Moving to the Sunny Side of the Street: Growing Residential Solar Electricity in New Zealand

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Abstract

This paper investigates the financial incentives for domestic photovoltaic (PV) array installation in New Zealand. It assesses costs, electricity rates, and the importance of locally used versus grid-exported power. It considers domestic water heating as an alternative use of a domestic PV installation, and shows that while less energy is harvested, the financial return to the householder is greater. Some aspects of the impact of PV installations on electric power grid operation are briefly discussed.

1. Introduction

Photovoltaic (PV) panels are often mentioned as part of the mix of distributed renewable generation that can contribute to our future electric energy needs. Panels may be installed in solar farms, reaping economies of scale and operational benefits, or on domestic householders' roofs, reaping the benefit of existing support structures and local electrical wiring. This paper is focussed on householder funded domestic installations, in locations where there is ready or existing access to the electric power grid.

It is very important to quantify the costs and benefits of installing a PV panel array for domestic householders, to assist them with the decision making process, and so that the likely uptake of this technology can be assessed by system planners. The aim of this paper is to calculate and clarify the return on investment that a PV installation is likely to provide for a home owner.

The value of a PV installation is strongly dependent on the use the power is put to. Grid connection is usually considered, as every watt generated is fed into the grid, generating income and reducing our national dependency on other resources. For a domestic consumer to generate as much power as they consume certainly has a 'feel good' factor. However, invariably the feed-in tariff is significantly less than the retail price, and income generated is taxed. Balancing power generation with power consumption certainly does not mean that income and costs are balanced. As buy-back tariffs may change in the future, there is also exposure to financial risk.

There are a few tools available to help the domestic householder decide on the value of a PV installation. NIWA's SolarView web application does an excellent job of calculating the solar energy available [1], but doesn't calculate the output power for a PV array, or the likely financial return. The National Renewable Energy Lab (NREL) in the USA provides a user friendly web tool to calculate the power generated and financial return for a grid connected PV array [2]. Within New Zealand, Christchurch, Wellington and Auckland are the only sites with data. It also assumes that all the energy is exported. Homer [3] is a free PC based program developed by NREL. Although it requires more effort, understanding, and data from the user, it is a useful package that can optimise a range of power systems including grid connected and stand-alone systems. It includes an hourly profile of load, and grid retail and buy-back prices, as well as system capital and O&M costs. With sufficient data, Homer should be able to replicate the results in this paper. A number of grid connect inverter manufacturers provide basic tools; [4] provides a good summary of them. It is clear that there is a need for a New Zealand based public domain PV analysis tool, to allow householders to relatively simply calculate the value of a PV investment.

It is possible to increase the value of the power generated by storing the energy in the home for later use. Batteries are still very expensive, but most houses have a significant energy store - their hot water cylinder. Although this is a low grade of energy, it is a cheap and effective energy store. Although systems to heat water using the electricity from PV panels are not commercially available, this paper argues that they should and will be.

This paper examines the economic value of domestic photovoltaic systems in grid connected and water heating applications. It draws conclusions about the expected uptake of the technology, and its implications for management of the electricity supply system.

A number of models are required to calculate the economic value of a PV investment. Insolation and its variability is important, as is the number of solar panels, their angle, and temperature. The install cost is critical, as is the proportion of energy generated that is locally used and the proportion that is either injected into the electric grid or discarded, which requires load modelling and time of use assumptions. If electricity is injected into the grid, the buy-back price offered by retailers is important, as are the tax implications. Even the choice of electricity plan between controlled and uncontrolled rates is important. All of these factors are discussed in the following sections.

The paper is structured as follows. Firstly, the test case for the analysis is described. Then the solar resource and panel modelling are discussed, followed by an overview of capital costs and electricity pricing. The merits of grid connection and water heating are presented, and the economics of both systems is assessed. Finally, there is a very short discussion of some of the implications of the proposed systems on the operation of our electric power systems.

