potential uptake can be inferred. This paper extends the economics of PV to residential users to all regions of New Zealand, to understand the local irradiation and retail electricity pricing components, uses a greater sample of households' load profiles, and looks at the potential uptake based on PV system cost. The paper also looks at the sensitivity of potential uptake based on PV system cost. It concludes that if all homes for which PV is financially viable under existing distribution pricing regimes install PV, the PV system cost is close to a point in most regions where the installed capacity of PV will rise very rapidly. From the analysis, the PV system cost needs to fall to about 2.3 $/Wp for the New Zealand wide median NPV to be at zero (i.e. where PV is financially viable for 50% of households), subject to assumptions. This is an important conclusion, as the PV system cost in New Zealand is not far from this already, and worldwide PV prices are forecast to continue to fall. The paper also concludes that for some regions, such as Marlborough and Gisborne, this point occurs at a higher system cost, around 3 $/Wp (i.e. those regions are already close to the point where PV is financially viable for around 50% of the population). The reasons for this relate mainly to high irradiation and variable retail prices in those regions. The same conclusion could not be made for the Nelson and Tasman regions due to lack of load profile data.

1. Introduction

Photovoltaic solar power (PV) continues to grow in New Zealand, as shown in Table 1, with about 90% of installations by capacity being residential. In the 2015 paper by Miller et al. [1], the economics of photovoltaic solar power (PV) at three levels (residential, commercial and utility) was examined. Commercial and utility installations were investigated across New Zealand, whereas residential was investigated for Christchurch only. From that analysis, it was observed that there is a group of consumers for whom PV is now economic. PV system costs have declined steadily over time (78% from 2006 to 2014 [2]) and from [2] and [3] are forecast to continue to fall. Given this ongoing fall in PV system costs, the authors postulated that the size of the group for whom PV is economic will increase.

This paper investigates the economics of PV to residential users across most New Zealand regions using net present value (NPV), and the sensitivity of NPV to PV system cost. It then looks at the potential uptake of PV, if all residential consumers for whom PV is economic install it. Section 2 outlines the methodology used in this study, while Section 3 presents the study's results. The paper is concluded with a discussion in Section 4 and a conclusion in Section 5.

Table 1: Regional uptake of PV in New Zealand to 31 March in each year[1]

Regional Council Region	Total Installed Capacity (MW)			Watts Per Person		
	2014	2015	2016	2014	2015	2016
Northland region	0.6	1.4	2.5	4	8	14.6
Auckland region	2.4	6.3	9.3	2	4	5.8
Waikato region	0.9	2.0	3.8	2	5	8.5
Bay of Plenty region	0.8	1.3	1.9	3	5	6.4
Gisborne region	0.0	0.1	0.3	1	3	6.2
Hawke's Bay region	0.4	1.2	1.8	3	7	11.0
Taranaki region	0.2	0.5	0.8	2	4	6.8
Manawatu-Whanganui region	0.3	0.6	1.4	1	2	5.8
Wellington region	0.5	1.0	1.9	1	2	3.8
Tasman region	0.6	0.9	1.2	12	18	23.9
Nelson region	0.4	0.7	1.0	9	14	20.1
Marlborough region	0.3	0.6	1.2	6	12	26.1
West Coast region	0.0	0.1	0.1	1	2	2.3
Canterbury region	1.9	4.2	6.7	3	7	11.1
Otago region	0.7	1.6	2.3	4	7	10.7
Southland region	0.2	0.6	0.8	2	6	8.2
Total North Island	6.2	14.3	23.7	2	4	6.6
Total South Island	4.1	8.5	13.3	4	8	12.2
Total New Zealand	10.3	22.8	37.0	2	5	7.9

[1] PV installation data was obtained from the Electricity Authority's EMI reports website (http://www.emi.ea.govt.nz/), Installed distributed generation trends. Population statistics used are Statistics NZ, Subnational population estimates at 30 June 2006-15 (with 2015 regional boundaries). The 2016 population it is estimated from 2015, assuming the same population growth as 2014 to 2015.

2. Method

2.1 Load Profile Collection

In the previous study documented in [1], load profiles were classified into representative load profiles according to their characteristics, for example electric hot-water, high or low electricity user, electric space heating, on a day/night rate tariff. Eight representative load profiles were used to determine the net present value (NPV) for eight 'household types' to which they corresponded. Over 2,000 load profiles were obtained for Christchurch on an anonymous basis, with the classification performed on those.

In the study reported in this paper, the analysis of the value of PV to a household is performed for each of 18,522 households, and the results reported in aggregate – so that no single household's results are given on their own. Load profiles for other New Zealand regions were obtained, enabling the study to be extended to other regions with load profiles more representative of homes in those regions. In total 18,522 load profiles were used, mainly for the main centres of each region. The number of load profiles per region is shown in Table 2.

