# The EECA energywise™ PV Solar Calculator

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## Abstract

In 2016 the Energy Efficiency and Conservation Authority (EECA) will launch a new calculator on its energywise™ web site, the PV Solar Calculator. The calculator has a dual purpose; the first is to allow any householder in New Zealand to evaluate the economic value of PV solar power at their own home, and the second is to educate householders regarding the characteristics of solar power, the importance of how the power is used, and some basic financial principles. The calculator establishes the sun-path for their location, the PV generation profile over days of a typical year, and an energy use profile based on a few simple questions. A report is generated showing energy generation and usage, and various financial measures. The calculator was developed by the authors (originally called the PV Web Tool) with assistance from the GREEN Grid research programme, with the aim of informing the New Zealand public about PV solar power in an unbiased way. This paper details how the calculator works, the assumptions it is based on, and the information required for it to work.

## Post Conference Revision

This paper has been updated since the EEA conference to include the results of load profiles from most other local Government regions of New Zealand. It also includes additional formulae and validation of model results. This paper has been reviewed by the University of Wollongong, School of Electrical, Computer and Telecommunications Engineering. The School of Electrical, Computer and Telecommunications Engineering hosts the Australian Power Quality and Reliability Centre (APQRC), who specialise in many aspects of electric power systems, including distributed generation.

## About the EPECentre, Department of Electrical and Computer Engineering, and GREEN Grid

The EPECentre is a centre of excellence in Electric Power Engineering. It is one of three research centres in the College of Engineering, University of Canterbury, and sits alongside the teaching departments. The EPECentre works closely with the Department of Electrical and Computer Engineering, which teaches the Bachelor of Engineering with Honours in Electrical and Electronic Engineering and the Bachelor of Engineering with Honours in Computer Engineering. The EPECentre and Department of Electrical and Computer Engineering work together to supervise post graduate engineering degrees, including Masters and Ph.D.s. The EPECentre has led the GREEN Grid research programme since 2012, a six year research programme looking at increasing New Zealand's renewable energy generation. Academic staff of the Department have contributed to GREEN Grid research. More information about the EPECentre and GREEN Grid is available at: www.epecentre.ac.nz.

## 1. Introduction

Domestic householders considering domestic photovoltaic (PV) systems in New Zealand suffer from lack of knowledge and information about the characteristics of these systems and their financial value to the households. It is no surprise that most PV system owners have made the decision to invest for reasons other than the financial value of the investment (Ford et.al, 2014). Calculating the financial value is simply too hard.

To allow householders to make a more informed decision, a free web-based calculator, the PV Solar Calculator, is being made available on the Energy Efficiency Conservation Authority (EECA) website. The calculator asks questions of the user to characterize their location, their planned PV system, their likely load profile, and their system funding costs. It provides them with a printable report assessing their proposed system.

Any PV system calculation tool requires data, makes some calculations and makes some assumptions. In particular, a calculator such as this, which is intended for use by the general public, should not require demanding technical knowledge or too much data input from the user. It is likely that most users will approach this calculator with little more than a single monthly power bill in their hands, and no understanding of what the calculator does in the background. It should also return enough information that the user is satisfied that they have a relevant result. Web-tools that simply return a numerical value tend to be rather unconvincing for the user. This calculator attempts to tread a middle path, where questions for the user are limited to those that can be answered fairly quickly, results are presented to the user with some backing evidence and explanation, and assumptions are available to the more engineering-oriented users.

The aim of this paper is to describe the calculation process behind the PV Solar Calculator, to put the strengths and limitations into the public domain. Section 2 of this paper describes the model in detail, including the irradiance data, PV panel energy calculations, representative household load profiles, the PV system energy calculations, and financial calculations. Section 3 of the paper describes the user experience, while Section 4 discusses validation of the PV Solar Calculator solar model. Assumptions are introduced in the text of Section 2, with all assumptions summarised in Appendix One.

## 2. Model

The PV Solar Calculator comprises a web interface, developed by EECA with the EPECentre, and a 'PV calculation engine', developed by the EPECentre. The PV calculation engine developed by the EPECentre is a set of Python modules, ported to php modules by EECA, which interface with the web interface, as shown in Figure 1. As also shown in Figure 1, the PV Calculation Engine obtains irradiance (Watts/m$^2$) from the National Institute of Water and Atmospheric Research (NIWA), specific to the address given by the user in the website interface. For ease of use of the PV Solar Calculator, it also accesses a database of standard load profile shapes, which are discussed in Section 2.3. This section describes the operation of the PV calculation engine.

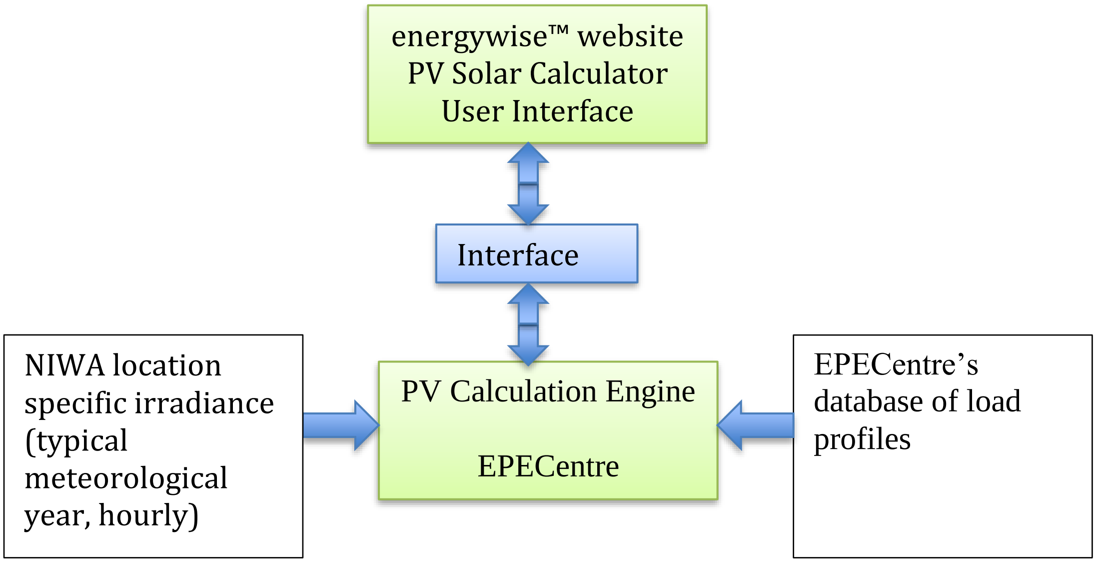


Figure 1: PV Solar Calculator Structure.

The PV calculation engine requires a number of inputs, and uses a number of assumptions, which are discussed throughout the text. The PV Solar Calculator was first described by Wood and Miller (2013), with updated analysis described by Miller et al. (2015).

### 2.1 Irradiance Data

The geography in New Zealand is highly variable, resulting in quite different sunshine data in different locations. The National Institute of Water and Atmosphere (NIWA) has been recording meteorological data for many years at a range of locations within New Zealand, and has been contracted to supply data for use in the PV Solar Calculator. The irradiance received by a solar PV array comes in three components. The first is direct irradiance, which represents the direct path from the sun to the panels, attenuated by the amount of atmosphere it passes through. The panel angle directly affects how much of this radiation is intercepted by the solar array. The second is diffuse irradiance, which is scattered by clouds. The diffuse irradiation received by the array is un-affected by the panel angle. The third component is albedo, which is reflected by the surrounding physical features (Boland et. al. 2013). This is typically high in snowy locations, but is low otherwise. NIWA accepts from the calculator the user location, array tilt from horizontal and panel azimuth. From this it returns a sun-path diagram, including an approximation of local shading and albedo, and a dataset giving the typical hourly irradiation profile received by the solar array. This is not an averaged data-set, but a representative data-set that captures average values and also captures typical monthly, daily and hourly variation. A temperature data-set is also supplied. This data forms a key component of the calculator.

### 2.2 Energy Calculations

There are a number of steps and approximations used in converting from the tilted irradiance and ambient temperature data to the solar system power output. While it is possible to go to considerable lengths to accurately determine the daily power generated, a computationally straightforward approach is used here.

The PV array power output for each one hour period is proportional to the irradiation intercepted by the panels, and is modified by the calculated cell temperature. The cell temperature in turn is calculated by using the Nominal Operating Conditions cell temperature (*NOCT*, or in this paper $T_{cell,NOCT}$) and the ambient temperature (*Ta*), assuming that the cell temperature rise is linearly related to the irradiation power density (*Ga*). This is converted to array power via the array power rating, and a power temperature coefficient ($\alpha_p$).

Panel data-sheet ratings are usually given under more than one operating condition. The most common are Standard Test Conditions (*STC*), with an irradiance of 1000 W/m$^2$ ($G_{STC}$) and a module temperature of 25$^o$ C ($T_{m,STC}$), and Nominal Operating Conditions (*NOC*) of 800 W/m$^2$, ($G_{NOC}$), an ambient temperature ($T_{a,NOC}$) of 20$^o$C, and a wind speed of 1m/s. Often the only piece of data supplied under normal operating conditions is the cell temperature, *NOCT*, or $T_{cell,NOC}$. The calculator assumes $T_{cell,NOC}$ to be 48$^o$C, and $\alpha_p$ to be -0.4667%/°C.

Firstly the operating cell temperature is estimated as

$$T_{cell} = T_a + \frac{G_a}{G_{NOC}} \left(T_{cell,NOC} - T_{a,NOC}\right) \times 0.5^{1}$$

Following this the array maximum power point power is calculated as

$$P_{MPP} = P_{rated} \times \frac{G_a}{G_{STC}} \times \left(1 + (T_{cell} - T_{m,STC})\alpha_p\right) \text{ (kW)}$$

Where $P_{rated}$ is the panel's rated power (kWp).

For the year under analysis, this output power is further derated by a number of factors. A wide range of rerating factors are discussed in the literature, which are conveniently summarised by Santos and Lemon (2015).

System losses are a contentious subject. Much data comes from California, where isolation transformer losses and soiling are significant factors, and would be less so in New Zealand. Initially the array power is derated by dc wiring losses (-2%), ac wiring losses (-1%), connector losses (-0.5%), mismatch of panels in an array (-2%), panel soiling (-1%) and power conversion losses (-4%), system availability (-1%).[2] The initial PV system rating is set at 88.5% of the array nameplate rating. This is roughly consistent with Santos-Martin and Lemon, 2015, and Dobos, 2014. It is assumed that the inverter is rated for more than the full array power even though it has been shown that this is not necessarily an optimal choice (Chen et.al, 2013).

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[1] As discussed in Section 4, the temperature rise is halved to account for New Zealand's windy conditions and to match measured data.

[2] Note that panel soiling and system availability losses have been set to match measured data as discussed in Section 4.

The system is further derated by the aging process (Jordan and Kurtz, 2103). Most solar panels are guaranteed to maintain 80% of their output power after 25 years. In the PV Solar Calculator, a degradation rate of 0.8% per annum is assumed for computational simplicity.

$$P_{PVSystem} = P_{MPP} \times 0.885 \times d^{year} \text{ (kW)}$$

where

d is 1 – the degradation rate (*d= 1 – 0.008 = 0.992*), and

0.885 refers to the system efficiency (1 – system losses).

The first year is assigned the number 0, the final year is 24. The end-of life panel efficiency is almost the same computed by either method. While this describes the model of PV system degradation, it is not implemented until later in the calculation process.