2. The Test Case

The return on investment for PV panels is strongly dependent on many factors, and the result will be different for every situation. However a situation does have to be assumed to make any calculations, and in this paper a fairly typical household is used. The house is located in Christchurch, and has an approximately average power consumption of 9,000kWh/year. The water heating consumption is indirectly defined in NZS/AS4234 for an average Christchurch house as an annual power consumption of 3,000kWh per year, or 33% of the total consumption. It has enough north facing roof for 25 190 Watt panels, at an angle of 30 degrees from horizontal. Panels are flush mounted. Other more general assumptions are outlined in the following sections.

3. Solar Resource and Panel modelling

This paper uses a number of models to calculate the energy availability from solar panels. As power generation is dependent on panel angle, sun position, weather conditions, panel temperature (which depends on ambient temperature and insolation conditions), and load characteristics, all these effects are included.

3.1 Insolation and Temperature models

NIWA run an excellent insolation model, that is freely available to the public [1]. It provides average insolation data for each hour of the day, on either a monthly or daily basis. It requires a user entered location, and calculates the average hourly solar energy available based on insolation measurements from the nearest weather station and the effect of shading from local terrain. This is an excellent resource for anyone considering installing a PV array. Daily radiation data on a horizontal surface is also provided by request from the Surface meteorology and Solar Energy (SSE), via a renewable energy resource web site sponsored by NASA [5].

However, the use of average values is not necessarily appropriate. For example, for water heating, while the average insolation may be sufficient, low insolation days will result in insufficient heating, and high insolation days will result in some energy being discarded. Use of average values may give an optimistic calculation of the value of such a system. Even with grid connection, the variation changes the avoided utilisation/exported to grid mix. This paper uses daily global horizontal irradiation data from SSE [5], and average monthly temperature data from NIWA [6]. From these it generates hourly radiation, using the random number seeded time dependent auto-regressive model of Aguiar and Collares-Pereira [7], and temperature variation from the method proposed by Dumortier [8], which is based on average, minimum and maximum values, and provides hourly values based on insolation and different warming and cooling rates. Insolation is further split into its direct and diffuse components, using Maxwell's model [9]. It takes into account scattering of light from cloud and the air mass the light has to pass through. The result is a reasonably detailed model that captures the insolation on and temperature of a tilted PV panel at a specified location.

3.2 Photovoltaic Panel Model

Data sheets provided for PV panels usually provide limited information, which restricts the complexity of the panel model that can be used. Typically the data provided is limited to the open circuit voltage and short circuit current, and the maximum power point voltage and current under Standard Test Conditions (STC), the temperature coefficients for the voltage, current, and maximum power and the cell temperature under Normal Operating Cell Temperature (NOCT) conditions. These are tabulated in Table 1 for a 190 Watt NESL panel.

Open Circuit Voltage	V_{oc0}	46.14V
Short Circuit Current	I_{sc0}	5.56A
Max Power Point Voltage	V_{mp0}	38.59V
Max Power Point Current	I_{mp0}	5.05A
Temperature Coefficient, V	α_V	-0.345 %/K
Temperature Coefficient, I	α_I	+0.1055 %/K
Temperature Coefficient, P	α_{Pmax}	-0.4667 %/K
NOCT Temperature	T_{NOCT}	48 ^{o}C

TABLE 1: Typical PV Panel Data

The properties of a PV cell are reasonably accurately encapsulated by

$$I = I_{ph} - I_s(e^{V/mV_T} - 1) \qquad (1)$$

where I_{ph} is the current generated proportional to the irradiance G (W/m^2), V_T is the threshold voltage for conduction of the reverse diode inherent in the cell structure, V_s is the saturation current, V is the terminal voltage and m is the diode factor. The equation can be approximately scaled in both the current and voltage for a panel.

The current I increases linearly with insolation, and more weakly with increasing temperature. The cell voltage decreases linearly with temperature such that the panel power decreases with temperature.

The panel data sheet provides enough conditions that the full panel characteristic of (1) can be calculated. These equations are solved for the maximum power point for the simulated sunlight and temperature conditions.

A 10% loss is assumed to allow for panel soiling, AC and DC wiring losses and inverter losses for grid connected systems, and a 8% loss for the water heating application, reflecting the simpler power electronics and the probable reduced cable length required. In each case a further 1% loss in panel capacity per year is included.