Table 2: Number of complete load profiles of households obtained for each region as well as the number of occupied dwellings taken from the 2013 Census[2,3]

Region	Number of Load Profiles	Occupied Dwellings
Northland	548	60,192
Auckland	4,085	473,448
Waikato	2,535	152,493
Bay of Plenty	549	103,500
Gisborne	0	16,185
Hawke's Bay	565	58,350
Taranaki	647	43,431
Manawatu-Whanganui	583	87,984
Wellington	3,557	177,813
Nelson	44	18,903
Tasman	15	18,885
Marlborough	230	18,195
Canterbury	2,212	208,146
West Coast	140	13,803
Otago	2,796	80,949
Southland	16	38,145
Total	18,522	1,570,422

All load profiles were provided on an anonymous basis, with the only information known about the household being whether it was on an 'anytime' or 'night-day' scheme. Electricity

[2] http://www.stats.govt.nz/StatsMaps/Home/People%20and%20households/2013-census-population-dwelling-map.aspx

[3] As load profiles were unavailable for the Gisborne region, Hawkes Bay load profiles were used in calculations to estimate regional NPV and uptake.

use in the load profiles was captured half-hourly, and a standard 365 day year was considered. Only households with complete data were used and in the case of multiple meters/registers data was aggregated for each individual ICP (Installation Control Point).

2.2 Calculation Method and Assumptions

The method of calculating NPV for each household was the same as that documented by Miller et al. in [1]. However some assumptions were changed, for consistency with other EPECentre models, such as the Solar PV Calculator introduced in [4]. The assumptions are summarised in Table 3.

Table 3: Assumptions used in the calculation of Net Present Value and total installed PV capacity by regionally and for New Zealand

Parameter	Residential PV
PV System Size (kWp)	3.5
PV System Cost ($/Wp)	$3.5
Inverter replacement time (years)	15
Inverter replacement cost after 15 years ($/Wp)	$0.5
Inverter cost escalation for replacement (%/year)	0%
Operation and maintenance cost ($/kW/year)	$20
Operation and maintenance cost escalation (%/year)	2%
PV System salvage value ($/Wp)	$0.0
PV Balance of System Losses (%)	10%
PV Annual panel degradation (%/year)	0.8%
PV Panel tilt (degrees)	30
PV Panel azimuth (degrees)	0
Irradiance (W/m^2)	NIWA typical metrological year and transposed for direct and diffuse radiation and a 30^o tilt
PV Temperature effects accounted for	No
Grid buyback rate (c/kWh)	8
Variable electricity retail price (c/kWh)	Obtained from Genesis Energy's web site for each region's main centre.
Annual price adjustment Retail & Export (%)	1.5% 0.5%
Analysis time period (years)	25
Discount Rate (%)	6%

The main changes to the assumptions are:

1. The balance of system losses have been increased to 10%, applied throughout the PV system, as per the SoL model.[4] I.e. the PV generation data used in the modelling incorporated system losses of 10%. Note that this modelling has been updated from the modelling which provided the data used in the analysis by Miller et al. (2015) [1]. Panel to inverter ratio used in the modelling is 1.0 (i.e. the panels are not oversized).
2. Retail prices are now regional, from the main centre in each region, which is critical, as different variable prices by region will affect the NPV significantly.

[4] Neither shading nor panel availability were included in the system losses. Wood et al. (2016) [4] use a higher loss as they include shading and system availability.

3. The price increments for retail price and grid buy-back price have been separated, with the grid buy-back price increase being lower.
4. A single discount rate of 6% is used (in Miller et al. (2015) [1] the NPV was shown to be sensitive to discount rate, which will enable the reader to appreciate how the results might change as discount rate changes, without repeating the analysis several times).
5. The inverter replacement cost at 15 years has been increased to 0.5 $/Wp for consistency with [4].

2.3 Calculation of Regional Generation

Generation by region was calculated using Typified Meteorological Year (TMY) irradiance data obtained from NIWA, as introduced in [1]. The hourly NIWA data for each region was interpolated to obtain half hourly generation. The generated values include direct and diffuse irradiation and reflect the resultant generation of a 1kW panel. The resulting capacity factors are given in Table 4.

2.4 Examination of Results by System Cost

The main result required was NPV, which was calculated as shown in [1] with the load profiles and assumptions discussed previously. The spread of NPV values was then examined. Importantly, NPV was examined at several different PV system costs, ranging from NZD 1 $/Wp to 4.5 $/Wp, in increments of 0.5 $/Wp.

In addition, a count of systems with positive NPV at each system cost was made. This count was then multiplied by the number of occupied dwellings in the region, divided by the number of load profiles for that region. The result was multiplied by the PV system size of 3.5 kWp to give a theoretical installed PV capacity if all homes with a positive NPV installed PV. This assumes that the households for which load profiles were available are representative of the overall population. This is unknown, and is a significant assumption in this analysis.

3. Results

Figure 1 shows the NPV results for the sampled households in New Zealand (all 18,522 households, considered by region).[5] This shows that, for New Zealand, the median NPV is zero at a system cost of about 2.3 $/Wp. The market PV price is currently somewhere in the region of 3 to 3.5 $/Wp, meaning that PV system costs do not have far to fall before PV is financially viable for a large number of households, at the current retail electricity prices. In some regions, where irradiation is higher, this may already be the case, such as Marlborough, shown in Figure 2, where the median falls at an NPV of zero at 3 $/Wp. Table 4 summarises the system cost required for each region to obtain a median NPV of zero.