## 2.3. Load Profile Classification

As shown in previous EPECentre work by Miller et al. (2015) the nature of electricity consumption of a household (i.e. load profile) is one of the main determinants of the economics of PV to a household. The best approach to valuing PV is to use the actual load profile of a household. However in order to simplify the model, five questions were devised to 'lookup', from a database, a standard normalised load profile by region. The normalised load profile, retrieved from the database, is scaled by the annual electrical energy consumption of the household. The result is the assumed load, $P_{Load}$, in kWh for each hour ($t$) of the year for the household.[3] This is used in Section 2.4.

The questions asked to classify the load profiles are listed in Section 2.3.1, with an explanation of why these questions were used. Each question has a binary response, giving a total of 32 possible combinations (two to the power of five). Analysis was then conducted on just over 18,000 load profiles to divide them into the 32 categories, and to derive a standard normalised load profile for each category. This analysis and process is described in Section 2.3.2.

Load profiles were also analysed by region, with the 16 local Government regions defined by Local Government NZ (2016) used – referred to as local Government regions in this paper. Regional analysis was performed to accommodate any possible locational differences in electricity usage profiles. Table 1 shows the number of load profiles obtained per region, and the resultant classifications.

### 2.3.1 Load Profile Lookup Questions

The five questions used by the PV Solar Calculator to determine the normalised load profile are:

[3] As obtained from the load profiles provided, and scaled from the normalised load profiles, $P_{Load}$ is actually energy in each hour, with units of kWh. Since it is over an hour, it can also be seen as average load over each hour, with units of kW.

1. Do you know how much electricity you use in a year?

   The answer to this question is used to determine whether the household is a low or high user household, and to scale the normalised load profile selected for the household. Annual energy consumption is a very important input to determine hourly energy consumption, by scaling the normalized load profile of the household. The scaling process is described in Section 2.3.3. If annual energy consumption is not known, it is estimated for the household from the electricity bill for a single month. This process is also described in Section 2.3.3.

2. What pricing scheme are you on? "Flat rate" or "Day / Night rate"

   Knowing the pricing scheme is important because a day / night rate scheme invariably leads the customer to shift energy consumption from day to night, and therefore alters the day time load. If a household is considering PV, but they are on night rate, they might want to consider running the model with night rate selected, then run it with flat rate selected to get an idea of how night rate versus a flat rate will change the economics of PV for them.[4]

   There are more complex pricing schemes, with shoulder rates and peak rates. For simplicity of the model only the two most common pricing schemes are used.

3. Do you use a lot of electricity at home between 10am and 4pm (e.g. electric heaters, washing machines, clothes dryers, showers)? "Electricity use in our house is usually low during the day." or "Electricity use in our house is usually high for more than five days a week."

   This is a particularly important question, as day-time energy consumption is a major determinant of how PV self-generation will offset load and therefore purchases from the grid at the day time retail rate. The answer to this question may depend on other factors than just whether a household is occupied during the day time or not. For example, if heating a swimming pool, or using heat pumps to heat under floor heating, during sunlight hours, the answer to this questions may be "Electricity use in our house is usually high for more than five days a week."

4. What is your main hot water heating source? "Electricity" or "Other e.g. Gas"

   Electric hot water heating represents a large source of electrical energy consumption. It therefore has a bearing on how the energy consumption by a household can be offset by PV generation, particularly if the household is on a flat rate pricing scheme.

5. What is your main heating source? "Electricity (electric heaters, heat pump etc)" or "Other (wood fire, gas etc)"

[4] Note that changing from night rate to day rate may change the day rate electricity tariff.

Electric space heating is a large load, which combined with being at home during the day, may lead to a large amount of grid energy purchases offset by PV generation.

### 2.3.2 Analysis of load profiles and classification to populate the database

Ideally, the classification into the 32 types requires information about each household that answers the five questions introduced in Section 2.3.1. The 18,000 load profiles obtained through the GREEN Grid project were provided on an anonymous basis, a key condition for provision of the data. The only available information about the households is the retail tariff, i.e. whether the household was on a flat rate tariff or a night/day tariff, and whether the household is a low or high user (determined from total energy consumption and region). Information which directly addresses questions 3 to 5 from Section 2.3.1 was not available. Consequently the EPECentre devised methods to infer the information from the load profiles themselves to address questions 3 to 5. These methods are summarised below:

3. Do you use a lot of electricity at home between 10am and 4pm (e.g. electric heaters, washing machines, clothes dryers, showers)? "Electricity use in our house is usually low during the day." or "Electricity use in our house is usually high for more than five days a week."

   To test for day time occupancy, average energy consumption between the hours of 10am and 4pm is determined. If the average energy consumption is above a threshold, the household is considered to be occupied during the day.

4. What is your main hot water heating source? "Electricity" or "Other e.g. Gas"

   In the first instance, if the household is on a night rate pricing scheme, it is assumed to have electric hot water heating, as most households who choose a night rate do so to reduce the cost of heating water. If not on a night rate scheme, the algorithm looks for particularly high energy consumption in the mid-morning, on the assumption that hot water heating is on at that time.

5. What is your main heating source? "Electricity (electric heaters, heat pump etc)" or "Other (wood fire, gas etc)"

   To estimate whether the household uses electricity for their main heating source, linear correlation coefficients were calculated between the daily energy consumption and the daily local average temperature and daily maximum temperature over the year. As the households were linked to a region, the "local" temperature refers to the average temperature of the major city in that region. If a strong negative correlation is found between either of the two correlation coefficients, the household is classified as using electricity for space heating.[5] Some ratification of this method was possible by looking at a small anonymous data set (about 30 households) from the University of Otago Centre for Sustainability's '100 hundred home trial' which has appliance data, such as whether

[5] The same principle may be extended in the future to look for a strong positive correlation between temperature and electricity consumption, which would indicate summer cooling using heat pumps.

the household has a heat pump or other electric heating device, as well as energy consumption profile for the household.

The final analysis step determines the normalised load profiles. The profiles in each category given in Table 1 were normalised, to preserve their shape, and the median value at each point in time taken to give a median load profile.[6] This was then normalized and stored in the database

The obvious disadvantage of the above methods is, because nothing is known about the households for which load profiles are available, it is not possible to definitively test the methods and assumptions. However visual examination of the normalised load profiles shows that the resulting load profiles are as expected. Ideally the actual individual household power consumption for the household being studied would be used, however this is not always easily available.

Note that by taking the median at each time period, sharp peaks and troughs typical in individual household energy consumption are smoothed somewhat, as does using an hourly time-scale for energy consumption. In reality the PV system and household consumption is responding at much shorter time scales, which introduces an additional approximation to this method.

Examples of normalised load profiles for some categories are shown in Appendix Two – Load Profiles.

[6] Normalized refers to the sum of all 8,760 hourly loads scaled to total 1,000 over a year. To achieve this, each hourly load (in kWh) in the profile under consideration is divided by the sum of all hourly loads and multiplied by 1,000.

Table 1: PV Solar Calculator Load Profile Classifications for 10 of the 16 regions with sufficient household electricity consumption data. Profile substitutions are noted for regions and profiles that are below threshold (shaded orange). Further details regarding the profile substitution rules are given in Appendix Three – Rules for Load Profile Substitution.

| Profile Type | Low or High User | Electric Space Heating | Home during week days | Tariff | Hot Water Heating | Northland | Auckland | Waikato | Bay of Plenty | Hawke's Bay | Taranaki | Manawatu-Whanganui | Wellington | Canterbury | Otago | Profile Substitutions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | 2 | 3 | 4 | 6 | 7 | 8 | 9 | 13 | 15 | |
| 1 | Low | Non-electric | Away | Flat Rate | Non-electric | 72 | 904 | 386 | 57 | 77 | 97 | 85 | 485 | 352 | 345 | - |
| 2 | Low | Non-electric | Away | Flat Rate | Electric | 127 | 213 | 276 | 104 | 113 | 178 | 103 | 432 | 31 | 327 | - |
| 3 | Low | Non-electric | Away | Night Rate | Non-electric | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 4 | Low | Non-electric | Away | Night Rate | Electric | 8 | 14 | 12 | 6 | 6 | 4 | 6 | 30 | 94 | 11 | Wellington |
| 5 | Low | Non-electric | At Home | Flat Rate | Non-electric | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 6 | Low | Non-electric | At Home | Flat Rate | Electric | 3 | 7 | 3 | 4 | 1 | 3 | 2 | 17 | 0 | 8 | Wellington |
| 7 | Low | Non-electric | At Home | Night Rate | Non-electric | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 8 | Low | Non-electric | At Home | Night Rate | Electric | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 4 |
| 9 | Low | Electric | Away | Flat Rate | Non-electric | 61 | 1187 | 631 | 61 | 63 | 63 | 78 | 657 | 514 | 444 | - |
| 10 | Low | Electric | Away | Flat Rate | Electric | 115 | 326 | 469 | 122 | 119 | 137 | 143 | 624 | 128 | 459 | - |
| 11 | Low | Electric | Away | Night Rate | Non-electric | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| 12 | Low | Electric | Away | Night Rate | Electric | 3 | 21 | 20 | 6 | 4 | 5 | 10 | 45 | 308 | 14 | Wellington |
| 13 | Low | Electric | At Home | Flat Rate | Non-electric | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| 14 | Low | Electric | At Home | Flat Rate | Electric | 1 | 2 | 1 | 1 | 0 | 0 | 2 | 4 | 1 | 4 | 10 |
| 15 | Low | Electric | At Home | Night Rate | Non-electric | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| 16 | Low | Electric | At Home | Night Rate | Electric | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 |
| 17 | High | Non-electric | Away | Flat Rate | Non-electric | 6 | 80 | 37 | 12 | 10 | 4 | 2 | 39 | 18 | 20 | Auckland |
| 18 | High | Non-electric | Away | Flat Rate | Electric | 22 | 134 | 64 | 28 | 31 | 38 | 17 | 90 | 42 | 104 | - |
| 19 | High | Non-electric | Away | Night Rate | Non-electric | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 17 |
| 20 | High | Non-electric | Away | Night Rate | Electric | 1 | 0 | 3 | 1 | 1 | 1 | 0 | 5 | 23 | 3 | Canterbury |
| 21 | High | Non-electric | At Home | Flat Rate | Non-electric | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 17 |
| 22 | High | Non-electric | At Home | Flat Rate | Electric | 26 | 111 | 102 | 16 | 24 | 27 | 20 | 92 | 13 | 75 | - |
| 23 | High | Non-electric | At Home | Night Rate | Non-electric | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 17 |
| 24 | High | Non-electric | At Home | Night Rate | Electric | 2 | 3 | 4 | 0 | 1 | 4 | 1 | 3 | 7 | 1 | 22 |
| 25 | High | Electric | Away | Flat Rate | Non-electric | 15 | 329 | 147 | 26 | 15 | 13 | 13 | 244 | 73 | 117 | - |
| 26 | High | Electric | Away | Flat Rate | Electric | 74 | 575 | 318 | 88 | 83 | 56 | 78 | 602 | 255 | 616 | - |
| 27 | High | Electric | Away | Night Rate | Non-electric | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 25 |
| 28 | High | Electric | Away | Night Rate | Electric | 4 | 4 | 5 | 5 | 3 | 2 | 2 | 34 | 225 | 15 | Wellington |
| 29 | High | Electric | At Home | Flat Rate | Non-electric | 0 | 1 | 2 | 1 | 0 | 0 | 0 | 4 | 0 | 3 | 25 |
| 30 | High | Electric | At Home | Flat Rate | Electric | 7 | 171 | 52 | 11 | 14 | 15 | 20 | 140 | 90 | 221 | Auckland |
| 31 | High | Electric | At Home | Night Rate | Non-electric | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 25 |
| 32 | High | Electric | At Home | Night Rate | Electric | 1 | 1 | 2 | 0 | 0 | 0 | 1 | 8 | 38 | 7 | Canterbury |
| Total Low Users | | | | | | 390 | 2674 | 1798 | 361 | 383 | 487 | 429 | 2295 | 1428 | 1612 | |
| Total High Users | | | | | | 158 | 1410 | 737 | 188 | 182 | 160 | 154 | 1261 | 784 | 1183 | |
| Total | | | | | | 548 | 4084 | 2535 | 549 | 565 | 647 | 583 | 3556 | 2212 | 2795 | |
| Ratio of low to high users | | | | | | 2.5 | 1.9 | 2.4 | 1.9 | 2.1 | 3.0 | 2.8 | 1.8 | 1.8 | 1.4 | |