4. Energy Usage Modelling

4.1 Electric Energy Usage model

Energy that is used at the time that the electricity is generated results in avoided electricity costs. This is by far the best outcome for the householder, as the value of each kWh generated is the retail price of the energy. However, in many cases householders are also not at home during the sunny hours of the day. Determining daytime energy usage is important to calculate the effective return on investment. Individual domestic loads are typified by a very low baseline load, such as phone chargers, parasitic electronic loads etc. (100-300W), regular fluctuations, driven by thermostatically controlled water heating or refrigeration (300W-

3kW), user controlled general loads, comprising lighting, entertainment, washing machines, heating etc. (0.5-3kW), and user controlled peak loads, driven by loads such as ovens, cooktops, electric kettle and microwaves (1-5kW) [10]. A more detailed breakdown for New Zealand is available in [11].

In this document it is assumed that for a grid connected system, the first 500 Watts of PV generated power is locally used, and results in avoided electricity bills. This allows for the baseline load, some morning water heating, and loads that the householder controls for when it is sunny.

4.2 Hot water Energy Usage model

If water is deliberately used as an energy store, energy generated during the day can be utilised as hot water in the evenings. The domestic water heating industry has generated a number of standards. The most relevant to this paper is AS/NZS 4234, which, amongst other things, tabulates typical hot water energy usage of three typical NZ household categories on an hourly basis for a full year. Energy usage peaks in August, due to a combination of colder inlet temperatures and greater hot water utilisation, and also peaks in the morning.

It is assumed that the water cylinder is large enough to hold one full day of hot water requirements, and that temperature stratification within the cylinder is maintained. It is assumed that once the daily energy need is met by the PV-based system, excess energy is not harvested. A medium sized household (4-5 occupants) is also assumed.

5. Capital Costs

Solar panels and their accessories are becoming commodities, and their prices have fallen dramatically. As the number of installations rise, installation costs should fall. Currently in NZ, the level of business is so small that suppliers and installers need to price in significant margins to survive. Indicative retail pricing is taken from Australia, where there is a significant domestic PV panel market, and costs have settled to a level consistent with greater market activity. It should be noted that prices vary widely. Grid connected inverters range in price between less than 10c per watt and more than $1 per watt. Panel pricing can vary by a factor of two. The water heating Maximum Power Point tracker cost is estimated. The prices indicated in Table 1 are only meant to be indicative. As time passes and the market matures, these prices will stabilise.

The size of the installation is limited to 5kW. 2 to 4 kW is a more likely installation size, covering some 13 to 27 square metres of roof. With the assumptions made in Table 1, Figure 1 shows the approximate cost of installation for a range of installed power ratings.

Up to about 1.5kW rating, fixed costs dominate. A 2.3kW grid connect installation costs about $8000, which is roughly consistent with local market rates. A similarly sized PV based water heating system would be around $2000 cheaper, mainly due to the reduced hardware and compliance costs.

General Costs	$NZ
Panels	1.35 per watt
Mounting frame	0.50 per watt
Building Consent	450
Grid Connect costs	
Inverter	0.6 per watt
Lines Company application	200
Lines Company inspection	60
Switchboard, fuses, breaker wiring	600
Installation labour	1500
Water Heating costs	
MPPT electronics	250
Switchboard, fuses, breaker wiring	300
Installation labour	1200

