**Economics of Photovoltaic Solar Power and Uptake in New Zealand**

Allan Miller* [1], Michael Hwang[1], Scott Lemon[1], E. Grant Read[2], Alan Wood [3],

[1] Electric Power Engineering Centre (EPECentre), University of Canterbury

[2] Adjunct Professor in Management Science, Department of Management, Marketing and Entrepreneurship

[3] Department of Electrical and Computer Engineering, University of Canterbury

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**Abstract**

Responding to the global challenges of maintaining energy security while combatting climate change, the New Zealand government has issued a target of generating 90% of the country's electricity needs from renewable sources by 2025. With much of New Zealand's generation already provided by hydro, geothermal and wind, questions remain as to whether this target should be achieved by more widely adopting solar photovoltaics (PV) into the energy mix.

Following from previous GREEN Grid research into the uptake of solar PV in New Zealand, this paper considers the economics of PV generation at a variety of scales: residential rooftop; commercial rooftop; and ground-mount utility. For each scale, discounted cash-flows were used to assess system costs and financial returns, and levelized cost of energy used to compare with other sources of generation.

In the case of residential generation, there is a significant difference in the value of energy which is locally consumed versus that which is grid-exported. Consequently the value of PV to a household depends on the consumption patterns of a particular household. To understand the value across different households, typical residential load profiles were found by clustering load profiles from over 2,000 houses, and resulting representative load profiles used to estimate financial returns based on the energy consumption patterns.

The paper concludes that PV is now a commercially attractive investment for some types of households, but that household load makes a major difference to the returns. In the commercial sector PV is also commercially attractive to the company making the investment in some cases, and for both residential and commercial, returns are very sensitive to discount rate, location, and type of retail tariff. However for both residential and commercial, improving energy efficiency is a lower cost option than PV, and should be considered first. At the utility scale PV is not yet commercially attractive, even excluding transmission and distribution charges and opportunity cost of land. However if the cost of PV continues to fall,

and electricity spot prices rise substantially, regions such as Nelson-Tasman (due to their high irradiance) and Auckland, Northland, and Taranaki (due to their higher spot prices and reasonable irradiances) are likely to be areas considered for large multi megawatt schemes.

The paper has examined the commercial attractiveness of PV from the point of view of PV investors in the residential, commercial and utility sectors. It has not examined whether PV is economic in the sense that it will produce a saving to the nation. It should be recognised that much of the individual benefit reported here arises because of the use of variable charges to recover fixed costs of the distribution network, in the residential sector and, to a lesser extent, the commercial sector. Thus the "savings" made by consumers who avoid that component of the variable charges, do not necessarily reflect an actual reduction in the costs of transmission, or retailing. This is reflected in the contrast between net present values in the residential and commercial sectors compared to the utility sector. Further research should consider the economic benefit of PV to New Zealand as a whole, based on an assessment of the true marginal cost savings from distributed PV in transmission, distribution, and retailing.

## 1. Introduction

Photovoltaic solar power (PV) continues to grow rapidly in New Zealand, from about 7MW at the end of 2013 reported in [1] to 20.2MW at February 2015, as shown in Figure 1.

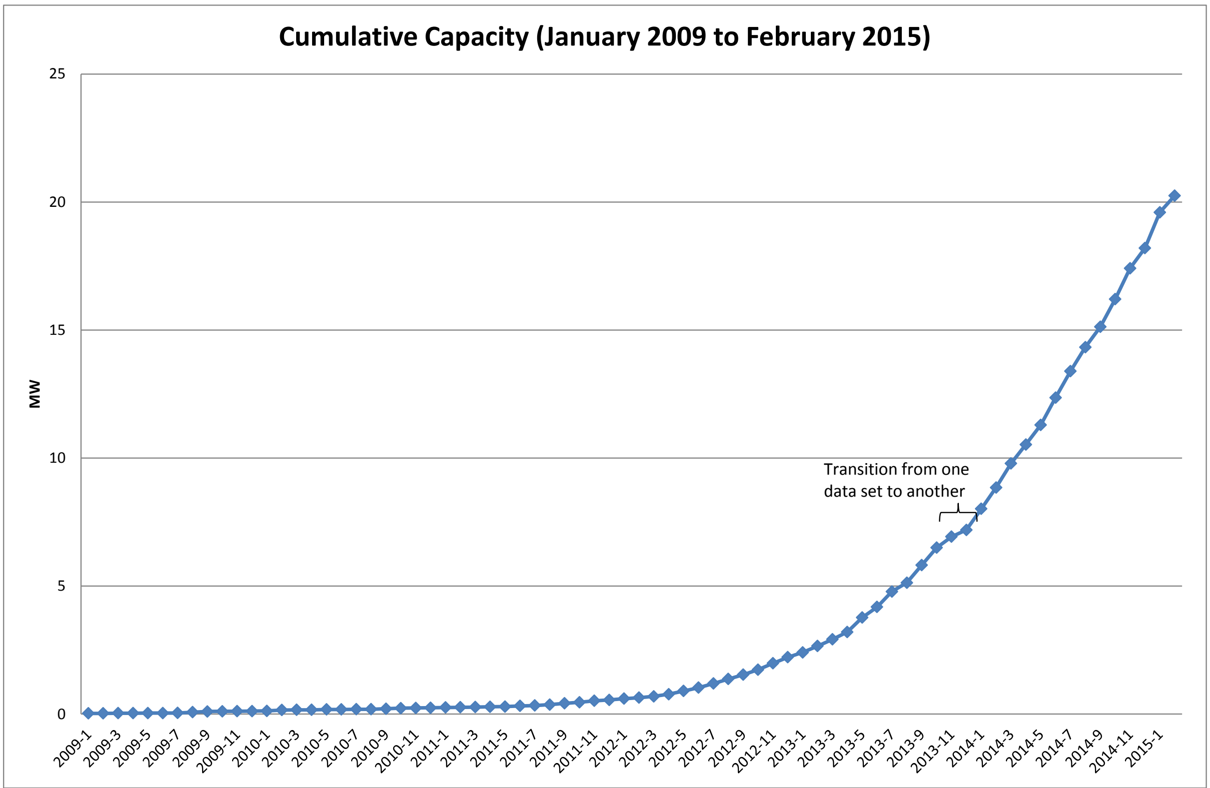


Figure 1: Photovoltaic solar power uptake in New Zealand to February 2015[1]

A regional breakdown of PV in New Zealand is given in Table 1. This shows PV at February 2015 essentially by market segment; systems under 10kW are assumed to be residential, while systems over 10kW are assumed to be commercial. Commercial system cumulative installed capacity has grown at an average rate of about 12% per month in the last six months, the highest rate since the Electricity Authority began collecting statistics in August 2013. Contrasting this is a reduction in the rate of increase of residential system cumulative installed capacity over the last six months, from about 12% in February 2014 to 6% in February 2015.[2] This suggests that commercial PV systems are becoming more commercially attractive, while residential systems may not be so attractive in the light of the reduction in buy-back rates in November 2014 [2]. This paper examines the economics of PV to the investor by market segment. It begins by introducing the measures used to examine the economics of PV, followed by the method of analysis and results for residential, commercial, and utility scale systems. It is concluded with a discussion of the results.