Notes:

1 Region 5, Gisborne uses Hawkes' Bay's load profiles,

2 Regions 10, 11, 12, 14, Nelson, Tasman, Marlborough and the West Coast use Canterbury's load profiles

3 Region 16, Southland uses Otago's load profiles.

### 2.3.3 Load profile scaling

Normalised load profiles, represented as $\hat{P}_{Load}$ for each hour of a year, region $r$, and user type $p$, are stored in a database.[7] The load profiles are normalised such that they total to 1,000 over a year, i.e.

$$\sum_{hour=1}^{8,760} \hat{P}_{Load} = 1{,}000 \text{ for all } p \text{ and } r$$

To determine an estimate for individual householder's load profile, $P_{Load}$, in kWh at each hour of the year, the normalised load profiles, appropriate to the user, must be scaled by the householder's annual energy consumption, $Energy\_consumption$ (kWh). The following equation describes this:

$$P_{Load} = \frac{\hat{P}_{Load} \times Energy\_consumption}{1{,}000} \text{ (kWh) for the appropriate values of } p \text{ and } r$$

$Energy\_consumption$ can be determined by adding the energy consumption from monthly power bills over a year for the household, or from the portal on the energy retailer's website. If the householder does not have full yearly energy consumption information, this can be estimated from a single month's power bill, described in the following sub-section.

#### 2.3.3.1 Load profile scaling with partial energy consumption information

Not all users of the PV Solar Calculator will have their annual energy consumption readily available to them, but they should have at least one month's power bill. For this reason, the PV Solar Calculator incorporates the ability to estimate the annual energy consumption from any month's energy consumption. The estimate uses the normalised representative load profile for that region, determined for the household. The process of estimating annual energy consumption is as follows:

(1) Ensure that the region is known from the address (this gives $r$).
(2) Ensure that answers to the four user type questions are known (electric hot water, electric space heating, night rate or flat rate, and home during the day) and assume the user is a low user (this gives $p$). (In determining the load profile, initially assume the user is a low user, since the determination of low or high user is not possible because the annual energy is not available).
(3) Take the normalised representative household load profile $\hat{P}_{Load}$ for the user type $p$ and the region $r$.
(4) For the month $m$ for which $Energy\_consumption_{month}$ (kWh) is given, determine the estimated annual energy consumption according to:

[7] Actual scaling of load profiles was performed on the half-hourly data (the 18,000 load profiles obtained by GREEN Grid were half-hourly), which were then re-sampled to hourly load profiles to match the NIWA data (also hourly). Re-sampling was achieved by adding each set of two half-hourly values. The time basis used is New Zealand standard time to match the NIWA data and remove any shift in time by an hour that daylight saving introduces.

$$Energy\_consumption_{est} = \frac{Energy\_consumption_{month}}{\left(\frac{\sum_{hour=m_s}^{m_e} \hat{P}_{Load}}{1{,}000}\right)} \text{ (kWh)}$$

where $m_s$ and $m_e$ are the start and end hours of the month, defined in Table 2.

If either:

(a) the year of the electricity invoice is known, it is a leap year, and the user gives their energy for February of that leap year; or

(b) the user gives their energy for February, and the current date is between March of a leap year, and February of the year following a leap year, assume that the February energy consumption given pertains to a leap year,[8]

scale the result by 28/29. I.e.

$$Energy\_consumption_{est} = \frac{\frac{28}{29} \times Energy\_consumption_{month}}{\left(\frac{\sum_{hour=m_s}^{m_e} \hat{P}_{Load}}{1{,}000}\right)} \text{ (kWh)}$$

(5) If estimated annual energy consumption is greater than the low user threshold in kWh, return to Step 3 but use the normalised load profile, $\hat{P}_{Load}$, that corresponds to a high user. The low user thresholds are region dependent and given in Table 3.

(6) Multiply the estimated annual energy consumption from (4) by the appropriate normalised load profile. The result is the load profile for use in the PV Solar Calculator , as follows

$$P_{Load} = \frac{\hat{P}_{Load} \times Energy\_consumption_{est}}{1{,}000} \text{ (kWh)}$$

Table 2: Month start and end hours (non-leap year).

| Month | Start hour, $m_s$ | End hour, $m_e$ |
|---|---|---|
| **1 (January)** | 1 | 744 |
| **2** | 745 | 1,416 |
| **3** | 1,417 | 2,160 |
| **4** | 2,161 | 2,880 |
| **5** | 2,881 | 3,624 |
| **6** | 3,625 | 4,344 |
| **7** | 4,345 | 5,088 |
| **8** | 5,089 | 5,832 |
| **9** | 5,833 | 6,552 |
| **10** | 6,553 | 7,296 |
| **11** | 7,297 | 8,016 |
| **12** | 8,017 | 8,760 |

[8] This is an assumption that the invoice pertains to the leap year, but avoids an additional input from the user, i.e. the year of their invoice.

Table 3: Low user thresholds.[9]

| Local Government Region | Low user threshold (kWh) |
|---|---|
| **Northland** | 8,000 |
| **Auckland** | 8,000 |
| **Waikato** | 8,000 |
| **Bay of Plenty** | 8,000 |
| **Gisborne** | 8,000 |
| **Hawke's Bay** | 8,000 |
| **Taranaki** | 8,000 |
| **Manawatu-Whanganui** | 8,000 |
| **Wellington** | 8,000 |
| **Nelson** | 8,000 |
| **Tasman** | 8,000 |
| **Marlborough** | 8,000 |
| **Canterbury** | 9,000 |
| **West Coast** | 8,000 |
| **Otago** | 9,000 |
| **Southland** | 9,000 |

It should be noted that while some effort is expended to characterise the load profile of a household, it is difficult to extrapolate the load profile into the future. In 25 years, peoples' personal circumstances change. More energy efficient products are likely to become available, although perhaps people will own a greater number of electrical products. The extension of load profiles into the future is a significant assumption in the calculation.

## 2.4 Balancing locally used and exported energy

Once the household load profile for year 0 is determined, it is compared on an hour-by-hour basis (8,760 hours) with the first year of PV system power. When the PV system power is less than the household load, all the PV system power is locally used. When the PV system power is greater than the household load, the household load defines the local usage, and the remainder is exported. The locally used and exported power are summed for each hour to give the total energy locally used and exported in Year 0 in the following fashion:

$$Energy_{local,year0} = \sum_{hour=1}^{8,760} \begin{cases} P_{PVSystem}, & when\ P_{PVSystem} \leq P_{Load} \\ P_{Load}, & when\ P_{PVSystem} > P_{Load} \end{cases}$$

and

$$Energy_{ExpSum,year0} = \sum_{Summer\_hours} P_{PVSystem} - P_{Load}, \quad when\ P_{PVSystem} > P_{Load}$$

[9] The low user thresholds in this table for the local Government region of Canterbury do not match exactly the actual area of low user threshold for Canterbury, which strictly only covers all areas south of and including Christchurch, but excluding the West Coast. Hence someone in North Canterbury would have a low user threshold of 9,000 kWh applied, whereas a threshold of 8,000 kWh should be applied. This is not considered too much of an issue, as the low / high user threshold is used to select the load profile shape for scaling monthly energy to annual energy, which is an approximation anyway.

$$Energy_{ExpWin,year0} = \sum_{Winter\_hours} P_{PVSystem} - P_{Load}, \quad when\ P_{PVSystem} > P_{Load}$$

where

$P_{PVSystem}$ is the PV system generation for each hour, from Section 2.2, in kW, which is also kWh since it is the average power over an hour,

$P_{Load}$ is the estimated hourly household load from Section 2.3.3,

$Energy_{local,year0}$ is the total PV system energy used within the household in the first year,

$Energy_{ExpSum,year0}$ is the total PV system energy exported to the grid during the summer of the first year, and

$Energy_{ExpWin,year0}$ is the total PV system energy exported to the grid during the winter of the first year.

Winter hours are from 1 May to 1 September. This establishes the energy balance in the first year (Year 0) of PV system operation. However, as the PV system output degrades, a greater proportion of the solar energy is locally used, and a smaller proportion of it is exported. In the absence of any firm basis for load profile prediction, it is assumed that the household load profile remains the same for each year. The three energy calculations are repeated for year 24, and then calculated for the intervening years by firstly calculating a separate degradation rates $r_{Local}$, $r_{ExpSum}$, $r_{ExpWin}$ as follows

$$r_x = 10^{\left(\frac{log(Energy_{x,year24}) - log(Energy_{x,year0})}{24}\right)}$$

and each year of the three energy categories is calculated as

$$Energy_{x,year} = Energy_{x,year0} \times r_x^{year}$$

where *x*= *Local*, *ExpSum*, and *ExpWin* respectively. This method of calculation is used to ensure computational efficiency, as the system will be implemented on a server with potentially many requests in a short space of time, requiring a real-time response. This is a departure from calculating the energy balance for each hour of the year across all 25 years as implemented by Miller et al. (2015), which had the luxury of no real-time response requirement, and only a small set of results required.

## 2.5 Financial Calculation

Simple Payback Period is often used as a measure of time for the savings generated by an investment to pay back the initial system cost. It is a popular measure because of its simplicity, and a useful first approximation of payback time. However it does not take into account the time value of money, i.e. that savings realized, or income generated, in the future have a lower value than those generated today. The owner's capital required to invest in a PV system comes at a cost – the opportunity cost – which is the return that could be earned from alternative investments, or the cost to borrow the capital. The time value of money can be accounted for by discounting future savings back to today's value using the opportunity cost, referred to as the discount rate. The net present value (NPV) calculation is commonly used to implement discounted cash flow. The PV Solar Calculator presents Simple Payback Period, Discounted Payback (which takes the time value of money into account) and NPV. Each of these come with an explanation to educate the user.

Firstly the savings achieved by the PV system in each year are calculated. This is simply a multiplication of the energy savings by the appropriate electricity rate. For electricity price rises, more assumptions must be made. The retail price of electricity is assumed to rise at a rate $R_{pp}$, of 1.5%. The buy-back rate is assumed to rise as well, at a rate $R_{bb}$, of 0.5%

$$Savings_{local,year} = Energy_{Local,year\ 0} \times r_{local}^{year} \times Tariff_{year0} \times (1 + R_{pp})^{year}$$
$$Savings_{ExpSum,year} = Energy_{ExpSum,year\ 0} \times r_{ExpSum}^{year} \times Buyback_{Sum,year0} \times (1 + R_{bb})^{year}$$
$$Savings_{ExpWin,year} = Energy_{ExpWin,year0} \times r_{ExpWin}^{year} \times Buyback_{Win,year0} \times (1 + R_{bb})^{year}$$

These are the savings for all of the 25 years, including panel degradation, tariff and buy-back prices, and an approximation of the local-use/export mix. They are summed for each year, according to

$$Savings_{Total,year} = Savings_{Local,year} + Savings_{ExpSum,year} + Savings_{ExpWin,year}$$

Although PV systems are generally reliable, there is an industry expectation that inverter lifetime is around 15 years. Inverter replacement is planned at the 15 year mark, at a cost of \$0.5/Watt. This cost is also referred back to the present day. This does not contribute much to the system costs – at a discount rate of 6%, the inverter replacement cost referred to the present day is just \$0.21/Watt. At 25 years, the system is assumed to have a salvage value of zero. Using these predictions, the savings through local use of PV system power and through exported power are calculated for a 25 year PV system life.

$$Savings_{Total} = \sum_{year=0}^{24} \frac{Savings_{Total,year}}{(1 + r)^{year}}$$

The system costs are

$$Costs_{Total}\ (\$) = Cost_{Initial} + \frac{\frac{0.5\$}{Watt} \times P_{rated} \times 1{,}000}{(1+r)^{15}} + \sum_{year=0}^{24} \frac{\frac{Daily\_charge\_increase}{100} \times 365 \times (1 + annual\_retail\_price\_increase)^{year}}{(1+r)^{year}}$$

where

$Cost_{Initial}$ is the initial system capital cost (\$),
$0.5\$/Watt$ is the inverter replacement cost,
$P_{rated}$ is the system rating (kWp),
$r$ is the discount rate,
$Daily\_charge\_increase$ is the daily charge increase (cents per day) [10],
$annual\_retail\_price\_increase$ is the annual increase in electricity retail price, and
$year$ is the year of calculation, with the first year of installation and operation being 0.