Table 1: Cost approximations

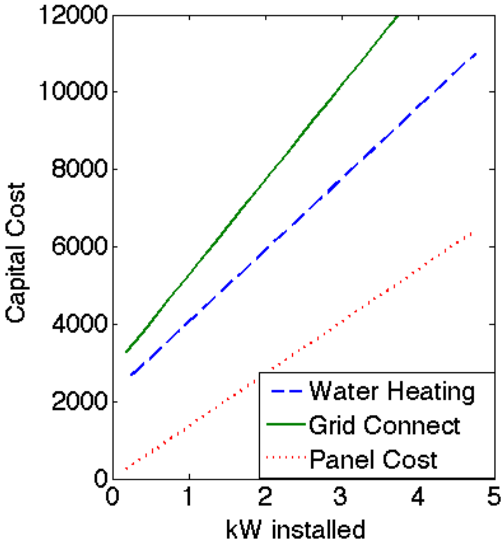

Figure 1: PV system typical costs

6. Retail Prices

The multitude of pricing schemes offered by electricity retailers makes calculation of savings quite difficult. If a property has a single meter, a single rate is offered, typically around 25c/kWh. If the property has two meters, a differential rate is offered; the un-controlled rate is typically between 24 and 30c/kWhr, and the controlled rate is between 12 and 20c/kWhr. It is clear that while consumers with two meters have the opportunity to make savings with their controlled loads, they pay a premium for their uncontrolled power usage.

7. Buy-Back Prices

Meridian Energy is proposing a new buy-back scheme for 2013, offering the first 5kWh each day at 25c/kWh, and then 10c for each subsequent kWh of exported energy. For these schemes, the prompt payment discount on the monthly power bill will longer apply. For a typical household (9,000kWh), grid injection of 5kWh each day results in an annual (after-tax) income of $320 - however the loss of the prompt payment discount costs around $220. It is apparent that for an average customer the effective after tax return is not very attractive.

Contact Energy is the most generous buyer of small scale distributed energy, currently offering slightly more than 17c/kWh. Tax conditions vary according to the individual, but assuming a 33% tax rate, this reduces to 12c/kWh. Other companies offer much closer to the average wholesale rate, between 3.5 and 7c/kWh.

At their best, after tax buy-back prices are less than half the retail rate. It is clear that avoided electricity usage is of far greater economic value to the small PV investor than grid injection.

Retail rates protect domestic users from variations in electricity market spot prices and from system requirements such as reserve, peak shaving, frequency control, voltage control etc. However, they also exclude domestic users from participating in these markets. The value of local generation to the electricity industry varies with time, and it is arguable that if domestic consumers are exposed to appropriate pricing incentives, they may modify their behaviour and/or investments so that they can benefit from market participation.

8. Grid Connection

Grid connection is the usually considered option for domestic rooftop PV. Every kWh generated by the panels is used, either by avoiding electricity usage, or injecting power into the grid. However, grid connection carries a cost overhead (inverter, installation, and compliance), and injected power has only half the dollar value of avoided power usage. All grid connect converter have a Maximum Power Point Tracking (MPPT) algorithm, which ensures that the panels are electrically loaded in such a way that the generate as much power as possible.

9. Water Heating

Water heating is not a well established option for PV panels. However, connecting the PV panels to the heating element, and storing the energy as heat for use in the evening or the following morning has some advantages over grid connection. Grid connection equipment and compliance costs are avoided, and higher value avoided energy usage results. PV based water heating has no pumps, plumbing, freezing and boiling issues, is potentially simpler to install than a thermal collector based system, and should require less maintenance. However, much greater roof area is required, in summer excess energy goes un-utilised, and currently there is no established standard for this sort of system. Nevertheless it is included in this paper, as the idea has merit. Consistent with solar thermal systems, the size of the system is very important - too many panels and the un-utilised summer energy reduces the return on capital, while too few results in the fixed installation costs reducing the return.

9.1 Direct Connection, PV water heating

There is always value in keeping things as simple as possible, and directly connecting the panels to the resistive water heating element is about as simple as it can get. In order for the panels to produce the most power, the load resistance and the combination of panels must be matched. However, as the sunshine and temperature vary, the components don't match properly, and the inability to manage this results in a reduction in harvested energy.

9.2 Maximum Power Point Tracking, PV water heating

As discussed earlier, maximum power point tracking allows the panels to generate at their best at all times. Analysis not reported in this paper shows about a 15% increase in the effectiveness of the system if MPPT is used. This exceeds the additional losses in the power electronics by a significant margin.

9.3 DC or AC

Electrical heating of water is subject to AS/NZS 60335.2.21:2002 where, in particular, it is stated that "closed water heaters shall incorporate a thermal cut-out providing all-pole disconnection and which operates independently from the thermostat." The existence of a thermal cut-out and a thermostat switch in series with the element is easily accommodated with an AC supply, as regularly occurring current zero crossing facilitate breaking of the element current. However, direct connection with either DC or through a DC/DC maximum power power tracking converter doesn't provide such zero crossings. As a consequence it is necessary to provide a suitable snubber circuit across the element/switch combination, to absorb the necessary energy during switching. If the same element is to be used for connection to the grid, a change-over relay must be used, with appropriate electrical isolation. This all adds to the cost of the installation.