[5] This means that the representation in the NPV by region will depend on the number of household in the sample.

To give an indication of what the uptake of PV might be if all households installed PV if it was financially viable (i.e. a positive NPV), the installed capacity, calculated as outlined in the previous section, was plotted against PV system cost. Figure 3 shows this for New Zealand, while Figure 4 shows this for the larger regions, Figure 5 for the smaller North Island regions, and Figure 6 for the smaller South Island regions.

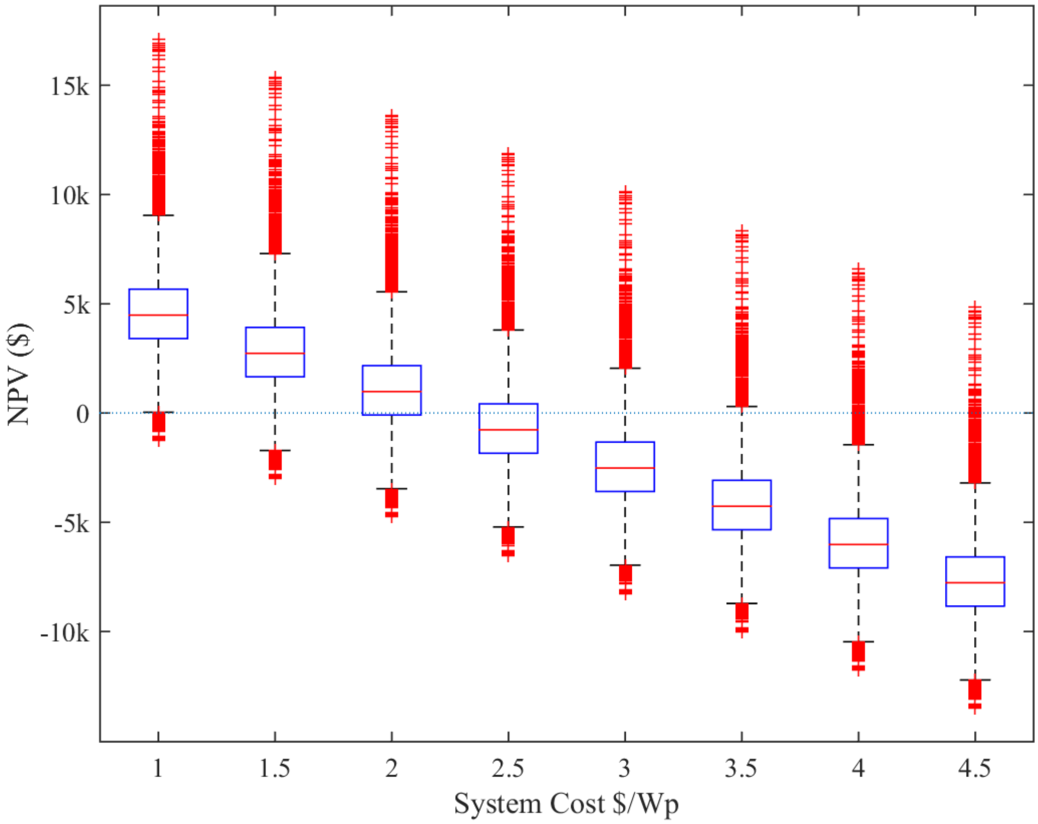

Figure 1: Net Present Value of a 3.5kW PV system calculated from load profiles of the 18,522 New Zealand households as a function of system cost[6]

[6] The bottom and top of the boxes represent the 25th and 75th percentiles respectively with the difference between the bottom and top of the box representing the interquartile range. The line in the middle represents the sample median. The whiskers show the points encompassing 1.5 times the interquartile range above and below the box top and bottom respectively. Outliers are represented as crosses outside the whiskers.