In both equations $r$ is the discount rate, entered by the user as their cost of capital. The key PV Solar Calculator output from these intermediate variables is the Net Present Value (NPV), which is just the sum of all the income minus the costs over the lifetime of the system, referred back to the present day. A positive NPV suggests that the system is worth more than it costs, and could be considered a wise investment. NPV is calculated using income and costs referred to the present day, as follows:

$$NPV = Savings_{Total} - Costs_{Total}$$

These variables are also used to calculate the discounted payback period. This is very simply implemented by progressively summing the discounted savings for consecutive years, until they match the total costs.

The simple payback is similarly calculated by progressively summing the un-discounted savings for consecutive years, until they match the total costs.

[10] This is the question at Step 2 of the Solar Calculator, "would you have to pay an additional daily fixed charge for a solar electricity system?". It accommodates situations where the daily fixed charge increases as a result of installing solar PV (i.e. the Unison style fixed charge increase for high users with PV). It also ensures that the daily charge increase is brought back to present value.

## 3.0 The User Experience

On opening the PV Solar Calculator, the user is faced with a set of questions looking approximately like that shown in Figure 2.

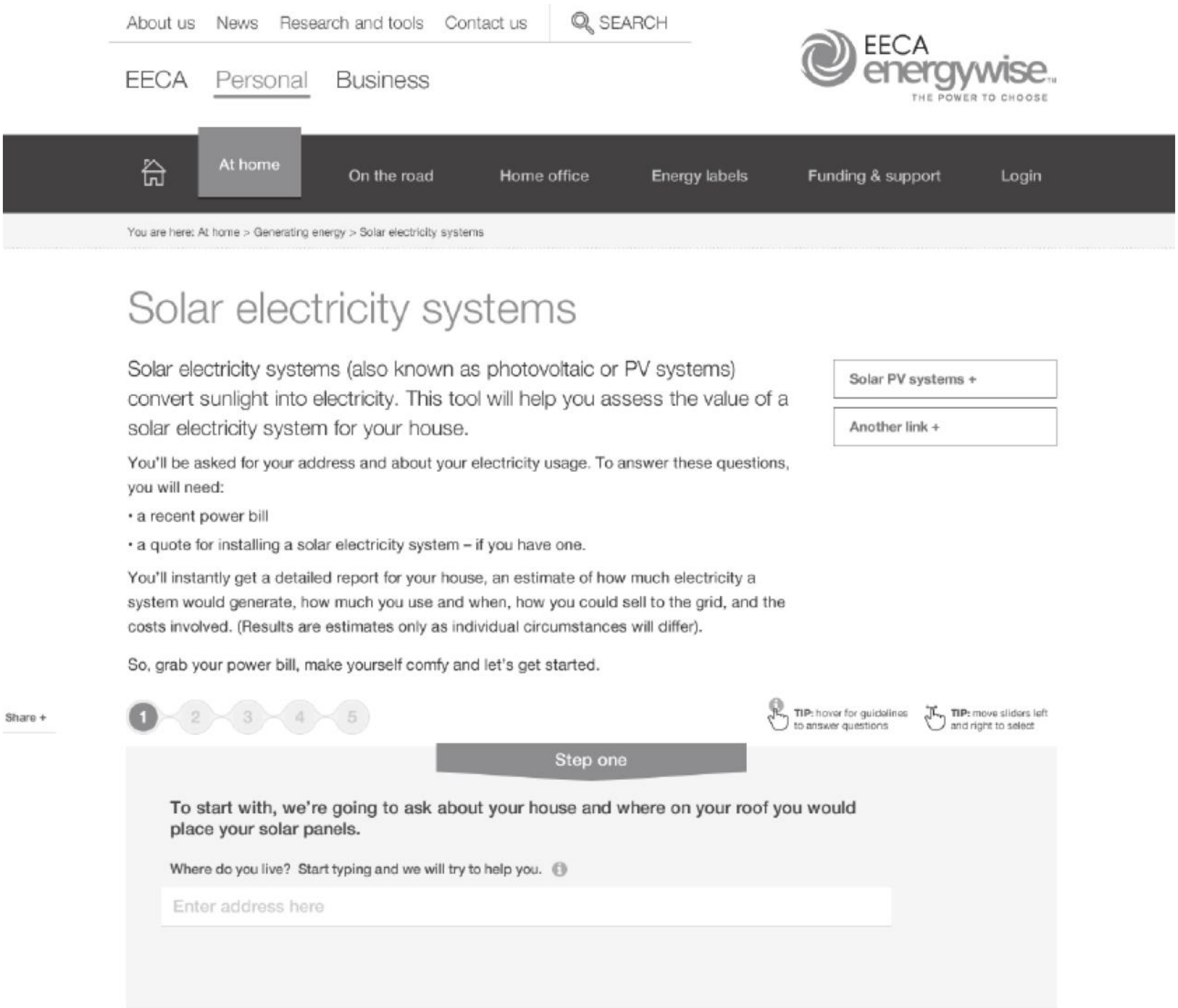


Figure 2: First web site page of the PV Solar Calculator.

A series of questions are asked, and help files are provided. In the end a report is provided in pdf format, which includes a sun path diagram, and graphs showing power generation and consumption on a summer and a winter day, to clarify for the user the importance of the timing of generation and load.

## 4.0 Solar Generation Model Validation

The irradiance data supplied by NIWA and the subsequent calculations to convert the irradiance values into an estimated generation for the PV Solar Calculator were validated by comparison with both measured data and an alternative generation simulation tool. 'Real world' measured data was available via the Genesis Energy 'Schoolgen' project, which publishes measured data from a number of New Zealand schools that have PV generation installed. Data from this project was made available to the EPECentre for the GREEN Grid project under a confidentiality agreement between the University of Canterbury and Genesis Energy, with a condition that any results published are anonymous.

Complete year measured data (or as complete as possible) was obtained for 24 New Zealand schools. The most recent year with the most complete generation data was selected and missing data was interpolated by providing values from the preceding days. Clearly, interpolating for missing data removes system unavailability losses from the resultant measured data but this was undertaken as the reason for the missing data is unknown. The majority of Schoolgen sites have 2.04 kW polycrystalline (also known as multi-crystalline) arrays installed between 2008 and 2009. They cover the North Island reasonably well, but do not cover the South Island. In terms of actual model validation this was not considered significant, although it would be useful to have greater coverage if one was validating the entire system (NIWA irradiance to PV system output, which was not the objective of this validation).

The address of each Schoolgen site, the orientation and tilt of the solar panels and the peak panel capacity was entered into the EECA Solar PV Calculator and a generation figure obtained. Panel degradation of the Schoolgen panels was subsequently taken into account by calculating the number of years from when the system was installed until the year of measurement. A standard degradation figure of 0.8% per year was then applied to account for the drop in efficiency as the panels age – the same value that is used in the PV Solar Calculator, as discussed in section 2.2.

The outputs of the PV Solar Calculator were also compared to an alternative PV generation tool PVWatts API (version 5). PVWatts is a web service provided by the National Renewable Energy Laboratory (NREL), USA, which calculates the energy of grid-connected PV systems using the latitude and longitude, azimuthal angle and tilt of the panels. Default total system losses were used, with availability loss set to zero, which results in a balance of system losses of 11.4%. The beta PV Solar Calculator assumed a balance of system losses of 13%.

### 4.1 Validation Results

After validating the Schoolgen data it was clear that the beta version of the PV Solar Calculator was consistently underestimating generation, with median and mean errors between 6-7% as shown in the first line of Table 4. The PVWatts (v5) tool developed by NREL provided much closer generation estimates with median and mean errors of 0 and -1% respectively as shown in the third line of Table 4. Interestingly the PVWatts tool notes that the version 5.0 is estimating generation between 7-9% higher than the previous PVWatts version 4.0 tool due to a reduction in the default balance of system losses values used. Besides the PVWatts tool using a slightly lower balance of system losses than the beta PV Solar Calculator, different albedo values are assumed, 0.2 for PVWatts and 0.1 albedo in the NIWA data.

One possible source of underestimation error between measured and the beta PV Solar Calculator is around the applied temperature correction. Temperature is one of the hourly meteorological parameters provided by NIWA and this is used to correct for the solar panel efficiencies. As the temperature increases, the solar panels become less efficient. Initially a standard temperature correction was applied, which assumes a standard 1 m/s wind-speed (3.6 km/hr). In New Zealand this could be considered a very conservative correction, as for most parts of the country it is common to have much higher wind speeds. Increased wind speed cools solar panels, and thereby improves panel efficiency. Wind cooling effects have been reported by Koehl et al. (2011) to be as much as 15-20°C for wind speeds of 10 m/s (36 km/hr) at a solar irradiance of 1000 W/m2. To bring the PV Solar Calculator estimated generation values more in-line with the measured generation values, the temperature correction was halved (see section 2.1) and the system overall efficiency increased by 1.5% to 88.5%. The effect of these changes is shown in line 2 of Table 4. The combined effect of halving the temperature correction and increasing the system efficiency reduces the mean error by over 6% to -0.2% and the median error is reduced by over 5% to -0.8%. Figure 3 shows the difference between the different generation simulations and measured data for the 24 Schoolgen sites.

Table 4: Mean and median percentage difference errors of the generation estimation tools when compared to measured Schoolgen data over a year.

| | Balance of System Losses | Median Error (%) | Mean Error (%) | Mean Absolute Error (%) |
|---|---|---|---|---|
| **Beta PV Solar Calculator** | 13% | -6.1 | -6.6 | 6.8 |
| **PV Solar Calculator with modified temperature correction & BOS losses** | 11.5% | 0.8 | -0.2 | 4.1 |
| **PVWatts (v5)** | 11.4% (default) | -0.2 | -1.1 | 3.9 |

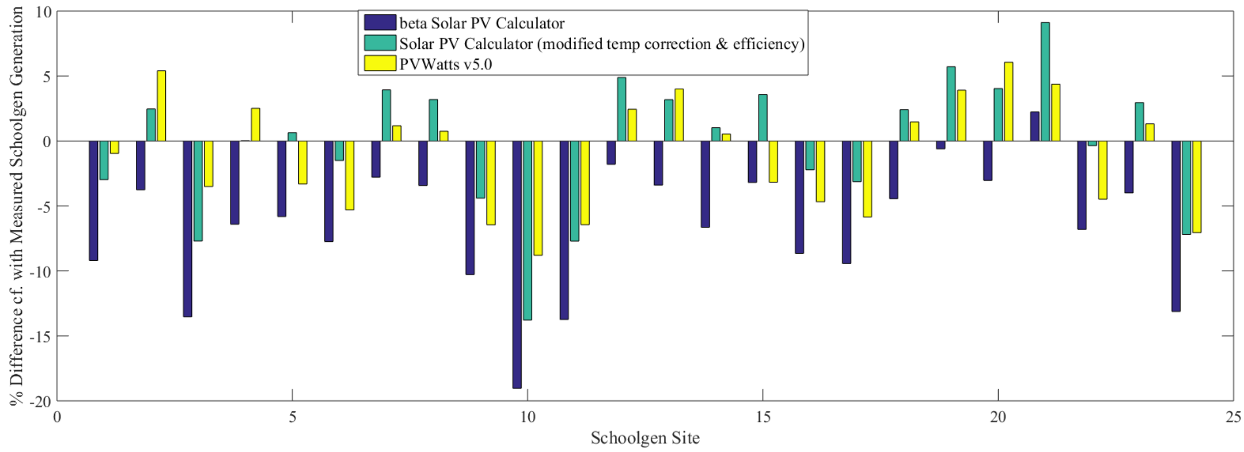


Figure 3: Bar graph showing the percentage difference of the three generation estimation tools compared to the measured generation for 24 Schoolgen sites. The generation estimator tools are

the beta version of the PV Solar Calculator, a modified version of the PV Solar Calculator incorporating adjusted temperature correction and losses and the NREL PVWatts tool. A negative value of the % difference indicates instances where the generation estimator is under-estimating generation compared to the measured Schoolgen data.