10. Results

It is worthwhile examining the variation in solar energy available during the year. Fig. 2 shows, for a year of data, the daily variation in energy available from a 2.3kW panel array, and the daily water heating energy required. It can be seen that the water heating requirements nearly double from mid summer to mid winter, while the energy available from the panels nearly halves. There is considerable daily variation in the available energy, which reflects typical weather conditions.

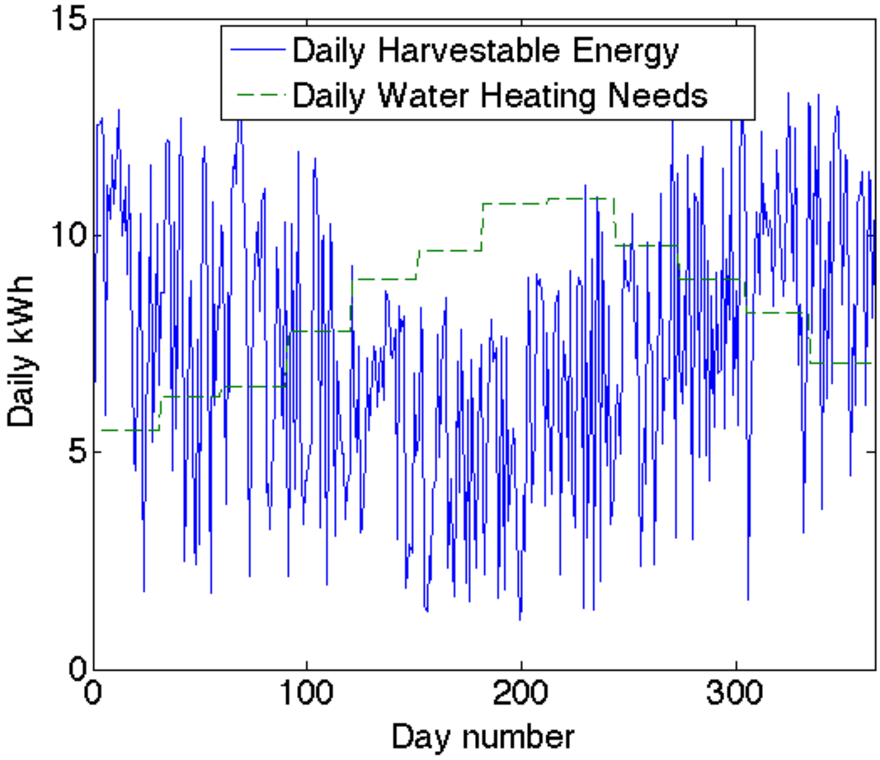

Figure 2: Daily variation in PV power and water heating load

Grid connected systems have a balance between locally used (high value) and exported (low value) energy. Figure 3 shows this balance for a range of system sizes. It also shows the local energy used if the system is used to heat water. This result is strongly dependent on the assumption of an average of 500 Watts of local load while the sun is shining. However, it is an indication of the value of energy storage. As hot water can store energy harvested during the day for use at any time over an assumed 24 hour period, considerably more of the energy can be locally utilised. As discussed, locally utilised power has the highest value to the householder.