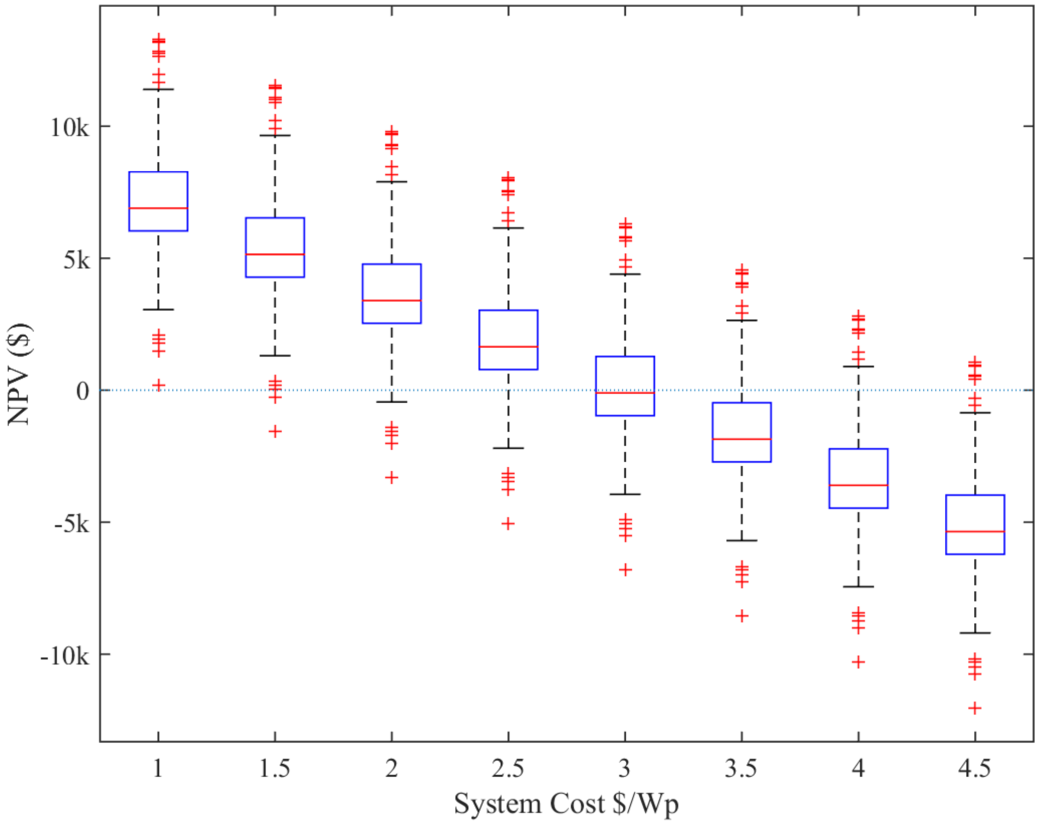

Figure 2: Net Present Value of a 3.5kW PV system calculated from load profiles of 230 Marlborough households as a function of system cost

Table 4: Capacity factors for each region from the PV system, including system losses, referred to in Sections 2.2 and 2.3 and PV system cost where the median NPV is zero

Region	PV System Capacity Factor	PV System Cost ($/Wp) at which the median NPV is zero
Northland	0.145	2.57
Auckland	0.154	2.23
Waikato	0.150	2.36
Bay of Plenty	0.154	2.51
Gisborne	0.159	3.13
Hawke's Bay	0.159	2.72
Taranaki	0.160	2.47
Manawatu-Whanganui	0.150	2.23
Wellington	0.148	2.15
Nelson	0.167	2.88
Tasman	0.167	2.73
Marlborough	0.167	2.97
Canterbury	0.143	2.46
West Coast	0.145	2.63
Otago	0.125	2.09
Southland	0.124	1.92
New Zealand		2.28

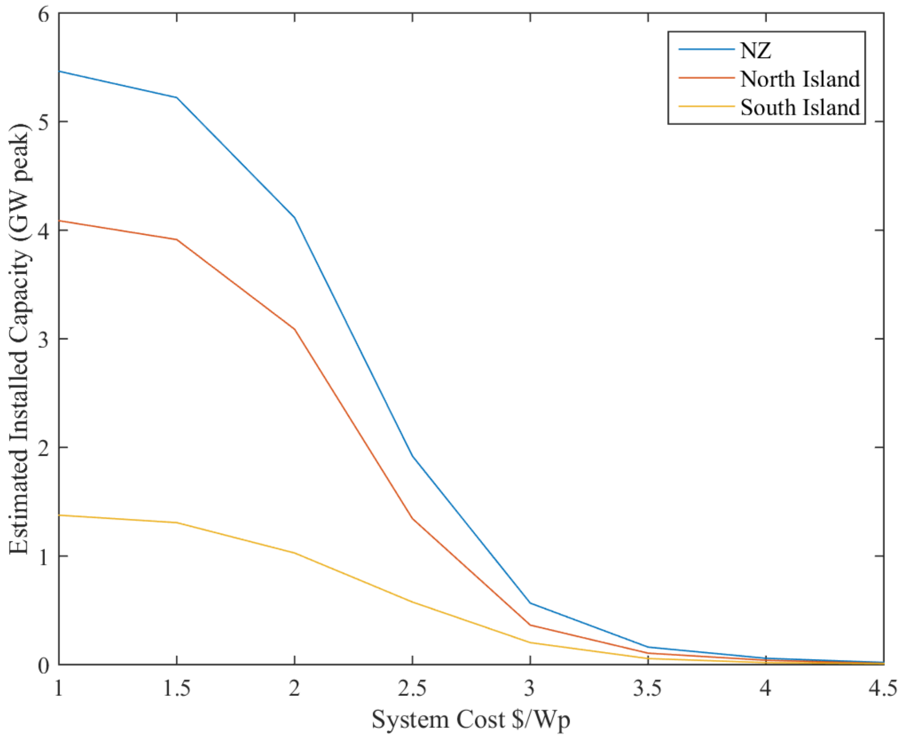

Figure 3: Potential peak installed capacity of residential PV for New Zealand systems as a function of system cost