[1] Data since August 2013 was obtained from the Electricity Authority's EMI reports website (http://www.emi.ea.govt.nz/), Installed distributed generation trends. Data prior to August 2013 is that used in [1] and [3].

[2] The rate of residential system installs has also declined, while the average system size has remained almost constant.

Table 1: Photovoltaic solar power by local government region in New Zealand at February 2015[3]

| Region | Total PV (MW) | Proportion of PV capacity | | Watts Per Person |
|---|---|---|---|---|
| | | Less than or equal to 10kW | Greater than 10kW | |
| Total New Zealand | 20.249 | 91% | 9% | 4.5 |
| Northland | 1.054 | 94% | 6% | 6.3 |
| Auckland | 5.817 | 89% | 11% | 3.8 |
| Waikato | 1.816 | 89% | 11% | 4.2 |
| Bay of Plenty | 1.211 | 85% | 15% | 4.3 |
| Gisborne | 0.146 | 100% | 0% | 3.1 |
| Hawke's Bay | 1.090 | 94% | 6% | 6.9 |
| Taranaki | 0.452 | 85% | 15% | 3.9 |
| Manawatu-Wanganui | 0.538 | 88% | 12% | 2.3 |
| Wellington | 0.864 | 84% | 16% | 1.8 |
| Tasman | 0.907 | 89% | 11% | 18.5 |
| Nelson | 0.624 | 96% | 4% | 12.7 |
| Marlborough | 0.474 | 82% | 18% | 10.6 |
| West Coast | 0.048 | 100% | 0% | 1.5 |
| Canterbury | 3.191 | 95% | 5% | 5.6 |
| Otago | 1.430 | 93% | 7% | 6.8 |
| Southland | 0.587 | 91% | 9% | 6.1 |
| Total North Island | 12.988 | 89% | 11% | 3.8 |
| Total South Island | 7.261 | 93% | 7% | 6.9 |

## 2. Economic Measures Considered

Two particular questions about PV were of interest: first whether PV is financially viable to invest in, and second how PV's cost compares with other forms of renewable generation. Each question required a different measure, set out below.

1. To assess the financial viability of investing in PV, the net present value (NPV) of future cash flows generated by PV was used. The cash flows over a defined time period are discounted by an appropriate discount rate. The equation used for NPV is given in Appendix One.

2. To compare PV with other forms of generation, the levelized cost of energy (LCOE) was used. LCOE gives the per unit cost of generation (c/kWh) by discounting all life cycle costs over its life to a present value, and diving that by all energy generated over

[3] Population statistics used are 2014 data and were obtain from Statistics New Zealand (http://www.stats.govt.nz/browse_for_stats/population/estimates_and_projections/subnational-pop-estimates-tables.aspx), Subnational population estimates (RC, AU), by age and sex, at 30 June 2006–14 (2013 boundaries).

its life, discounted to a present value. The equation for LCOE is given in Appendix One. Further information about LCOE is given in [4] and [5].

A number of assumptions were required to determine the measures for each scale of system. All assumptions are given in Table 2.

Table 2: Assumptions and inputs used in the analysis

| | Residential PV | | Commercial PV | Utility PV |
|---|---|---|---|---|
| System Size (kWp) | 2 | 3.5 | 50 | 2,000 |
| System Cost ($/W)(1) | $3.5 | $3.0 | $2.5 | $2.0 |
| Inverter replacement cost after 15 years ($/W) | $0.4 | $0.4 | $0.4 | 0 |
| Operation and maintenance cost ($/kW/year) | 20 | 20 | 20 | 20 |
| Operation and maintenance cost escalation (%) | 2% | 2% | 2% | 2% |
| System salvage value ($) | 0 | 0 | 0 | 0 |
| Balance of System Losses (%) | 4% | 4% | 4% | 4% |
| Annual panel degradation (%/year) | 0.8% | 0.8% | 0.8% | 0.8% |
| Panel tilt (degrees) | $30^o$ | $30^o$ | $30^o$ | $30^o$ |
| Panel azimuth (degrees) | $0^o$ | $0^o$ | $0^o$ | $0^o$ |
| Irradiance ($W/m^2$) | NIWA typical metrological year and transposed for direct and diffuse radiation and a $30^o$ tilt(2) | | | |
| Temperature effects accounted for | No | No | No | No |
| Grid buyback rate (c/kWh) | 8(3) | | NA - all PV production is used by business | Spot price(4) |
| Variable electricity retail price (c/kWh)(5) | (6)<br>Low user flat rate: 25.395<br>Low user day of night rate: 29.022<br>High user flat rate: 23.462<br>High user day of night rate: 27.089 | | 10, 12, and 14 | NA |
| Electricity PPI annual adjustment (%) | 1.5% | 1.5% | 1.5% | 1.5% |
| Analysis time period (years) | 25<br>Income begins in the same year as capital investment | | 25<br>Income begins in the year following capital investment | 25<br>Income begins in the year following capital investment |
| Discount Rate (%) | 4%, 7%, and 20% | | 6% and 8% | 6% |
| Depreciation tax shield accounted for | No | | Yes | Yes |
| Method of depreciation | NA | | Straight line over analysis time period | |
| Corporate tax rate | NA | | 28% | |
| Load profiles used | 8 different load profiles (see table for details) | | NA - all PV offsets businesses load | NA - all energy is sold on the spot market |

(1) Neither land value nor opportunity cost of use of land (utility) or roof space (commercial) is included.

(2) See [6] for more information. The Perez diffuse irradiance transposition model is used in this work to transform irradiance to a the tilted surface of the PV panel [7].

(3) Based on Contact Energy's buy-back rate

(4) Spot prices from 2010 to 2014 are used, with the series repeated every 5 years, and escalated at the electricity PPI annual adjustment.

(5) In the case of residential, household load below the PV generation is treated as an avoided cost at the retail price and PV generation above the household load is injected at the grid buyback rate. In the case of commercial, all PV generation offsets the businesses load and is treated as an avoided cost at the retail price.