## 5.0 Discussion and Conclusions

As anyone knows, predicting the future is not easy. However, this is exactly what any investment decision requires, and, with its 25 year forecast period, it is what this PV Solar Calculator attempts. There are many assumptions built into the model, some of which are summarized below:

- the user load profile can be reasonably approximated by some basic questions and some analysis of a range of known load profiles;
- normalized median value of a number of load profiles is representative of an individual household;
- sunshine patterns remain effectively unchanged for the system lifetime;
- user load profile shape and total energy consumption remain unchanged over the system lifetime;
- matching of PV generation and household load profile, to determine self-consumption and export, is appropriate at an hourly level, rather than more frequent samples;
- cost of capital remains substantially unchanged over the system lifetime;
- electricity tariffs and rates applicable to domestic PV system owners will not structurally change; and
- energy storage systems remain too expensive for widespread implementation.

The implementation of the model itself has also required assumptions about certain parameters. These are summarized in Appendix One. Many of the assumptions listed above are made because there is no clear better choice. For example, it is clear that tariff structures for PV system owners will change, but there is insufficient information to predict what these might be. It is also possible that smarter control of hot water heating, as encapsulated in some products entering the market, may add to system savings, although of course they also add to system costs. While acknowledging these limitations, the PV Solar Calculator provides an unbiased and fair assessment of the value of a PV system to a domestic householder; a service that has not been freely available to date.

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## Appendix One - Assumptions

| Parameter | Solar Calculator Assumption |
|---|---|
| PV System Size (kWp), $P_{rated}$ | User Input |
| PV System Cost ($/Wp) | User Input |
| Inverter replacement time (years) | 15 |
| Inverter replacement cost after 15 years ($/Wp) | 0.5 |
| Inverter cost escalation for replacement (%/year) | 0 |
| Operation and maintenance cost ($/kW/year) | 0 (based on New Zealand's predominantly rainy conditions) |
| Operation and maintenance cost escalation (%/year) | 0 |
| PV System salvage value at 25 years ($/Wp) | 0 |
| PV Balance of System Losses (%) | 11.5 (i.e. 88.5 efficiency) |
| PV Annual panel degradation (%/year) | 0.8 |
| PV Panel tilt (degrees) | User Input |
| PV Panel azimuth (degrees) | User Input |
| Irradiance (W/m$^2$) | Obtained from NIWA for the given location, panel tilt, and orientation |
| PV Temperature effects accounted for | Yes, although slightly de-rated due to New Zealand's windy conditions, which lead to more efficient PV panel production. |
| Variable electricity retail price (c/kWh) | User Input |
| Summer grid buyback rate (c/kWh) | User Input |
| Winter grid buyback rate (c/kWh) | User Input |
| Daily charge increase (cents per day) | User Input |
| Summer hours | 1 October to 30 April |
| Winter hours | 1 May to 1 September |
| Annual retail price adjustment (%) | 1.5 |
| Annual buy-back price adjustment (%) | 0.5 |
| Analysis time period (years) | 25 |
| Discount Rate (%) | User Input |
| Load profiles used | 32 representative load profiles, per NZ region, based on a database of 20,000 load profiles. |
| Annual electricity consumption | User Input |
| Pricing scheme (night rate or flat rate) | User Input |
| At home and using electricity in the daytime | User Input |
| Main hot water heating source | User Input |
| Main heating source | User Input |

The electricity retail price increase is based on historical general CPI from 2008 to 2014, which was 1.4%, obtained from the Reserve Bank of New Zealand inflation calculator (RBNZ 2016). While the MBIE (2016) sales based residential electricity costs show an average increase of 3.7% (nominal) and 1.7% (real) over the same time period, a figure closer to the general CPI figure was used. This ensured a more conservative estimate of solar returns. One reason for this more conservative choice of annual retail price increase was that the most recent annual change in residential electricity costs was negative (MBIE 2016). Consequently it was felt the use of the historical nominal residential electricity cost increase of 3.7% was unrealistic for every year for the next 25 years. Hence a conservative figure of 1.5% was used. It is noted that a higher figure would increase the NPV, although cash flows contributing to this are discounted quite strongly (by 6% if the user chooses that option – i.e. if the user's cost of capital is based on their mortgage interest rate or an alternative investment with similar after tax returns).

The buy-back rate increase is based on a number of observations of wholesale prices and their trends:

- Observation by the Electricity Authority that wholesale electricity prices are not much higher now (2014) than they were in the 1980s (Electricity Authority 2014);
- The fact that buy-back rates have fallen substantially in the past two years (although that is more a matter of removing subsidies by generator-retailers to bring the buy-back rate closer to the wholesale electricity price); and
- The current buy-back rate is above the average wholesale price (2009 to date).

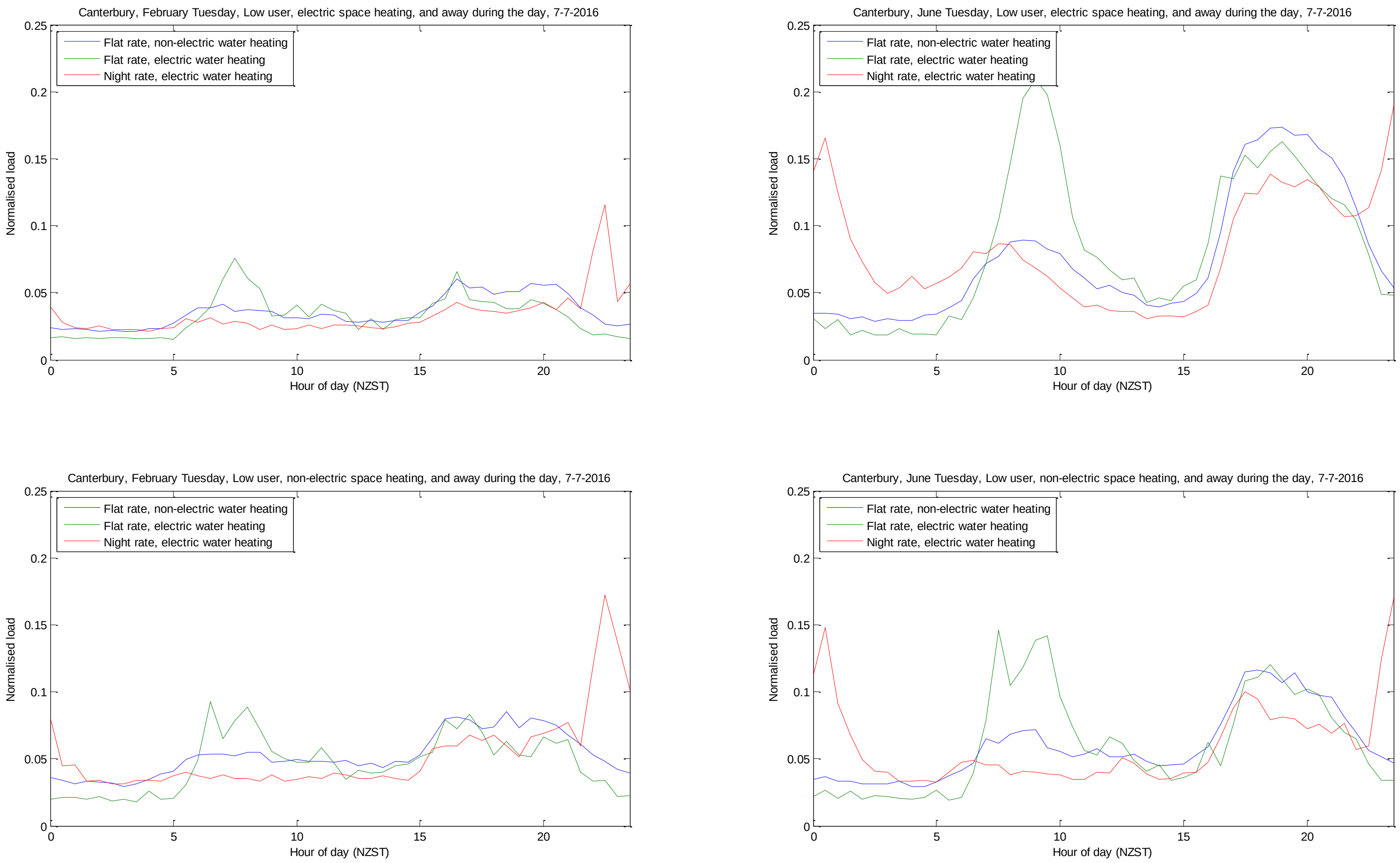
The buy-back rate increase will tend to move the NPV towards more positive numbers.

In both cases we are trying to predict what the rate of increase of each will be for each year of the next 25 years, which is simply impossible. In the design of the calculator it was considered preferable to leave these as fixed assumptions rather than user inputs. This is because the calculator had to strike a balance between everything being a configurable input and greater simplicity of inputs, noting that the output is clearly stated to be an estimate.