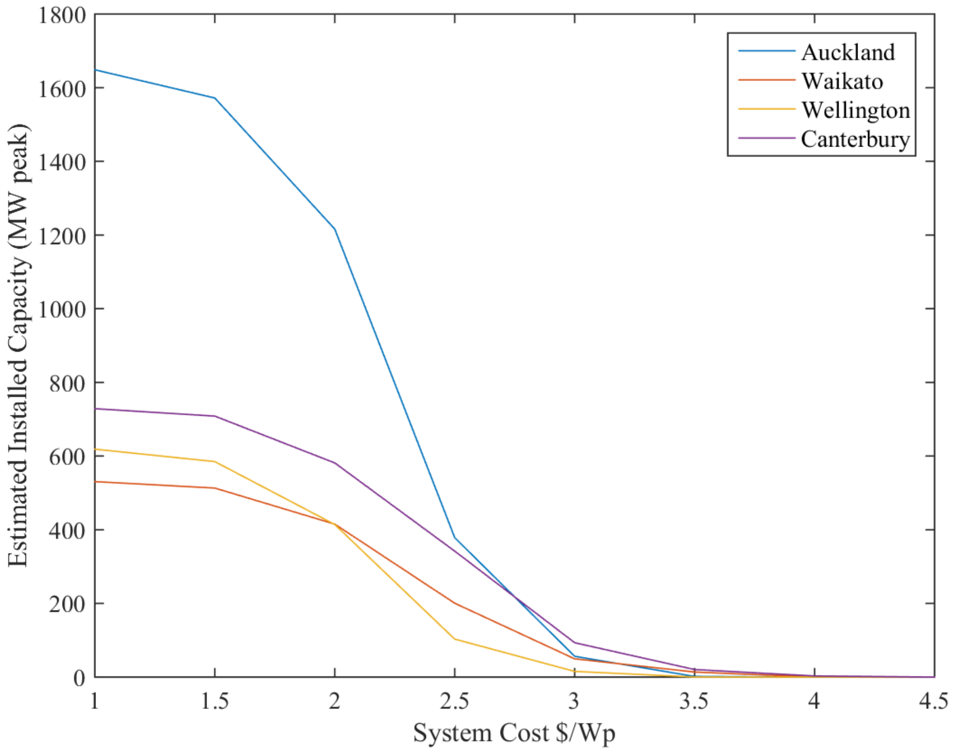

Figure 4: Potential peak installed capacity of residential PV systems for the four largest regions by population in New Zealand as a function of system cost

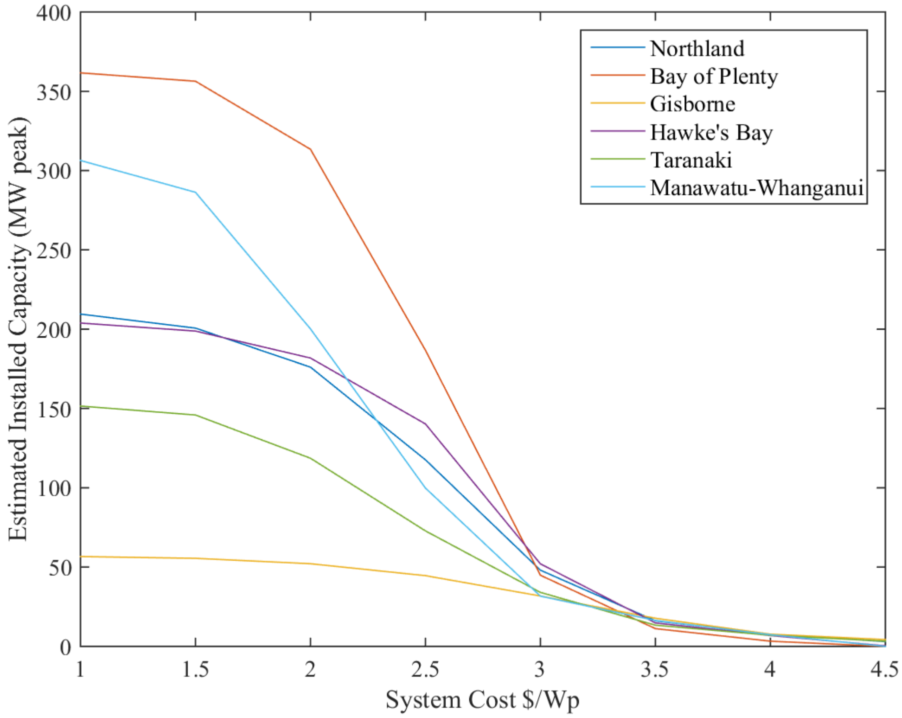

Figure 5: Potential peak installed capacity of residential PV systems for six regions in the North Island of New Zealand as a function of system cost