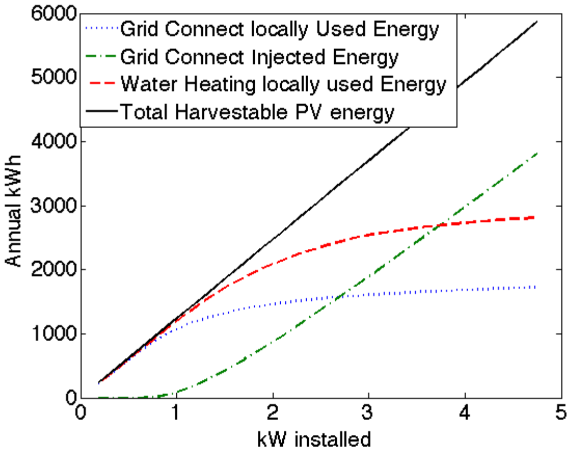

Figure 3: Balance between locally used and either exported or un-utilised energy

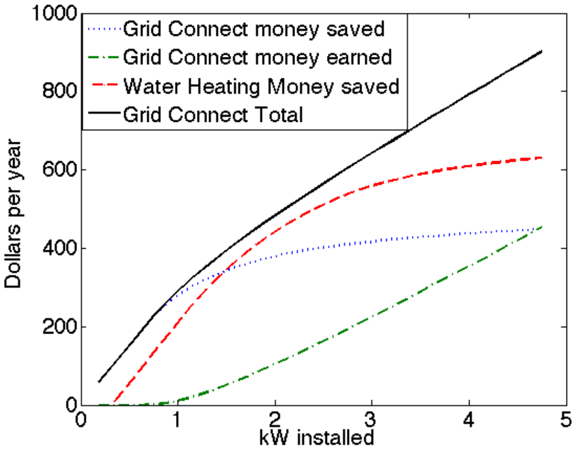

Figure 4: Balance between avoided expenditure and income generated.

This is shown in Fig. 4 which shows the same balance, but measured in dollars instead of kWh. This reflects the high value of locally used energy and the low value of exported energy resulting in a considerable boost in the value of local water heating. In fact, the monetary return from water heating is close to the total return from a grid connected system for system sizes between 1.5 and 3kW. This is in spite of the energy that goes un-harvested in the water heating application. This unharvested energy can be seen in Fig. 3 as the difference between the total harvestable PV energy and the water heating locally used energy curves. For a 2.3kW array, the energy lost is about 25% of the total possible energy generation.

Return on investment is an important indicator of the likely uptake of rooftop PV installations. Fig. 5 shows that the lower capital cost of the water heating system boosts its return to a peak of nearly 8%, while the peak for grid connection is close to 6%.

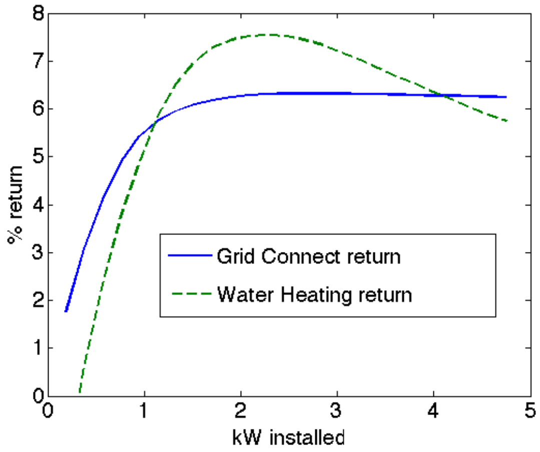

Figure 5: Percentage return on capital

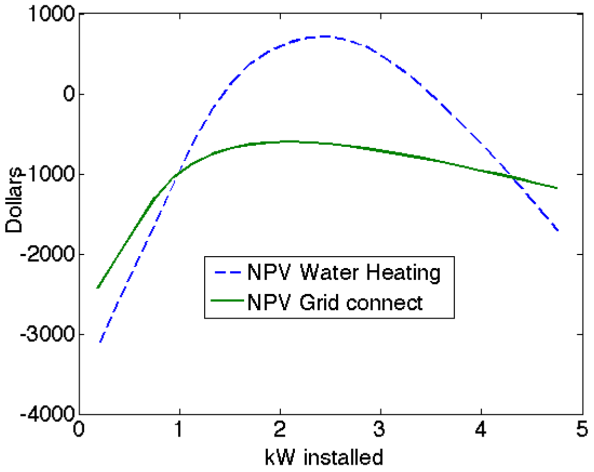

Figure 6: Net Present Value

Although return on investment is often quoted for systems like this, it is not really useful for a domestic householder. For this, the Net Present Value (NPV) is arguably a better measure. Fig. 6 shows the NPV of both water heating and grid connection with a 6% annual discount rate over 25 years, the expected lifespan of such an installation. Inflation of 2.5% is included, as is a 1% degradation per year for the panels. It shows that heating water has a greater NPV than grid connection, and is probably a wiser investment.