## Appendix Two – Load Profiles

Electric Space Heating

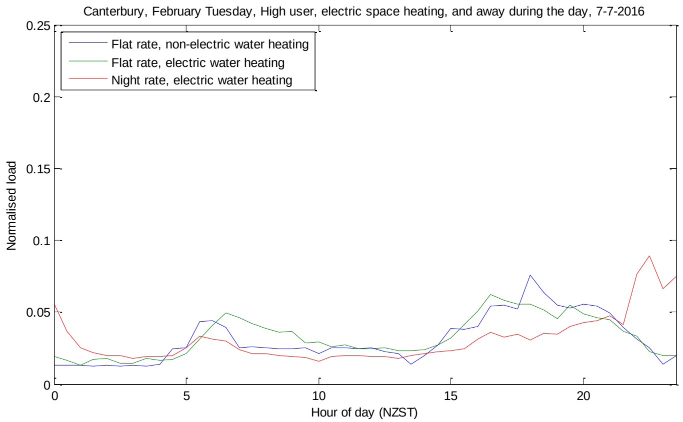
Non-Electric Space Heating

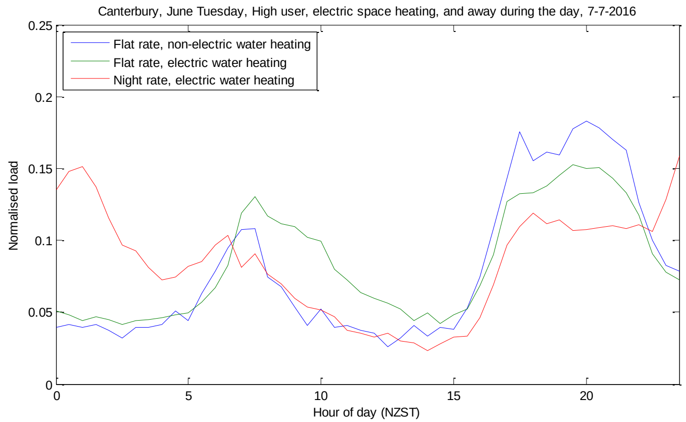



**Summer** **Winter**

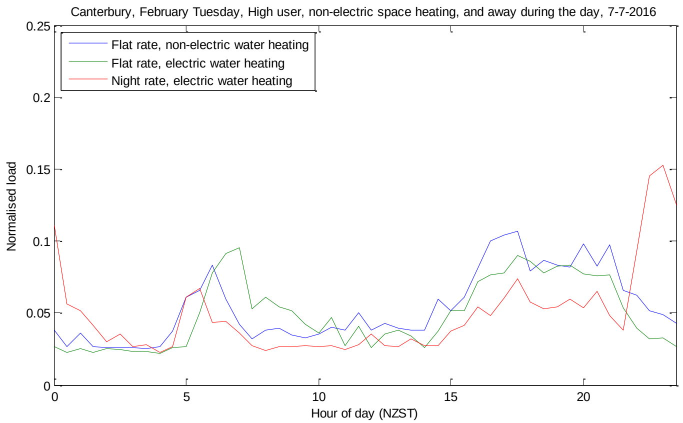
Figure 4: Canterbury low user, away during the day.

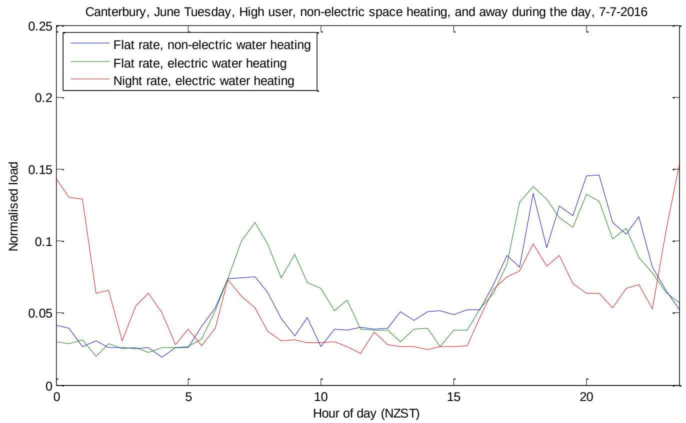
Electric Space Heating




Non-Electric Space Heating




**Summer** **Winter**

Figure 5: Canterbury high user, away during the day.

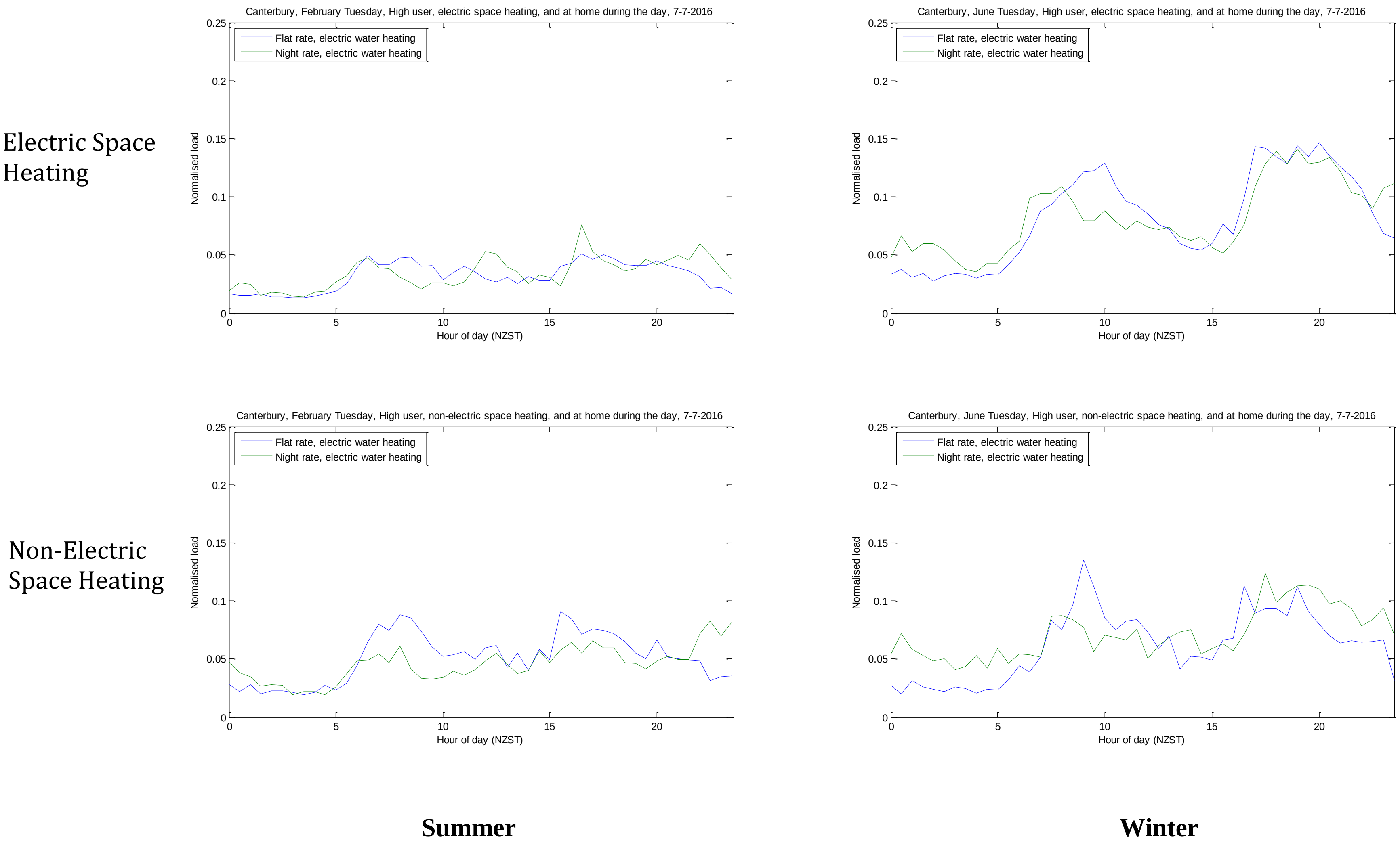
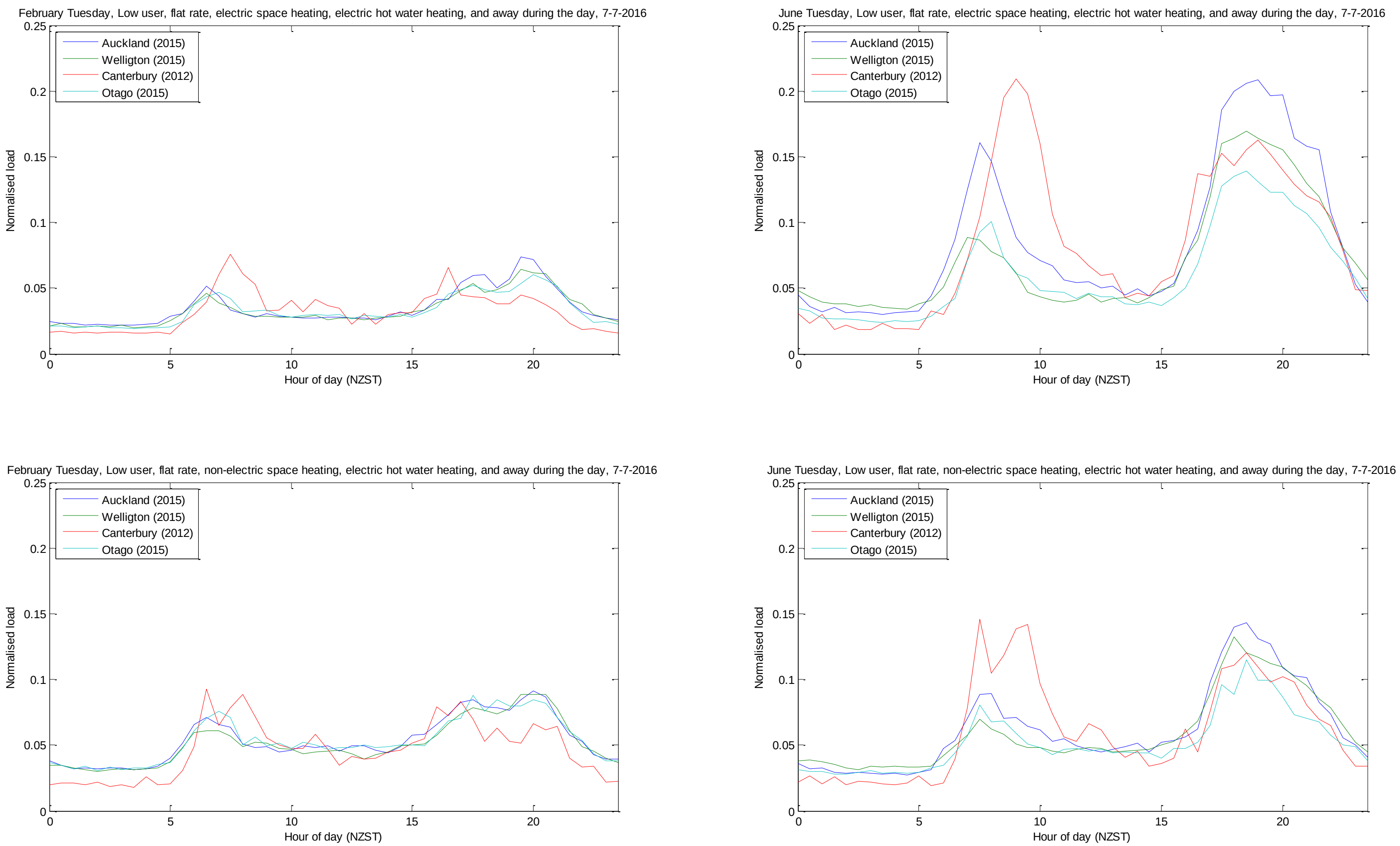



Figure 6: Canterbury high user, electric hot water heating, and at home during the day.