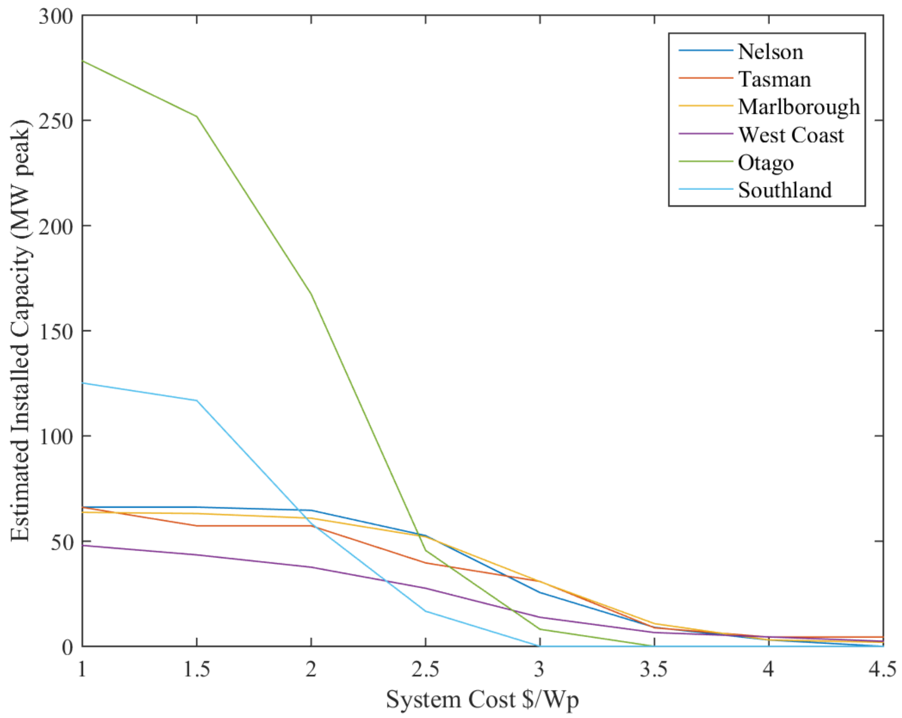

Figure 6: Potential peak installed capacity of residential PV systems for six regions in the South Island of New Zealand as a function of system cost

4. Discussion

Figures 3 to 6 give an idea of how uptake of PV might occur if everyone made their decisions on the financials, and if they had access to financial models to enable them to assess PV. What Figure 3 in particular shows, is that installed PV capacity from financially rational installation decisions is very sensitive to system cost in a range of about 2 to 3 $/Wp, and even sensitive up to 3.5 $/Wp. It can be concluded therefore, that the current PV system price does not need to fall too much before New Zealand could face a large uptake of PV. This must be tempered with the fact that PV uptake is currently nowhere near the level it could be at the current system cost of about 3.5 $/Wp (about 200MW across New Zealand, compared to the current uptake of 37MW). However as better information becomes available to householders, and marketing of PV systems increases, this situation may change, even at 3.5 $/Wp.

There are limitations to maximum uptake not taken into account in the analysis, such as hosting capacity of low voltage distribution networks and household location, orientation and suitability of roofs. Previous work by the EPECentre shows that these do not present significant barriers to substantial uptake, but the limit will be below the 5.5GW shown in Figure 3.

4.1 Load profile Assumptions and Price Schemes

Many assumptions must be made in the analysis of financial returns from PV. They include assumptions about a household's load profile. While actual load profiles have been used, it is assumed that no changes to households' load profiles will occur in the future. This is unlikely, as new appliances will be adopted, more energy efficient measures may be introduced, and load may be shifted from night to day time use to use more energy from the PV system.

Furthermore, the simulations assume that a household remains on the same tariff; a customer may change tariff in order to shift more energy to day time, or take advantage of lower night time tariffs and higher day time tariffs. With respect to pricing schemes, the paper uses a sub-set of the many pricing schemes available; the pricing schemes used are 'anytime' (flat rate) and 'night/day'. Retail price does affect the financial results of a PV system mainly through the day time variable rate, which is offset by PV.

4.2 Statistical Significance of Load Profiles

A number of regions, especially the main centres, have a good number of load profile samples, whereas some regions, such as Nelson, Tasman, Southland and the West Coast, do not. This will undoubtedly affect the results for those smaller regions. However even in the main centres it is not known whether the load profiles are truly representative of the population.

There were other challenges with load profiles, such as dealing with daylight saving savings shifts, and most load profiles being for 2015, but some being for 2012 (and therefore also requiring a leap year compensation).

4.3 Changes in Charges for Distributed Generators

As of 1 April 2016 the electricity distribution company Unison introduced new charges for distributed generation (DG). Two new pricing categories were introduced: one for consumers with electricity consumption below the high user threshold of 8,000 kWh, and another for consumers with electricity consumption above the 8,000kWh threshold. The new prices are shown in Table 4 along with the increase in price from the standard user charges. The effect of these price changes were investigated on PV uptake for Hawke's Bay.[7] Figure 7 shows the resulting NPVs, whereas Figure 8 shows the NPVs with the original charges in place. Figure 9 shows the potential peak installed capacity with and without the new charges by PV system cost.

Figure 9 indicates that there is some difference between the two, even at the current market price of about 3.5 $/Wp. Comparing Figures 7 and 8 it can be seen that the PV system cost must reduce by a further 0.75 $/Wp (from $2.74 from Table 4 to about $2) to achieve a median NPV of zero.

Table 5: New distributed generation charges introduced by Unison on 1 April 2016

	Fixed Daily Charge ($/Day)		Variable Charge ($ per kWh)			
			24 Hour or Anytime		Controlled	
	New Charge	Increase	New Rate	Increase	New Rate	Increase
Low User (<8kWh)	0.15	0	0.172	0.03	0.15	0.063
High User (>=8kWh)	1.805	0.655	0.0965	0	0.0745	0

[7] As no Night/Day category is available for consumers with DG, these households have been assigned the fixed '24 Hour rate', sometimes known as 'Anytime'. It is also assumed that the charges are passed directly on to the consumer without change by the retailer.