(6) Based on Contact Energy's Christchurch rates

(7) No subsidies are incorporated, except for the implicit subsidy of distribution network use.

(8) There are no transmission or distribution charges for commercial and utility PV. This is not required for LCOE, but should be included for utility scale PV to yield an accurate NPV. Commercial PV does not include it, as it is assumed there is a large fixed component to the commercial retail rate (giving lower variable rates) and the PV does not inject into the grid.

## 3. Residential Returns

Since residential PV offsets a home's electricity consumption, the revenue for the amount offset is considered to be the cost saving from not purchasing from the electricity retailer. In addition, the amount of PV generation above a home's load is sold to the electricity retailer at the buy-back rate, augmenting revenue. Since the retail and buy-back rates are so different in New Zealand, knowledge of the load profile, as well as the PV generation by time, is essential to be able to assess the total cost saving and therefore revenue earned by the householder. Load profiles vary significantly between houses, and in order to demonstrate potential cost savings, more than 2,000 load profiles from Christchurch were analysed and classified into types. Due to confidentiality, demographic information about the houses from which the load profiles are from was not available. Instead the load profiles were classified based on the following criteria:

1. Low user or high user (a low user household uses less than 9,000kWh per annum).
2. Tariff (single flat rate versus separate night and day rates with water heating controlled to turn on at night).
3. Winter energy consumption is significantly higher than summer energy consumption, suggesting electric space heating is used in the winter.[4]
4. Day time consumption, between 10am and 4pm, is significant suggesting occupancy during the day-time.
5. Energy consumption over the morning peak period (8am to 10am) is significant, suggesting electric water heating.[5]

The results were theoretically divided into 32 groups, however not all groups were populated. For example: no low user homes had significantly high day-time consumption; and very few high user homes with winter consumption similar to summer consumption had high day-time consumption (i.e. they were typically on night rate tariffs and used more load at night). A selection of eight categories was made, representing 85% of the load profiles examined, and the median load determined for each of the 17,520 half hours in the year. The categories are given in Table 3, and sample load profiles with PV generation shown in Appendix Two. The median was determined to ensure no particular home's load profile was used, to ensure anonymity.

Ultimately this analysis provided samples of load profiles to demonstrate returns for various load profile shapes and household energy consumptions. It is not an exhaustive analysis that enables precise calculation of returns for a particular home, nor by home type. However it gives an indication of returns, and shows promise for future work.

[4] This assumes that houses did not use significant amounts of air-conditioning in the summer.

[5] Homes on a night rate tariff were not assessed for this category since they were known to have electric water heating.

Table 3: Categories of houses considered for the analysis

| House Type | Winter Space Heating | Day Time Load | Tariff | Water Heating | Annual Consumption (kWh) | Number of Houses | Proportion of Sample |
|---|---|---|---|---|---|---|---|
| 1 | Other | Low | Flat rate | Non electric | 3,162 | 326 | 15% |
| 2 | Electric | Low | Flat rate | Non electric | 4,078 | 541 | 24% |
| 3 | Electric | Low | Flat rate | Electric | 5,878 | 116 | 5% |
| 4 | Electric | Low | Night Rate | Electric | 4,475 | 313 | 14% |
| 5 | Electric | Low | Flat rate | Electric | 9,843 | 255 | 12% |
| 6 | Electric | Low | Night Rate | Electric | 9,969 | 232 | 10% |
| 7 | Electric | High | Flat rate | Electric | 13,174 | 68 | 3% |
| 8 | Electric | High | Night Rate | Electric | 15,102 | 29 | 1% |
| Total | | | | | | 1,880 | 85% |

All parameters of, and assumptions about, the PV system for each home are given in Table 2.

Three discount rates were used, to represent the following types of households:

- 4% to represent householders who have paid off their mortgage and are seeking low risk investments (4% being similar to the bank interest rate).
- 7% to represent a middle income family with a mortgage (7% being similar to future mortgage rates).
- 20% to represent a household who finds finance difficult to obtain.

Electricity sold was not taxed, although as discussed in [8] tax should apply to electricity sold. Results are given in Table 4 for Christchurch; since load profiles were only available for Christchurch, only Christchurch's results are shown.

Table 4: Net present values for PV systems in Christchurch (capacity factor = 0.151)

| House Type | 3.5kWp system, $3.0 per Watt | | | 2.0kWp system, $3.5 per Watt | | |
|---|---|---|---|---|---|---|
| | 4% | 7% | 20% | 4% | 7% | 20% |
| 1 | -$1,030 | -$3,294 | -$7,139 | -$256 | -$1,876 | -$4,622 |
| 2 | -$975 | -$3,250 | -$7,117 | -$339 | -$1,936 | -$4,647 |
| 3 | $1,016 | -$1,742 | -$6,426 | $944 | -$961 | -$4,196 |
| 4 | -$1,082 | -$3,332 | -$7,155 | -$345 | -$1,942 | -$4,651 |
| 5 | $1,826 | -$1,128 | -$6,144 | $1,379 | -$628 | -$4,038 |
| 6 | $1,431 | -$1,433 | -$6,290 | $1,471 | -$565 | -$4,019 |
| 7 | $4,175 | $659 | -$5,314 | $2,501 | $231 | -$3,633 |
| 8 | $6,829 | $2,667 | -$4,398 | $4,245 | $1,557 | -$3,019 |
| LCOE (c/kWh | 16.9 | 21.2 | 41.0 | 19.4 | 24.4 | 47.6 |

## 4. Commercial Returns

While residential PV paradoxically generates when, in many cases, the household load is the lowest, many commercial premises consume the most during the day when PV generates. As such PV may be more advantageous to businesses, since it will offset their electricity purchases rather than inject into the grid, if sized appropriately. In doing so it will reduce their electricity purchase costs by the amount of energy generated at their variable retail rate. To examine the value of PV to a commercial premise, it was assumed that the business operates 365 days a year at a level where its internal load is greater than the PV peak generation. A 50kWp system was considered, with all inputs and assumptions given in Table 2. Results are given in Table 5.