Electric Space Heating

Non-Electric Space Heating

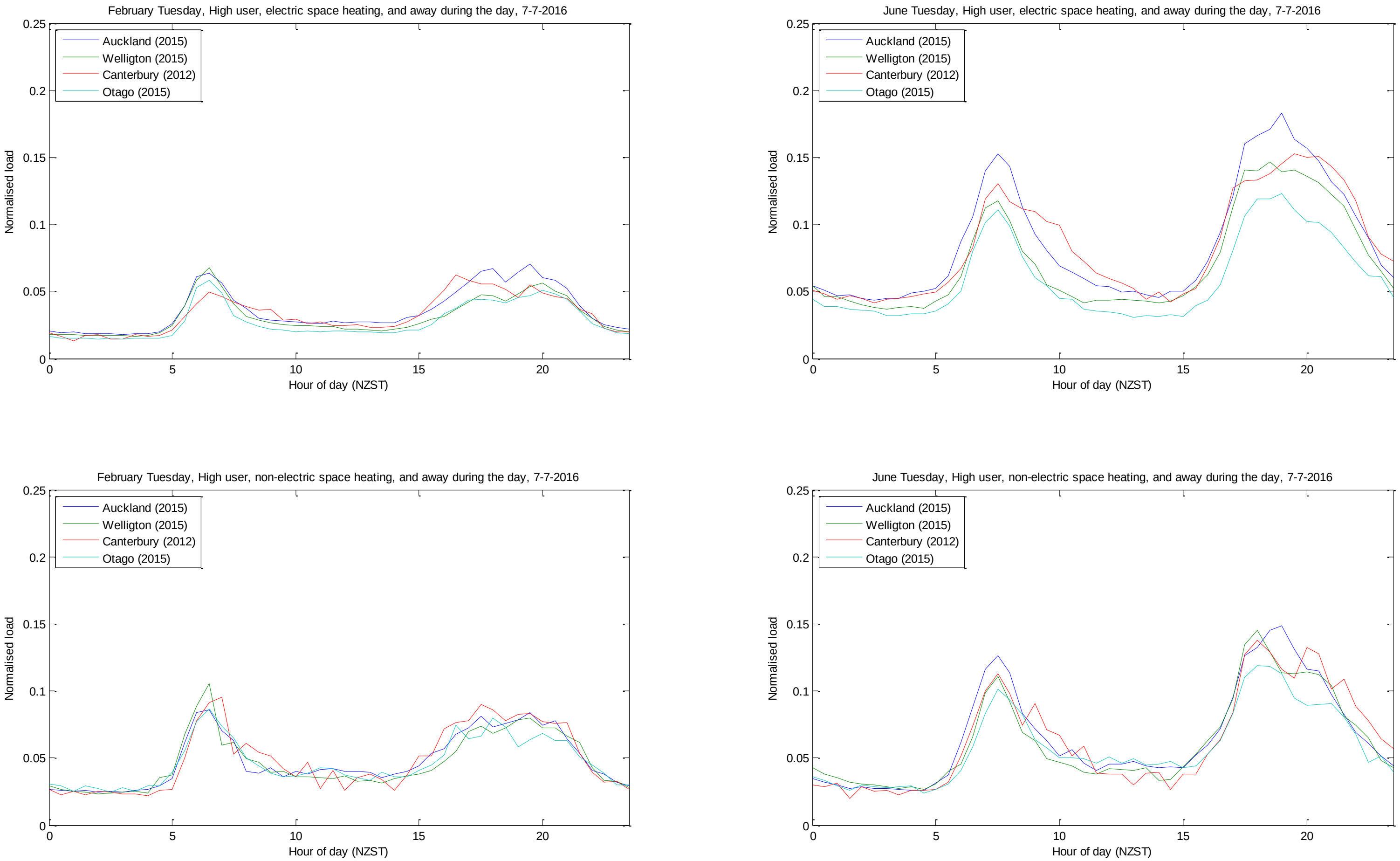



**Summer** **Winter**

Figure 7: Low user, electric hot water heating, flat-rate tariff, and away during the day.

Electric Space Heating

Non-Electric Space Heating

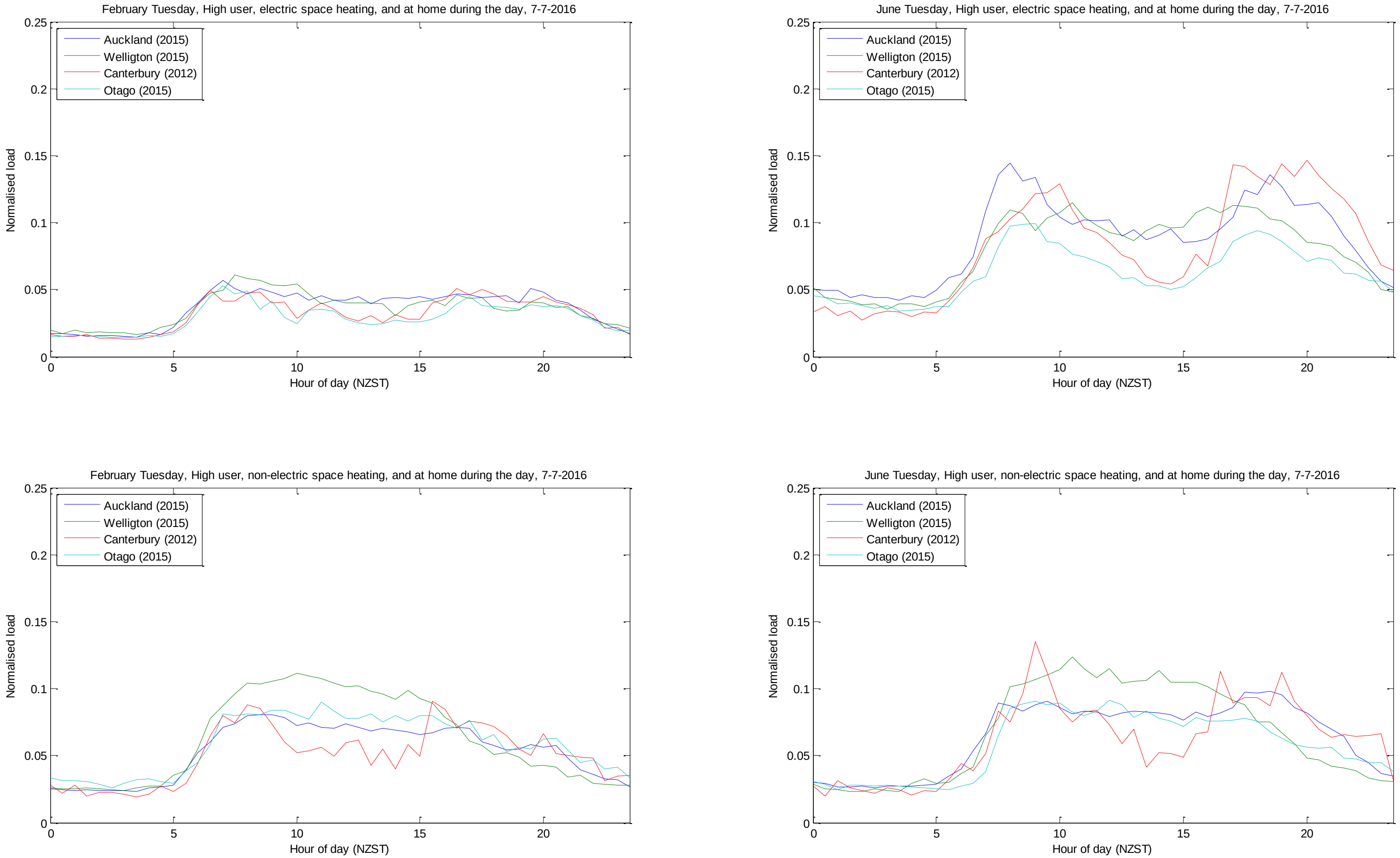



**Summer** **Winter**

Figure 8: High user, electric hot water heating, flat-rate tariff, and away during the day.

Electric Space Heating

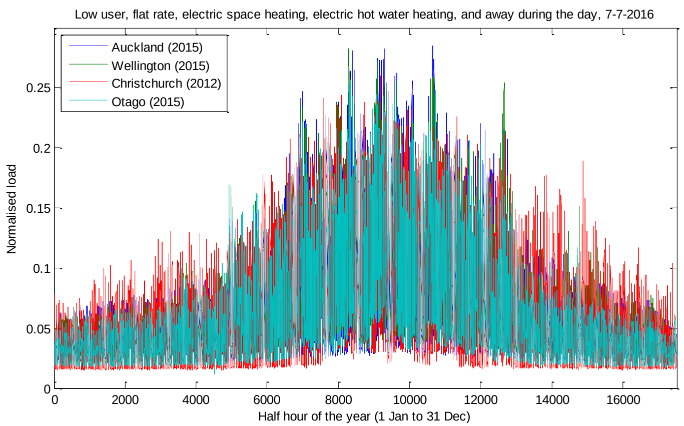
Non-Electric Space Heating

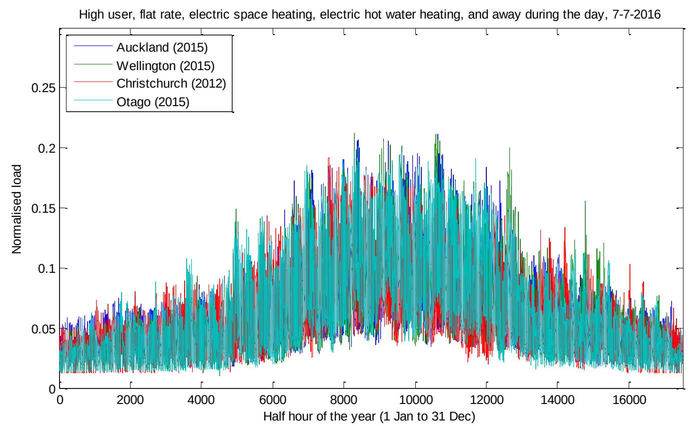



**Summer** **Winter**

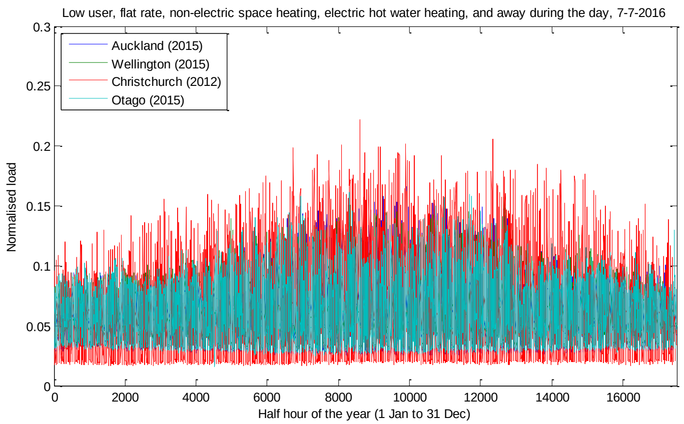
Figure 9: High user, electric hot water heating, flat-rate tariff, and at home during the day.