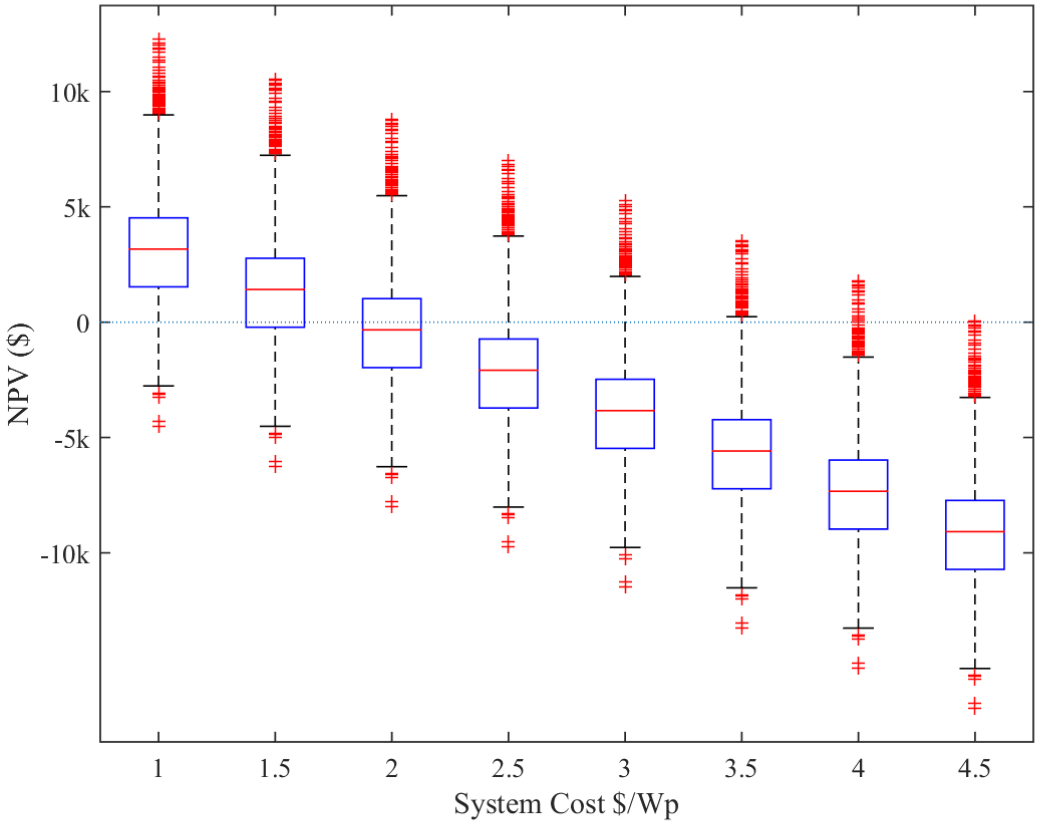

Figure 7: Net Present Value of a 3.5kWp PV system calculated from load profiles of 565 Hawke's Bay households and <u>including</u> the new DG charges introduced by Unison, as a function of system cost