Table 5: Net present values for a 50kWp PV systems on a commercial building with load above 50kW for most days of the year[6]

| | Discount rate of 6% | | | | Discount rate of 8% | | |
|---|---|---|---|---|---|---|---|
| | Net Present Value ($) | | | LCOE (c/kWh) | Net Present Value ($) | LCOE (c/kWh) | Capacity Factor |
| Variable retail rate (c/kWh) | 10 c/kwh | 12 c/kWh | 14 c/kWh | | 14 c/kWh | | |
| Auckland | -34,037 | -15,745 | 2,546 | 15.7 | -18,315 | 18.5 | 0.161 |
| Waikato | -37,730 | -20,176 | -2,623 | 16.4 | -22,607 | 19.3 | 0.155 |
| Bay of Plenty | -34,321 | -16,086 | 2,149 | 15.7 | -18,645 | 18.6 | 0.161 |
| Taranaki | -30,345 | -11,315 | 7,716 | 15.1 | -14,024 | 17.8 | 0.168 |
| Manawatu | -37,446 | -19,836 | -2,225 | 16.3 | -22,276 | 19.3 | 0.155 |
| Wellington | -37,446 | -19,836 | -2,225 | 16.3 | -22,276 | 19.3 | 0.155 |
| Nelson | -26,936 | -7,224 | 12,487 | 14.6 | -10,062 | 17.2 | 0.174 |
| West Coast | -40,740 | -23,789 | -6,838 | 16.9 | -26,106 | 20.0 | 0.149 |
| Canterbury | -39,491 | -22,290 | -5,089 | 16.7 | -24,653 | 19.7 | 0.151 |
| Otago | -53,011 | -38,514 | -24,016 | 19.8 | -40,366 | 23.4 | 0.128 |
| Southland | -52,670 | -38,105 | -23,539 | 19.7 | -39,970 | 23.3 | 0.128 |

[6] The NPV is positive in some locations at a retail rate of 14c/kWh despite the LCOE being higher than the retail rate. This is because the retail rate is escalated annually, and because the depreciation tax shield is accounted for in the life-time cost for LCOE, as shown in the Appendix.

## 5. Utility PV Returns

To assess the viability of utility scale PV systems, the energy generated by the PV system in each half-hour trading period was assumed to be sold at the spot market price. Irradiance from NIWA's typical metrological year was used to determine PV output, and the spot price from 2010 to 2014 was used as the forecast for the spot price from 2015 to 2020. For subsequent years, the 2010 to 2014 spot prices were escalated at an effective annual rate. The rate used was an assumed annual escalation of the electricity primary producer index (PPI), given in Table 2. Long term contracts for electricity output were not considered, as it was assumed that these would be priced according to spot price. However in reality these may have a premium associated with them. Neither transmission nor distribution connection charges apply, which will make the NPV of utility scale PV look more attractive, but will not affect the LCOE. Results are given in Table 6.

Table 6: Utility scale PV results

| Discount Rate | 6% | | 8% | | Capacity Factor |
|---|---|---|---|---|---|
| Region | Net Present Value ($) | LCOE (c/kWh) | Net Present Value ($) | LCOE (c/kWh) | |
| Auckland | -$718,867 | 11.5 | -$1,269,937 | 13.8 | 0.161 |
| Waikato | -$947,608 | 12.0 | -$1,460,683 | 14.3 | 0.155 |
| Bay of Plenty | -$1,008,843 | 11.6 | -$1,513,140 | 13.8 | 0.161 |
| Taranaki | -$792,090 | 11.1 | -$1,332,749 | 13.2 | 0.168 |
| Manawatu | -$1,041,727 | 12.0 | -$1,539,959 | 14.3 | 0.155 |
| Wellington | -$1,035,148 | 12.0 | -$1,534,412 | 14.3 | 0.155 |
| Nelson | -$737,849 | 10.7 | -$1,288,709 | 12.8 | 0.174 |
| West Coast | -$1,092,445 | 12.4 | -$1,582,387 | 14.9 | 0.149 |
| Canterbury | -$1,282,525 | 12.3 | -$1,740,466 | 14.6 | 0.151 |
| Otago | -$1,848,341 | 14.6 | -$2,209,390 | 17.4 | 0.128 |
| Southland | -$1,777,256 | 14.5 | -$2,150,266 | 17.3 | 0.128 |

## 6. Discussion

At the residential level returns from PV vary substantially by household type. By examining Figures 3-6 (Appendix Two) and Table 4 it is clear that the houses with higher day-time load have better returns, which is not surprising given they offset more of their higher retail rate. PV appears commercially attractive for homes that are large users, and even low users with electric hot water heating that are not on night rate tariffs. This largely supports the conclusion by Wood et al in [8]. However PV is still only commercially attractive for householders with ready access to finance and who seek low risk investments. These conclusions are dependent on the assumptions made about the costs of PV systems and future retail electricity prices; PV costs used are possibly lower than what is currently on offer, and future retail electricity price rises are modest. It is widely expected that the cost of PV will continue to fall, meaning that over time PV will become commercially attractive to a larger group of householders (more of the NPVs in Table 4 will become positive). Not all households have the ability to conduct extensive economic analysis of PV, although research by Ford et al in [3] suggests that economics is not their only factor in choosing PV.

A group that may have a greater ability to assess the economics of PV is the commercial sector. PV may hold more appeal to commercial companies such as shopping malls and supermarkets due to their high load during the day, on almost every day of the year. In turn PV would offset their full variable retail rate. While the exact nature of commercial pricing is unknown (only average rates from [9] and [10] were available), it is assumed that the commercial sector will have a greater fixed component in their pricing and the variable rate will be lower. For this reason a range of prices were used to give the results in Table 5. This is still simplistic, as there may be variable rates that apply to peaks, which have not been factored into this analysis. Further, the commercial loads assessed in this analysis are assumed to operate for about 365 days of the year, which is not necessarily the case for loads such as schools. A more extensive analysis is therefore required to fully assess the commercial attractiveness of PV to businesses.

Utility PV is shown to be the least commercially attractive investment, despite having the lowest LCOE. This is because all energy is sold on the spot market, which is lower than the variable retail price of residential and commercial. If transmission and distribution charges (if connected to the distribution network) of utility PV are taken into account it would be even less attractive. This conclusion is not surprising, and indeed utility scale schemes world-wide appear to be built in areas with significantly higher irradiance than New Zealand. However if such a scheme were to be built, the Nelson and Tasman regions have the highest irradiation (evident through the highest capacity factor) and hence the greatest potential. The Taranaki, Auckland, and Northland regions have slightly lower irradiation, but higher spot prices, making those regions equally attractive.

### 6.1 Comparisons

Figure 2 shows the LCOEs of different scale PV systems against one-another, with the ranges indicating the regional and discount rate differences. It is not surprising that the utility scale LCOE is lower, given the lower costs used. Comparing PV with other renewable sources obtained from the Lazard Report [11] shows that geothermal (at around 8-14 c/kWh) and wind (at around 4 to 11 c/kWh) are still more commercially attractive than PV in New Zealand. Of relevance to the homeowner, and even the business owner, is energy efficiency, which starts at 0 c/kWh. This suggests that before even considering PV, one should consider energy efficiency.