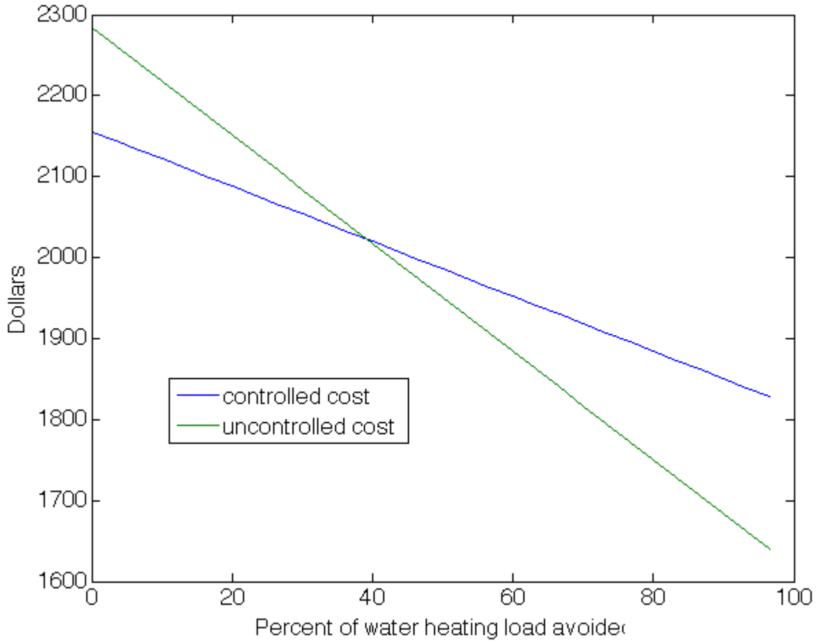

Figure 7: Annual Costs with solar water heating, with controlled or anytime rates

A significant penetration of solar water heating into the market has other consequences. Fig. 7 compares the total electricity cost for the paper's average house, with Contact Energy on its best value controlled and anytime plans. A typical solar based water heating scheme will substitute 70% of the water heating costs, and Fig. 7 shows that the uncontrolled plan is by far the best option. This result is common for most retailers, implying that a significant penetration of solar water heating will result in a significant loss of controllable load. The calculations of savings for this paper include the effect of the householder going from a controlled to an uncontrolled rate.

11. Discussion

This paper examines the economics for domestic householders installing photovoltaic panels on their roofs. It is shown that the value to the householder lies in generating power that avoids using power at the retail rate, and that the financial return for injecting power into the national grid is poor.

Electricity costs comprise an energy cost and a transport cost. Some of the transport cost is passed on to the consumer as a fixed charge, and some as a variable charge, based on the power consumed. Avoiding daytime energy usage through a PV installation does not affect the fixed charge, but does reduce the contribution to energy transport via the the variable charge. PV panels will not reduce the peak power consumption of a house, and will not reduce the infrastructure required for its delivery. Thus to some extent grid connected PV installations are unfairly subsidised by other users. For power injected back into the grid, 17c/kWh or less seems fair, if not very attractive. Without government intervention (as is the case in a number of countries), it is unlikely that these rates will rise. Government intervention is very unlikely in New Zealand, as any form of subsidy or support constitutes a politically unpalatable wealth transfer to those with enough money to install a PV system.

If the PV power is injected into the grid, and required later, effectively the grid is operating as a storage mechanism. Although it is electrically efficient to do this, it is not financially efficient. The grid storage cost per kWh is about half the retail price of the energy. This cost is still less than the cost of battery storage, but it can't compete against thermal storage, as long as low quality thermal energy is acceptable. Water can be heated and cooled an unlimited number of times without degradation, and with good insulation standing losses are low. Further to this, 75% of New Zealand households have existing electrically heated hot water cylinders, and on average these draw 34% of their electrical energy usage [11]. It is clear that thermal storage should not be overlooked.