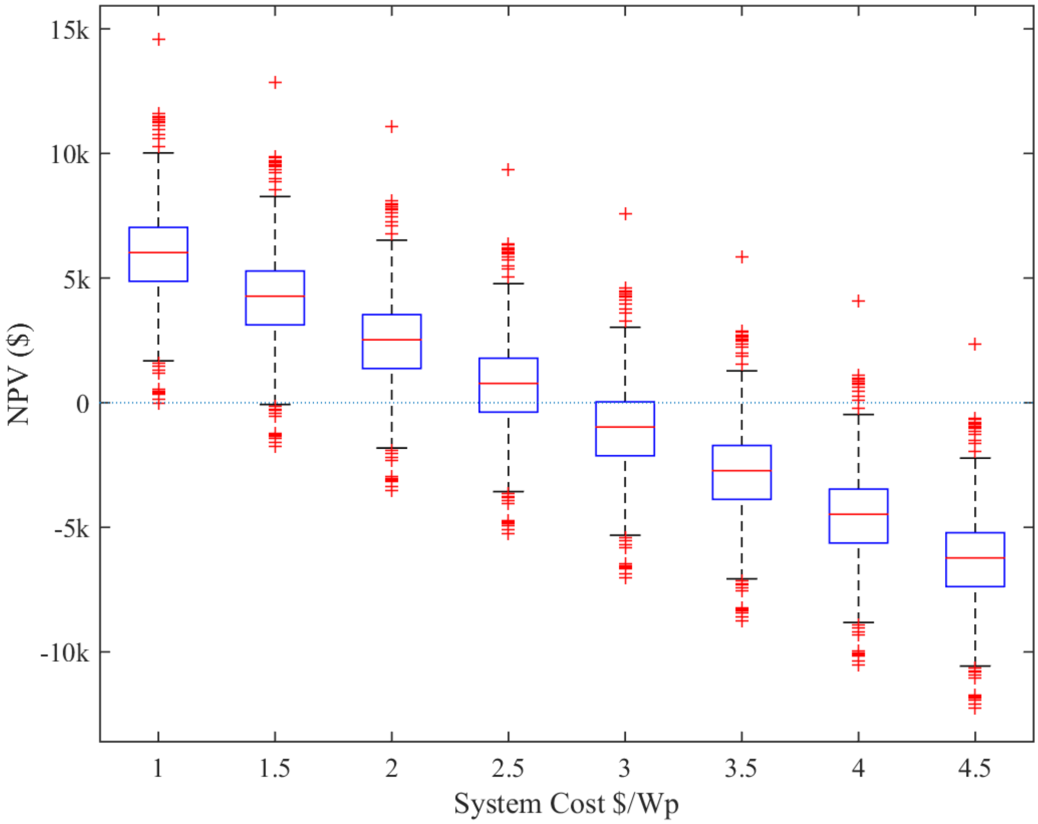

Figure 8: Net Present Value of a 3.5kW PV system calculated from load profiles of 565 Hawke's Bay households without the new DG charges introduced by Unison, as a function of system cost

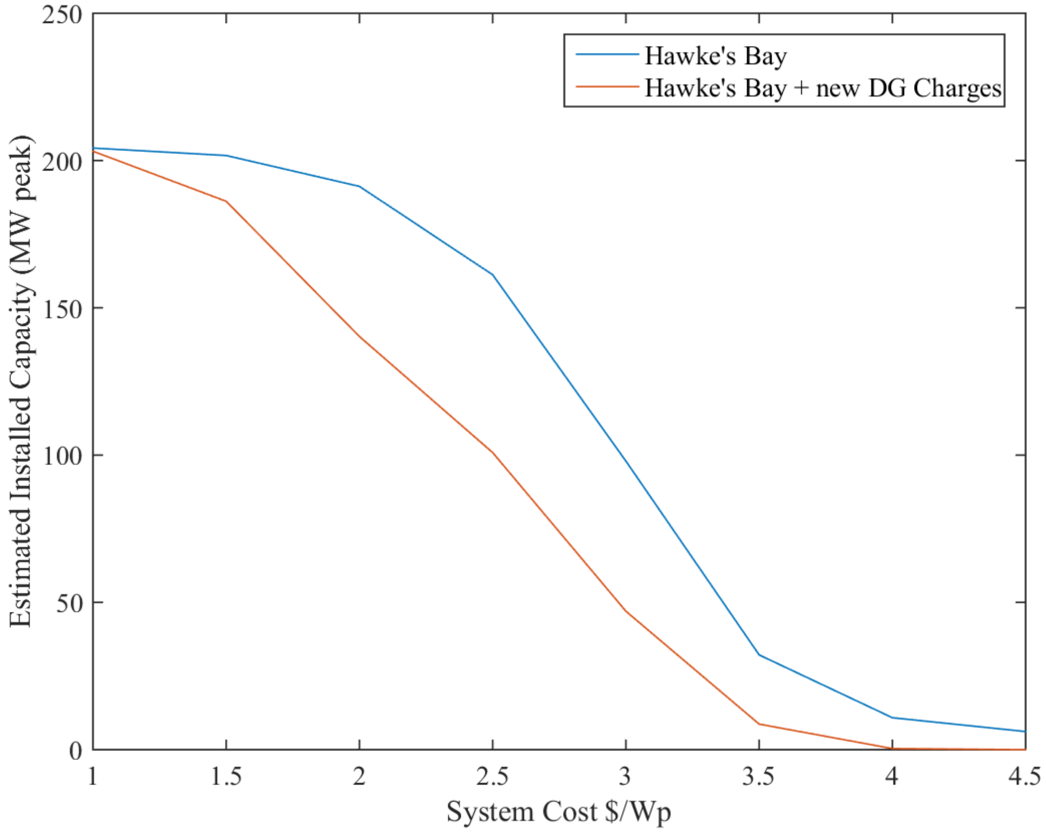

Figure 9: Potential peak installed capacity for Hawke's Bay comparing the PV uptake with and without the newly introduced DG charges

5. Conclusion

It can be concluded that the PV system cost needs to fall to about 2.3 $/Wp for the New Zealand wide median NPV to be at zero (i.e. where PV is financially viable for 50% of households), subject to assumptions. This is an important conclusion, as the PV system cost in New Zealand is not far from this already, and worldwide PV prices are forecast to continue to fall.

For some regions, such as Marlborough and Gisborne, this point occurs at a higher system cost (around 3 $/Wp). It can also be concluded that if all households make their decision to install PV based on rational financial decision making, New Zealand could see a large uptake of PV when the PV system cost falls below 3 $/Wp. This uptake might be enhanced by better information available on PV system economics and increased marketing by the PV industry. However there are limits to this uptake, based on the ability of local networks to host PV, and the availability of appropriate housing stock. Moreover, the current uptake of PV in New Zealand does not reflect the potential according to this analysis. This may also change further as better information about PV becomes available.

Many assumptions must be made in the analysis of financial returns from PV, meaning the results must be interpreted with these assumptions in mind. However the analysis shows important trends and possible uptake in the future.

6. Acknowledgement

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7. References

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