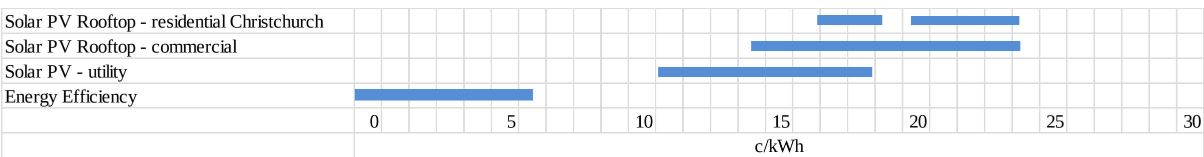


Figure 2: LCOE of different scale PV systems

## Conclusion

It is clear that PV is now a commercially attractive investment for some types of households – an investment that will provide a return over a 25 year period. For the commercial sector PV is also commercially attractive in some cases. Returns are very sensitive to discount rate, location, and specifics of the retail tariff. At the utility scale PV is not yet a commercially attractive investment, although if the cost of PV continues to fall, and electricity spot prices rise substantially, regions such as Nelson-Tasman, Auckland, Northland, and Taranaki might be suitable for large multi megawatt schemes.

The paper has examined the commercial attractiveness of PV from the point of view of PV investors in the residential, commercial and utility sectors. It has not examined whether PV is economic in terms of delivering a saving to the nation.

The analysis of PV at the utility scale gives more of an equal comparison with other forms of generation, since it sells its power at the spot price. In this case it is shown to be commercially unattractive, even without accounting for transmission and distribution charges, or costs. The national benefit would be even lower, to the extent that utility level PV did increase those costs.

If, however, distributed PV could reduce the cost of distribution and transmission, it might be more economic to the nation. Previous work by GREEN Grid has shown little, if any, ability for PV to reduce the system peak load (a winter evening peak), compounded by less PV generation on the coldest days. Nor does it increase the reliability of the electricity supply. That suggests little ability to reduce the cost of distribution and transmission. The implication is therefore that much of the 'saving' accruing to consumers who do install PV may not actually be a saving to the nation. Instead, the individual benefit arises because variable charges are being used to recover the fixed costs of the distribution and transmission networks in the residential sector and, to a lesser extent, in the commercial sector.

Thus avoiding these charges does not necessarily reflect much real cost saving, to the nation. Really, PV at the residential and commercial level should be valued using a combination of spot prices and actual marginal cost savings in transmission, distribution, and retailing. We have not attempted to estimate what those savings might be, and expect they may vary significantly depending on the situation faced in particular networks. Further research on that topic would allow a much more realistic assessment of the true economic benefits of PV to New Zealand as a whole, but it seems likely that the national benefits from residential and commercial PV installations will be lower than the analysis presented here might suggest.

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**Appendix One**

$$NPV = \sum_{i=1}^{N} \frac{Income_i - Cost_i}{(1+r)^i} - I + \frac{R}{(1+r)^N}$$

where

$I$ is the initial investment $= IC\,.SC \times 1000$,
$I$C is the installed capacity (kWp from Table 2),
$SC$ is the system cost ($/W from Table 2),
$r$ is the discount rate (from Table 2),
$i$ is the year,
$N$ is the number of years over which the cash flow is conducted (from Table 2), and
$R$ is the system salvage value (Table 2).

For Residential

$$Income_i = \sum_{t=1}^{17,520} \begin{cases} (Gpv_{t,i} - L_t).Rbb_i \ + \ L_t.Rretail_{t,i}, & Gpv_{t,i} > L_t \\ Gpv_{t,i}.Rretail_{t,i}, & Gpv_{t,i} \leq L_t \end{cases}$$

where

$Gpv_{t,i}$ is the half hourly PV generation in kWh = $IC.\,ir_t\ .(1 - L_{BOS})\ .(1-x)^{i-1}$ in year $i$,
$L_t$ is the household load in kWh,
$Rbb_i$ is the PV buy-back rate in year $i = \ BuyBackRate_t.(1 + Rppi)^{i-1}$,
$BuyBackRate_t$ is the retailers distributed generation buy back rate (Table 2),
$Rppi$ is the annual increment in electricity primary producer index (Table 2),
$Rretail_{t,i}$ is the retail rate at time period $t$ and year $i \ = RetailRate_t.(1 + Rppi)^{i-1}$,
$RetailRate_t$ is the retailers retail rate at time period $t$ (Table 2),
$L_{BOS}$ is the balance of system losses (Table 2),
$ir_t$ is the normalised irradiance (between 0 and 1) for each half-hour period at the location under consideration, and
$x$ is the annual degradation of the PV system.

For Commercial

$$Income_i = \ T.D_i \ + \sum_{t=1}^{17,520} Gpv_{t,i}.Rretail_{t,i}$$

where

$T$ is the corporate tax rate (Table 2),
$D_i$ is the depreciation in year $i$ (Table 2) such that depreciation reduces taxable income which thereby provides a depreciation tax shield.

For Utility

$$Income_i = \ T.D_i \ + \sum_{t=1}^{17,520} Gpv_{t,i}.Pspot_{t,i}$$

where

$Pspot_{t,i}$ is the spot price at time period $t$ and year $i$ (Table 2).

$$Cost_i = (1 - T).\sum_{i=1}^{N}(1 + CE)^{i-1}.C_i$$

Where

$C_i$ is the total operation and maintenance and inverter replacement cost in each year (Table 2), and

$CE$ is the annual cost escalation (Table 2).

$$LCOE = \frac{Total\ Lifetime\ Cost}{Total\ Lifetime\ Energy\ Production} =$$

$$\frac{I - \ T.\sum_{i=1}^{N}\frac{D_i}{(1+r)^i} + (1 - T).\sum_{i=1}^{N}\frac{(1+CE)^{i-1}.C_i}{(1+r)^i} - \frac{R}{(1+r)^N}}{IC.CF.8760.(1 - L_{BOS}).\sum_{i=1}^{N}\frac{(1-x)^{i-1}}{(1+r)^i}}$$

where

$T$ is the corporate tax rate as above, but equal to zero for residential and

$CF = \frac{\sum_{t=1}^{17,520} ir_t}{17,520}$ for the location for which irradiance is provided.

**Appendix Two**

This appendix shows the load profiles used for five sample days throughout the year considered, as well as PV generation profiles. Days of the year chosen represent the four seasons as well as a peak PV generation day in the summer.