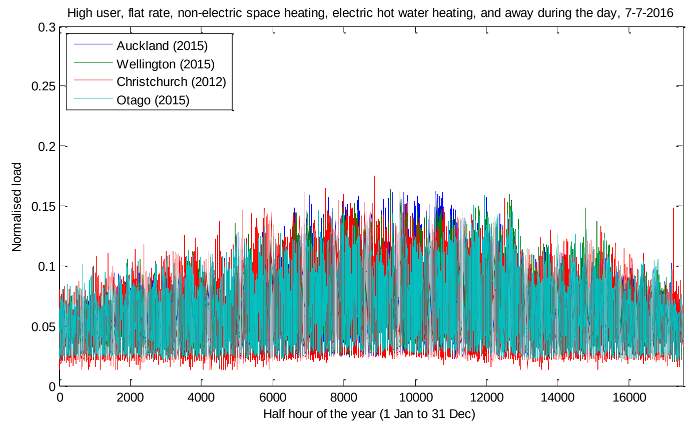
Electric Space Heating




Non-Electric Space Heating

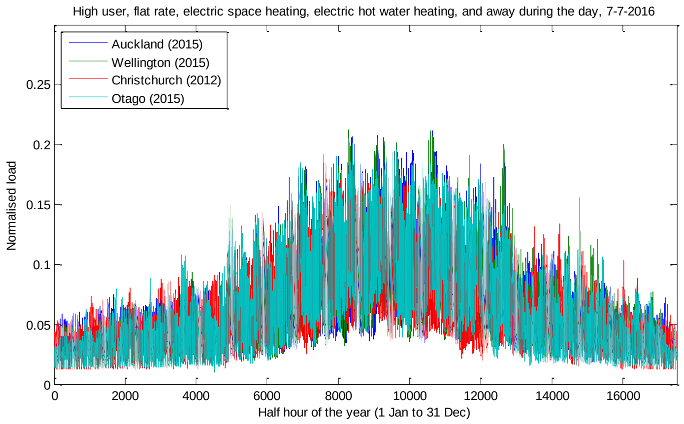


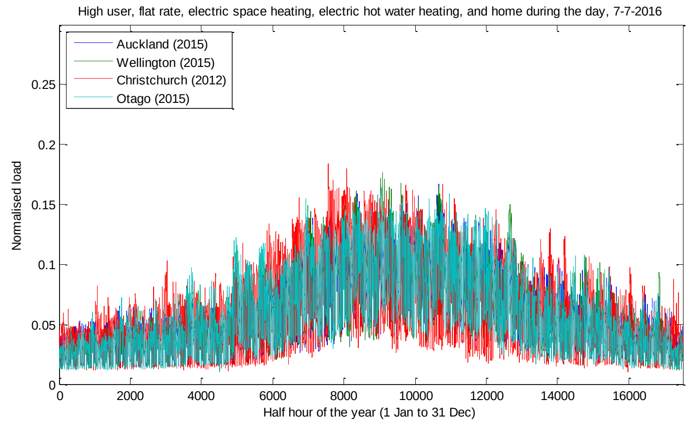




**Low User** **High User**

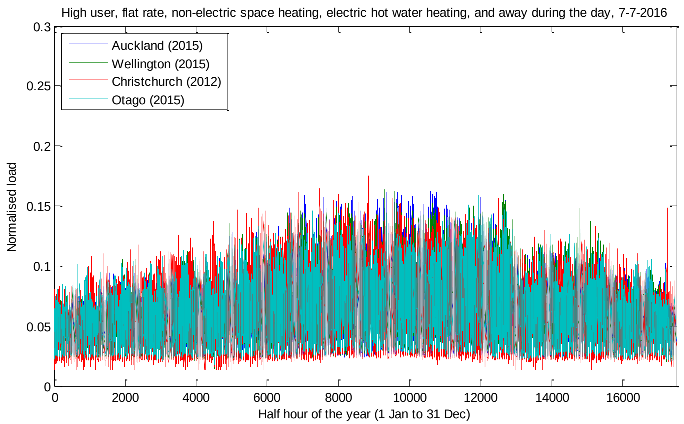
Figure 10: Electric hot water heating, flat-rate tariff, and away during the day. Plots are from 1 January to 31 December

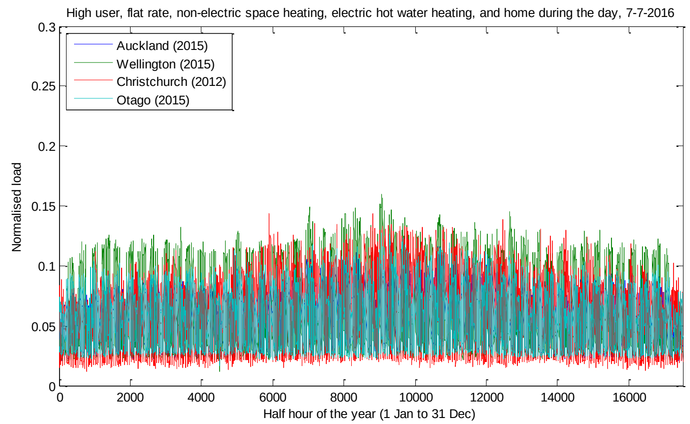
Electric Space Heating




Non-Electric Space Heating




**Low day time energy use** **High day time energy use**

Figure 11: Electric hot water heating, flat-rate tariff, and away during the day. Plots are from 1 January to 31 December.

## Appendix Three – Rules for Load Profile Substitution

The over 18 thousand load profiles were classified according to five classification parameters:

- High/Low User
- Electric or Non-electric Space Heating
- At Home/Away during the day
- Flat Rate/Night Rate tariff
- Electric or Non-electric Hot Water (HW)

This results in 32 ($2^5$) possible combinations. However not all combinations are commonly found in reality, and indeed, a Night rate tariff is used as an indicator by the classification algorithm to indicate a household has Electric hot water heating. Therefore no households are classified with a combination of Night rate tariff and Non-electric hot water, the justification being that typically Night rate tariffs are used to shift hot water heating loads to when the retailer offers a cheaper electricity rate. Nevertheless, this does not prevent the user from selecting such an input combination. However, some combinations simply result in a very low number of samples, in particular Profile Types, such as a High User with Non-electric Space Heating and Non-electric Hot Water Heating (profiles 17 and 21). Another notable difference leading to smaller sample sizes in some categories is that Night Rate is uncommon is many regions.

To overcome issues with empty or small sample sizes for determining a median load profile, a threshold was introduced. Median load profiles are only generated for a particular Profile Type and region if the classification process (described in Section 2.3.2) results in ten or more households being assigned to that category. If a Profile Type in a region is below this threshold, rules were determined to provide "the closest" load profile to substitute in.

The rules for reassigning a load profile are documented in Table 5 below. The column "Population Status" considers if a Profile Type over all Regions is populated. It is "Fully populated" if all regions have 10 or more households in that Profile Type. It is "Partially populated" if only some of the regions have 10 or more households and "Unpopulated" if none of the regions have 10 or more households for that profile type.

There are two main types of reassignment: in the "Partially populated" case, an alternative above threshold region is selected to be substituted (horizontal reassignment), and in the "Unpopulated" case, where no region has the requisite number of households for that profile classification, a different profile classification is substituted (a vertical reassignment).

#### Horizontal Reassignment Rules

For the "Partially populated" case, the region with the largest above threshold sample in the same island is selected as a substitute; if none is found then the region with the largest threshold sample in the country is used. For example, in Profile Type 4, Northland, Bay of Plenty, Hawke's Bay and Taranaki-Whanganui do not reach the threshold number of households, however Wellington has the largest number of households in this category for the North Island and is used as the substitute median load profile.

#### Vertical Reassignment Rules

When the Profile Type is "Unpopulated" the nearest vertical substitute is used: the re-classifications used are summarised below,

- Non-electric Hot water and Night Rate, changed to Flat Rate;
- At Home reclassified to Away; and
- Night Rate changed to Flat Rate (only Profile Type 24).

The following classifications (from the process described in Section 2.3.2) are always preserved:

- High/Low User;
- Electric & Non-electric space heating; and
- Electric/Non-electric Hot water.

The worst case vertical substitution changes two of the five classifiers for an under-represented Profile Type. As shown in Table 5, this happens with Profile Type 7, 15, and 31. It only occurs when there is a combination of Non-electric Hot water and Night Rate which attempts a substitution to a Flat rate tariff. If in turn this Profile Type is unpopulated, the At Home classification is reclassified to Away.

To give an example of a vertical redirect, Profile Type 3 has no households classified at all, as it specifies the disallowed combination of Non-electric Hot Water and a Night Rate tariff. Hence, a Flat Rate tariff (Profile Type 1) is substituted instead.

Note that in the case of a vertical substitution to a profile type that is only partially populated, the regions that are below the threshold will have a substituted region, and this will be the median load profile used for the vertical substitution also.

#### Missing Region Data

As detailed in Table 1, of the 16 regions considered, only 10 regions had sufficient households with power consumption data. Gisborne had no data, while Nelson, Tasman, Marlborough, West Coast and Southland had too few households to have meaningful sample sizes. Gisborne uses the median load profiles from its closest neighbour geographically, Hawke's Bay (and the associated Profile Type substitutions). Similarly Tasman, Marlborough and the West Coast use Canterbury's median load profiles, while Southland uses Otago's median load profiles.

Table 5: Summary of how Load Profiles were assigned to other Load Profile types when either low or no households classified in the associated Profile Type.

| Profile Type | Profile Population Status | Low or High User | Space Heating | At home during week days | Tariff | Hot Water Heating | Reassignment Principles (classification or region substitutions) | Substituted Profile Type/Region |
|---|---|---|---|---|---|---|---|---|
| 1 | Fully | Low | Non-electric | Away | Flat Rate | Non-electric | - | - |
| 2 | Fully | Low | Non-electric | Away | Flat Rate | Electric | - | - |
| 3 | Unpopulated | Low | Non-electric | Away | Night Rate | Non-electric | Non-electric HW & Night Rate -> Flat Rate | 1 |
| 4 | Partially | Low | Non-electric | Away | Night Rate | Electric | Use different region | 5 regions -> Wellington |
| 5 | Unpopulated | Low | Non-electric | At Home | Flat Rate | Non-electric | At Home -> Away | 1 |
| 6 | Partially | Low | Non-electric | At Home | Flat Rate | Electric | Use different region | 15 regions -> Wellington |
| 7 | Unpopulated | Low | Non-electric | At Home | Night Rate | Non-electric | Non-electric HW & Night Rate ->Flat Rate<br>At Home -> Away | 5 |
| 8 | Unpopulated | Low | Non-electric | At Home | Night Rate | Electric | At Home -> Away | 4 |
| 9 | Fully | Low | Electric | Away | Flat Rate | Non-electric | - | - |
| 10 | Fully | Low | Electric | Away | Flat Rate | Electric | - | - |
| 11 | Unpopulated | Low | Electric | Away | Night Rate | Non-electric | Non-electric HW & Night Rate -> Flat Rate | 9 |
| 12 | Partially | Low | Electric | Away | Night Rate | Electric | Use different region | 4 regions -> Wellington |
| 13 | Unpopulated | Low | Electric | At Home | Flat Rate | Non-electric | At Home -> Away | 9 |
| 14 | Unpopulated | Low | Electric | At Home | Flat Rate | Electric | At Home -> Away | 10 |
| 15 | Unpopulated | Low | Electric | At Home | Night Rate | Non-electric | Non-electric HW & Night Rate -> Flat Rate<br>At Home -> Away | 9 |
| 16 | Unpopulated | Low | Electric | At Home | Night Rate | Electric | At Home-> Away | 12 |
| 17 | Partially | High | Non-electric | Away | Flat Rate | Non-electric | Use different region | 3 regions -> Auckland |
| 18 | Fully | High | Non-electric | Away | Flat Rate | Electric | - | - |
| 19 | Unpopulated | High | Non-electric | Away | Night Rate | Non-electric | Non-electric HW & Night Rate -> Flat Rate | 17 |
| 20 | Partially | High | Non-electric | Away | Night Rate | Electric | Use different region | 15 regions -> Canterbury |
| 21 | Unpopulated | High | Non-electric | At Home | Flat Rate | Non-electric | At Home -> Away | 17 |
| 22 | Fully | High | Non-electric | At Home | Flat Rate | Electric | - | - |
| 23 | Unpopulated | High | Non-electric | At Home | Night Rate | Non-electric | Non-electric HW & Night Rate -> Flat Rate<br>At Home -> Away | 17 |
| 24 | Unpopulated | High | Non-electric | At Home | Night Rate | Electric | Night Rate -> Flat Rate | 22 |
| 25 | Fully | High | Electric | Away | Flat Rate | Non-electric | - | - |
| 26 | Fully | High | Electric | Away | Flat Rate | Electric | - | - |
| 27 | Unpopulated | High | Electric | Away | Night Rate | Non-electric | Non-electric HW & Night Rate -> Flat Rate | 25 |
| 28 | Partially | High | Electric | Away | Night Rate | Electric | Use different region | 7 regions -> Wellington |
| 29 | Unpopulated | High | Electric | At Home | Flat Rate | Non-electric | At Home -> Away | 25 |
| 30 | Partially | High | Electric | At Home | Flat Rate | Electric | Use different region | 1 region -> Auckland |
| 31 | Unpopulated | High | Electric | At Home | Night Rate | Non-electric | Non-electric HW & Night Rate-> Flat Rate,<br>At Home -> Away | 25 |
| 32 | Partially | High | Electric | At Home | Night Rate | Electric | Use different region | 15 regions -> Canterbury |