While space heating and cooling are other significant domestic energy requirements, most houses are not set up to store thermal energy for these needs. The analysis in this paper is restricted to domestic water heating.

There is already a well established solar thermal domestic water heating system industry in NZ, and it is only worth considering using PV panels to electrically heat water if the advantages outweigh the disadvantages. Solar thermal systems have the advantage of high efficiency, which means less roof area is required, with a consequent reduction in install cost. However, they do require a special solar-ready hot water cylinder, plumbing with pumps and valves, and have to be managed to avoid boiling and freezing temperatures at the collector. They may require occasional maintenance of the plumbing. PV systems are more expensive to buy, but cheaper to install. Maintenance costs are negligible, and boiling and freezing are not a problem. Existing hot water cylinders can be used (although twin element cylinders would be better), but there is some electronics required to manage the interface to the cylinder element. While PV systems are likely to be marginally more expensive, their operational benefits may make them more attractive in many circumstances.

Both solar thermal and PV based water heating have disadvantages. Hot water energy usage almost doubles between the summer and winter months, while the harvestable energy from a solar system nearly halves between the summer and winter months. This means that an economically-sized system will consistently fail to meet the winter hot water requirements, while in the summer excess energy must be managed for a solar thermal system, and simply not harvested in a PV based system. The optimum system size balances these two issues, and in both cases results in a system rating of between 2 and 2.5kW for an average household.

For an average household the net present value for domestic grid connected PV systems is not sufficient to justify the investment. While the numbers of such systems is increasing as early adopters invest in the technology, prices will have to come down significantly before significant market penetration can be expected. PV based water heating, once established, will be competitive with solar thermal systems and may take a significant market share as prices drop further. While small scale individual investors cannot benefit from economies of scale, there may be opportunities for larger investors, if they are able to manage an asset base that is distributed around New Zealand's housing stock and can sell energy directly to the

householders. This is a possible mechanism by which greater market penetration may be achieved.
It has been argued that as the power is not generated at times of peak load, PV panels or solar thermal systems cannot contribute to deferral of the construction of peaking power plant, and that construction of such plant locks in carbon emissions for the lifetime of that plant [12]. The New Zealand electricity system is predominantly hydro based, limited by seasonal hydro inflows and about three months of storage. Much of the time storage reservoirs are not full, and their generation stations are running at less than their peak capacity. While the reservoirs are not full, every unit of energy that is generated by domestic installations allows energy to be retained in hydro reservoirs for both base load and peaking use, which has value to our national power system.

The New Zealand power system is not only energy constrained; there are also significant transmission constraints to both the upper North and upper South Islands. Unless PV systems are grid connected, and able to mitigate the growing upper North Island air conditioning load, they do not contribute to managing this constraint. The analysis has shown that if a solar water heating system is installed, it is economically rational to convert to an uncontrolled electricity contract. It can be expected that each solar conversion removes a controllable load. Under times of system stress, when southerly storms are sweeping the country and solar water systems have reverted to grid electricity, these loads are active but unavailable for control, resulting in higher peak loads than currently exist. If solar water heating systems do become prevalent, some incentives to keep these loads controllable should be implemented.

12. Conclusion

This paper shows that calculating the economics of a domestic photovoltaic array is quite complex, requiring a number of assumptions. These calculations are beyond what most domestic householders are willing to take on. However, it does show clearly that the economics depend strongly on how much of the power is locally utilised, thus avoiding drawing power from the grid, and how much is exported. It is shown that use of PV panels for water heating, which provides energy storage for later use, is economically more viable than grid connection, even though excess energy in the summer months is not harvested. It is proposed to develop the analysis in this paper into a publicly available web-based tool.

Further to this, it is shown that any form of solar water heating, where electric water heating is incumbent, provides an incentive to consumers to go to an uncontrolled tariff. Domestic solar systems contribute to New Zealand's total energy needs, and the resultant higher lake levels will reduce generation constraints during dry periods. However the associated loss of controllable load is likely to increase peak system loads, particularly in the winter. This will constitute an early negative impact of such installations in some areas of New Zealand.

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