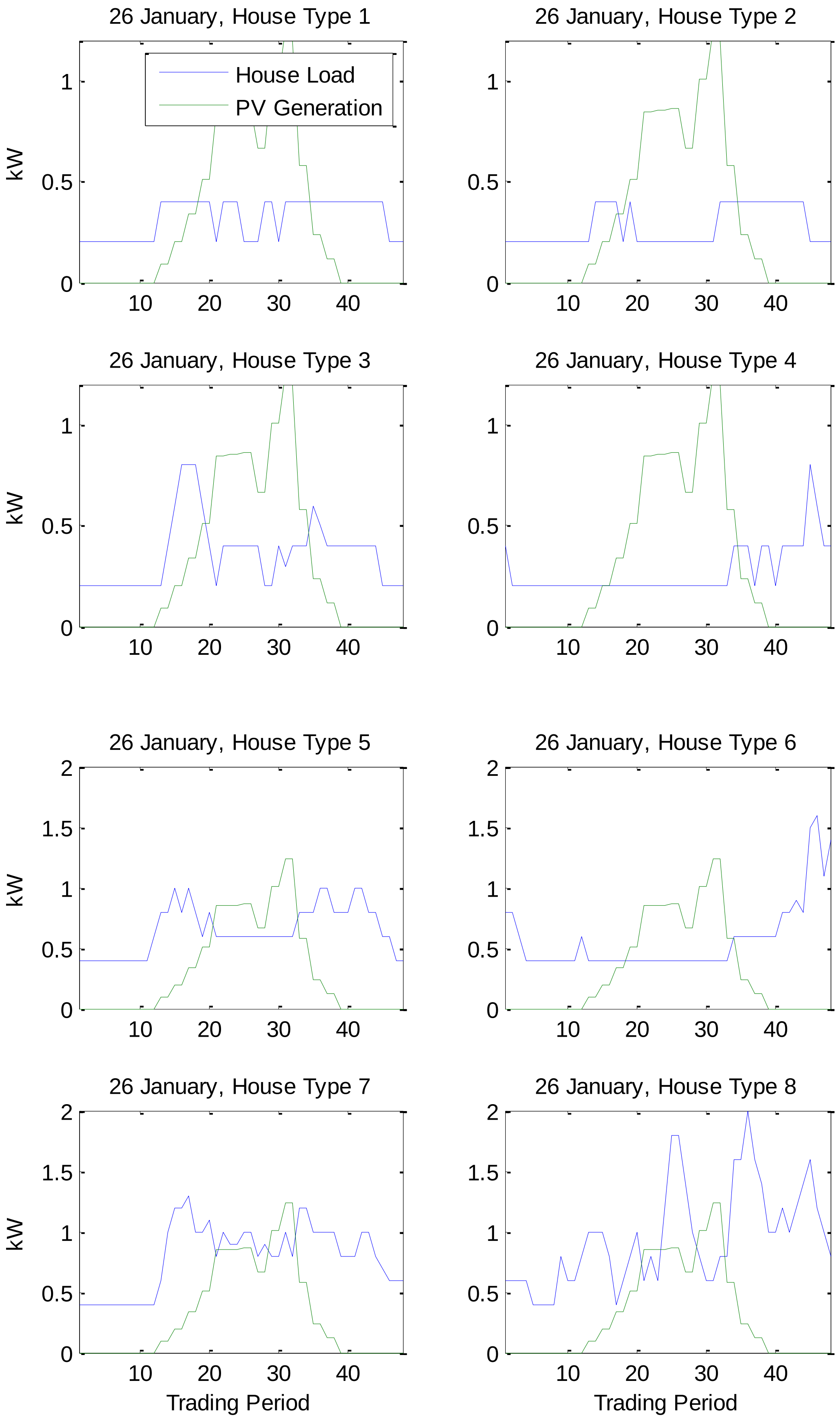


Figure 3: The PV system operating in its first year (no degradation in performance) and load, Thursday 26 January

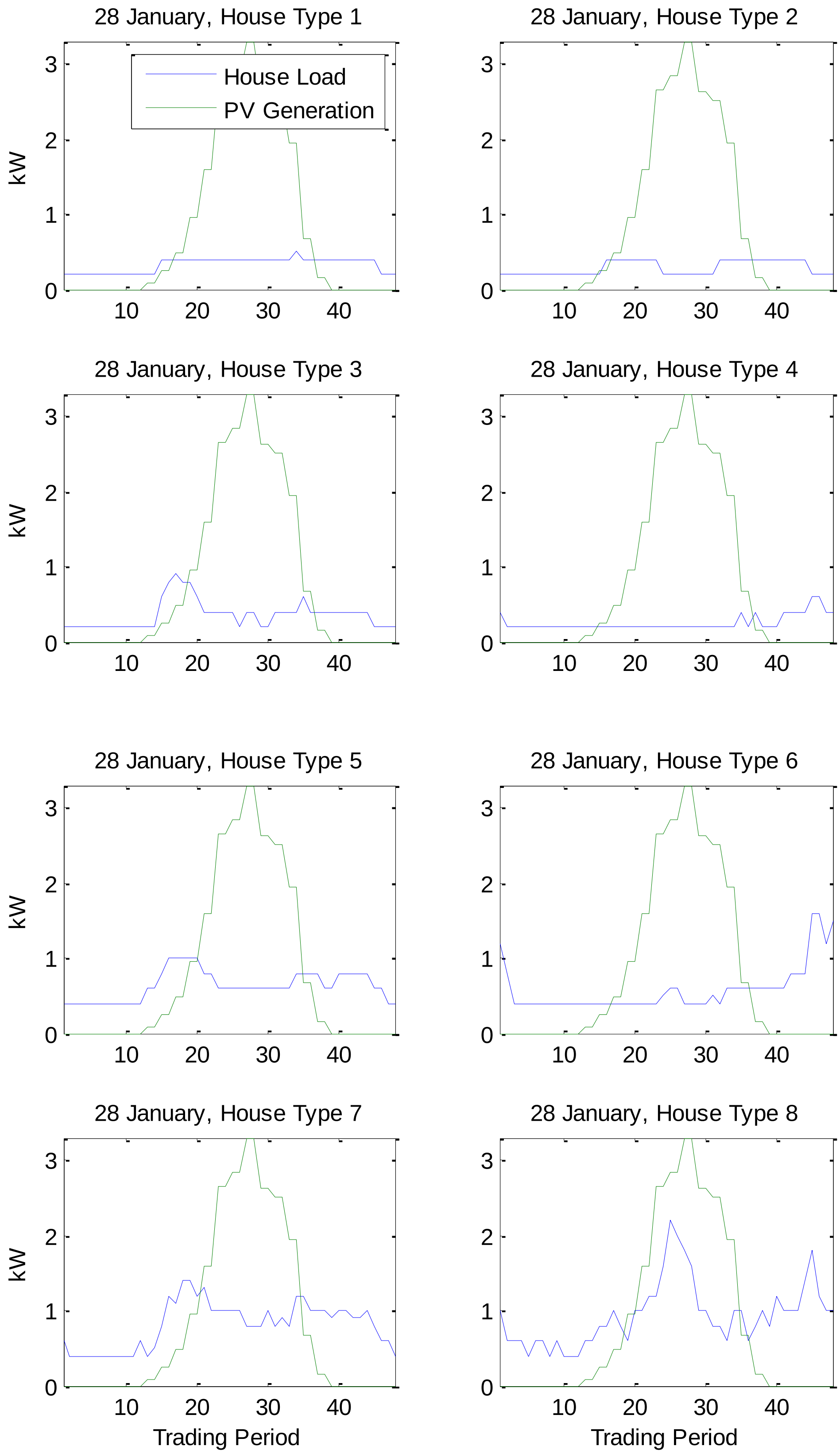


Figure 4: The PV system operating in its first year (no degradation in performance) and load Saturday 28 January

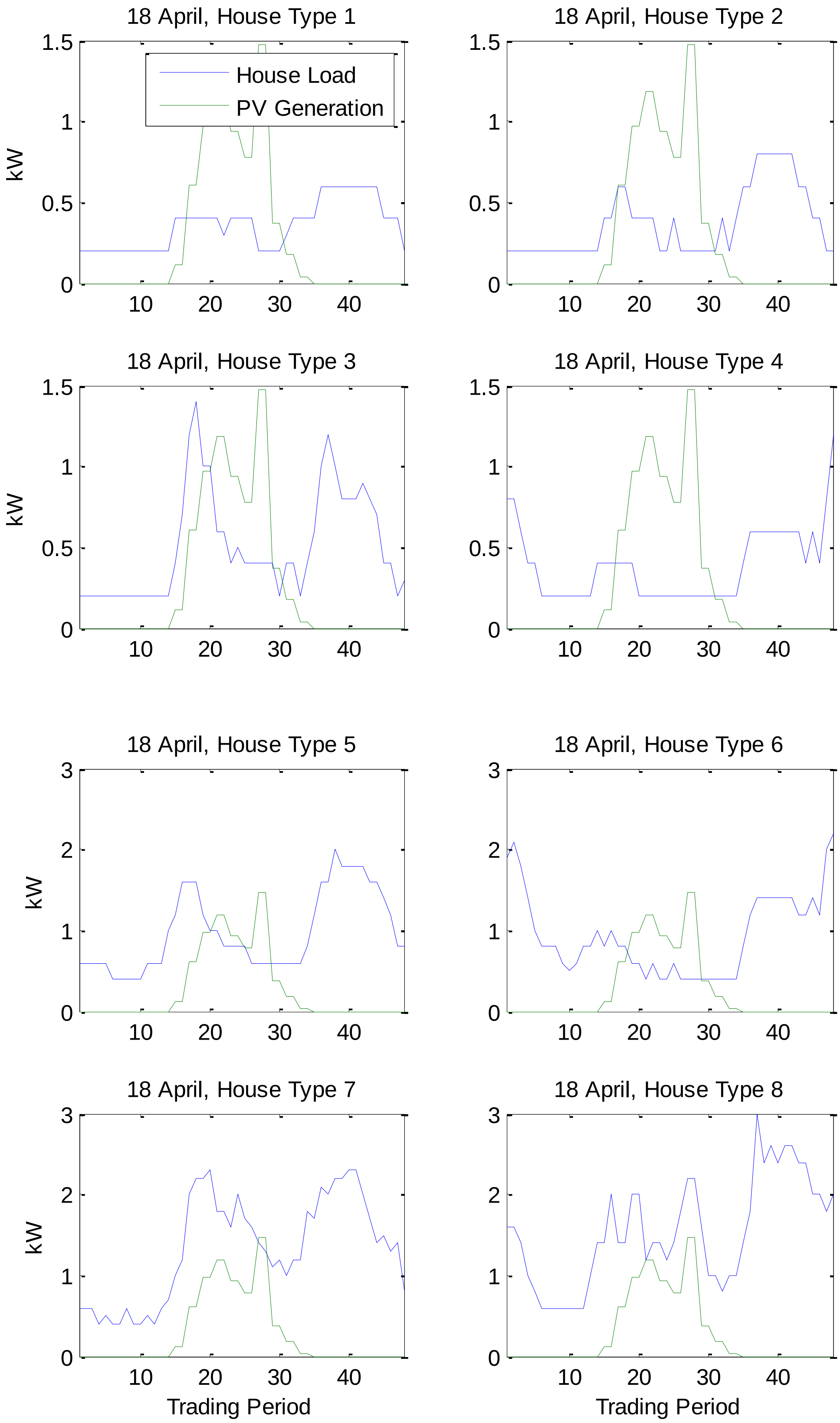


Figure 5: The PV system operating in its first year (no degradation in performance) and load, Wednesday 18 April

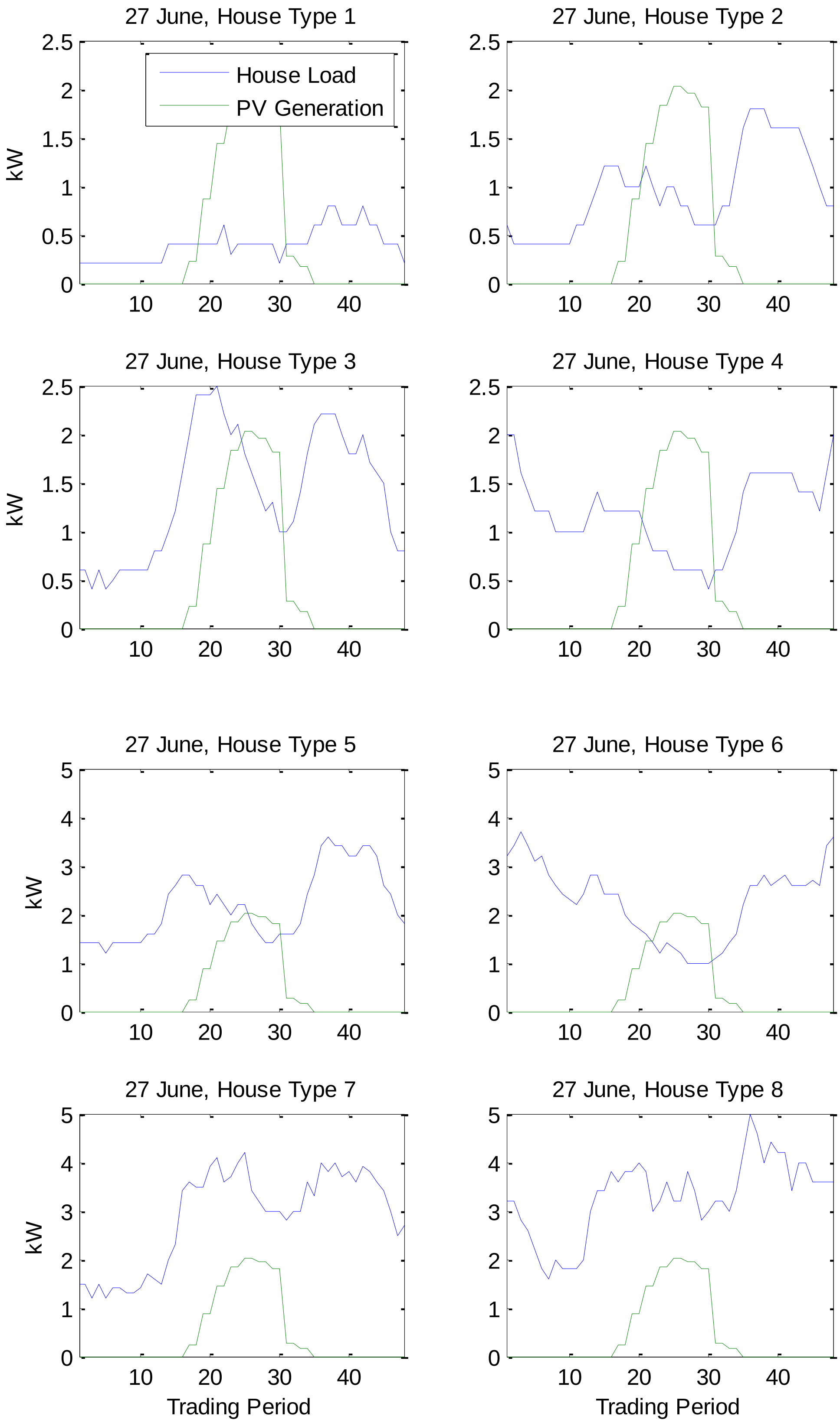


Figure 6: The PV system operating in its first year (no degradation in performance) and load, Wednesday 27 June

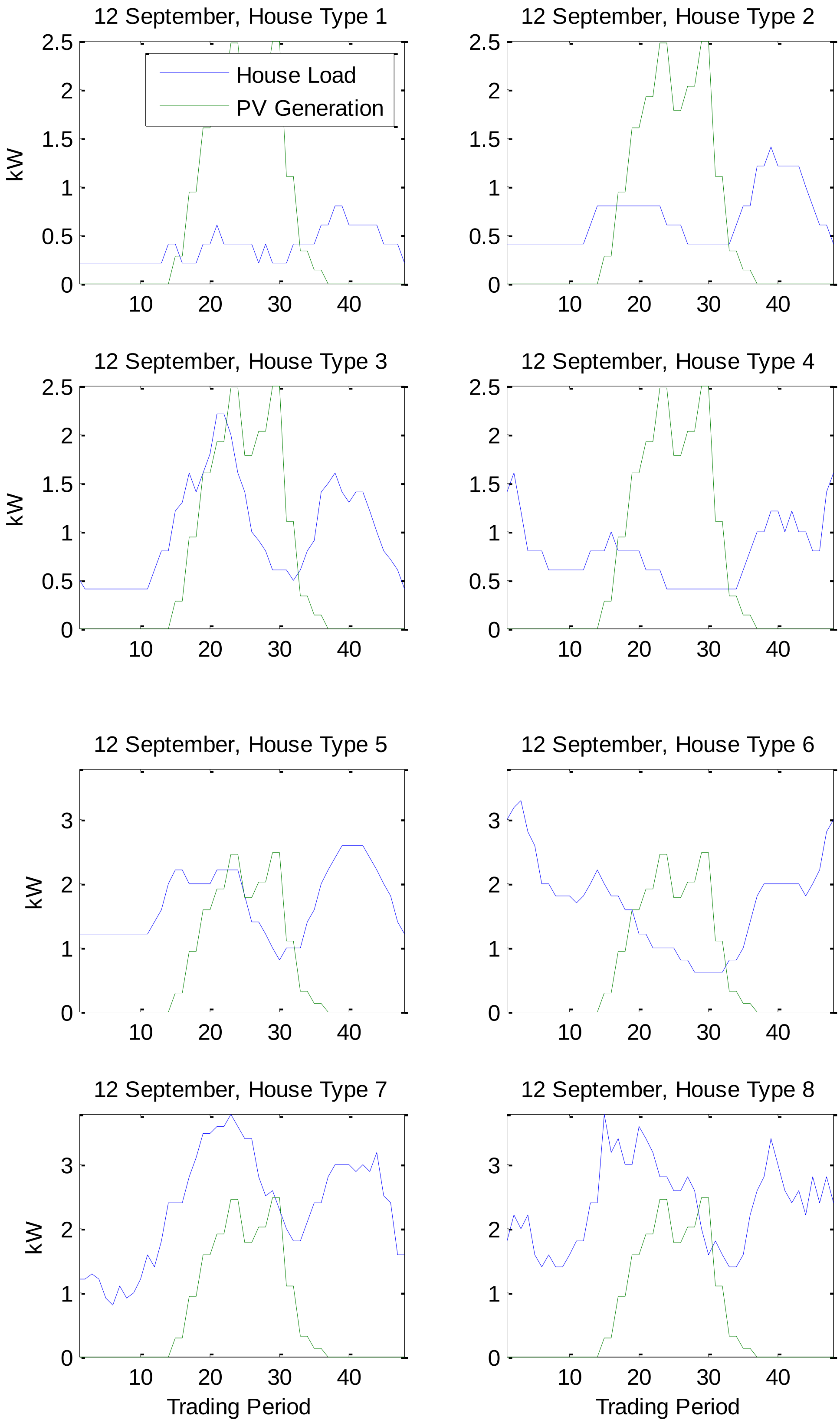


Figure 7: The PV system operating in its first year (no degradation in performance) and load, Wednesday 12 September

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