Analysis of a Roof-top Combined Photovoltaic / Solar Thermal Plant at Christchurch

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Abstract

This paper presents an economic perspective of rooftop solar systems consisting of a 1kWp grid-connected photovoltaic (GC-PV) and an evacuated tube solar collector (ETC) water heater (1.37m2 unit) as a case study at Christchurch, New Zealand. The study considers the case that both systems are partially covering the energy demand of a one-family house. According to the average availability of solar radiation at Christchurch the expected year ac energy yield of the 1kWp GC-PV system has been found to be 1018 kWh/year and that of the solar thermal collector 851 kWh/year. Economic analysis has been carried out on the basis that PV electricity is fully used, either directly at user premises or by feeding the utility grid whereas the thermal energy made available by the solar collector is assisting the usual electrical water heating system to supply the necessary hot-water demand. The assumption made in this analysis is that the energy provided by the solar water heater is entirely replacing the otherwise used electricity for heating water. The final electrical energy demand after installing the solar system is then calculated. The presented analysis can be applied for larger capacities for commercial and industrial users considering that repetitive units of the here presented modules can be considered.

1. INTRODUCTION

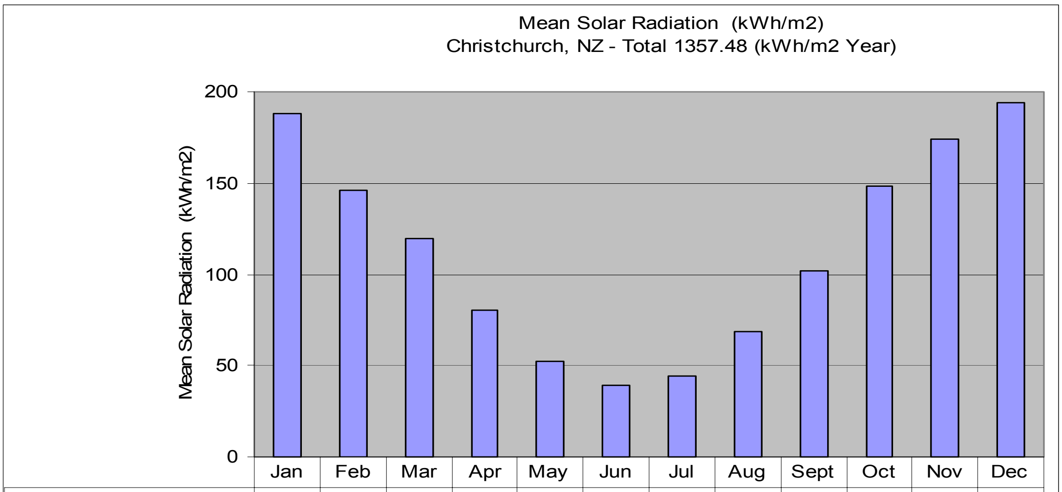
It is common place in New Zealand for water and space to be heated directly by electricity. This may lie on the fact that NZ preserves abundance of natural hydroelectricity produced, transmitted and distributed efficiently with minimal polluting effect. The energy consumption in water and space heating for domestic and industrial use is considered to account for 40 - 60 % of the total electricity energy consumption.

The recently released National Energy Efficiency and Conservation Strategy [1] announces a target to increase renewable energy supply to provide a further 25-55PJ/year (6,944–15,278 GWh/year) of consumer energy by 2012. The target represents a 19-42 percent increase over the current renewable energy supply. The renewable energy target is intended to give effect to the required progressive transition to renewable energy. In the last decade the market share of total consumer energy provided by renewables has declined and is currently 29 percent (132 PJ = 36,667 GWh).

Distributed generation (DG) - the location of electric generating facilities close to the end-user - provides benefits to the community, customers, and utilities which are not available from traditional large scale centralised generation. Grid connected PV (GC-PV) technology aims to provide solar electricity to customer and to the utility during periods of peak solar radiation. At weak solar radiation (and at night) energy will be extracted from the utility grid thus giving economic advantages for the PV user and the utility. The concurrent use of solar water heaters will assist in diminishing the electrical load otherwise required for heating water and thus will give more advantages for the proposed combined system.

2. THE MODEL

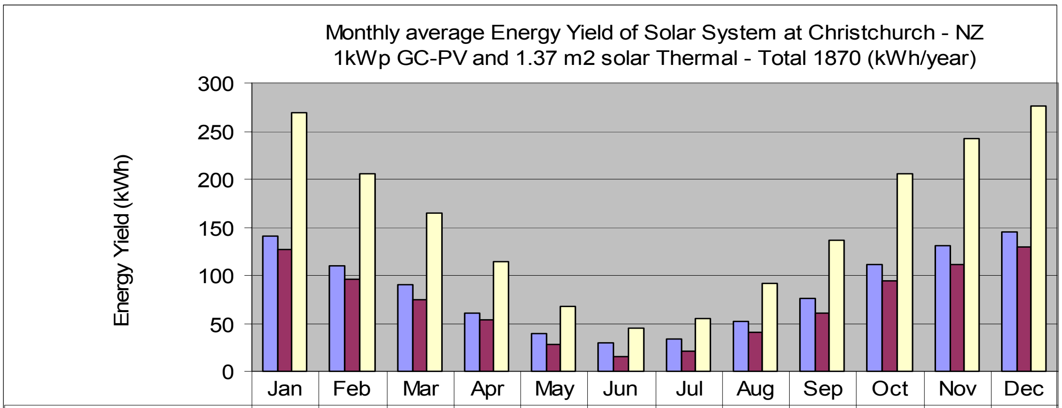
Operational data resulting from field measurements of an evacuated tube solar collector and the interpreted operation data of a 1 kW-GC-PV system at Christchurch, NZ is applied to economic models in order to help assess the economic performance of the combined system. Figure 1 shows the average availability of solar radiation at Christchurch.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Solar Radiation (kWh/m2)	188.5	146.2	119.7	80.1	52.39	39.3	44.64	68.82	101.7	148.2	174.3	193.8

Figure 1. Average availability of solar radiation at Christchurch.

The electrical output of a 1 kWp-GC-PV system will be considered to feed a suitable power-electronic inverter that transforms the PV dc power to utility-grid-compatible ac power. The maximum corresponding ac power resulting from a 1kW-PV device is about 700W. This amount of ac power corresponds to maximum solar availability. The real ac power made available by the system varies again according to the availability of solar radiation. Typically, this configuration can generate electrical energy of 1018 kWh under Christchurch weather conditions, suitable to partially supply one modest family house. The forecast for the energy output of the proposed PV system is based on weather data for Christchurch and common data of PV systems as shown in Figure 2.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟦 GC-PV-ac (kWh)	141.4	109.8	89.9	60	39.37	29.4	33.48	51.77	76.2	111	130.8	145.4
🟪 Solar Thermal (kWh)	127.1	95.2	74.4	54	27.9	15	21.7	40.3	60	94.55	111	130.2
🟨 Total (kWh)	268.5	205	164.3	114	67.27	44.4	55.18	92.07	136.2	205.5	241.8	275.6

Figure 2. Energy yield/year of the proposed combined solar system at Christchurch

The assessment made for this study of an evacuated tube solar water heater having a collector area of 1.37m^2 resulted in the energy yield shown in Figure 2[2]. The collector is considered to be suitable for a one-family house considered due to the correspondence of the energy yield in December (130.2 kWh) to thermal energy demand of the load for the same month (139.4 kWh). Considering larger solar collector units for the same load would mean over-dimensioned design especially in summer months.

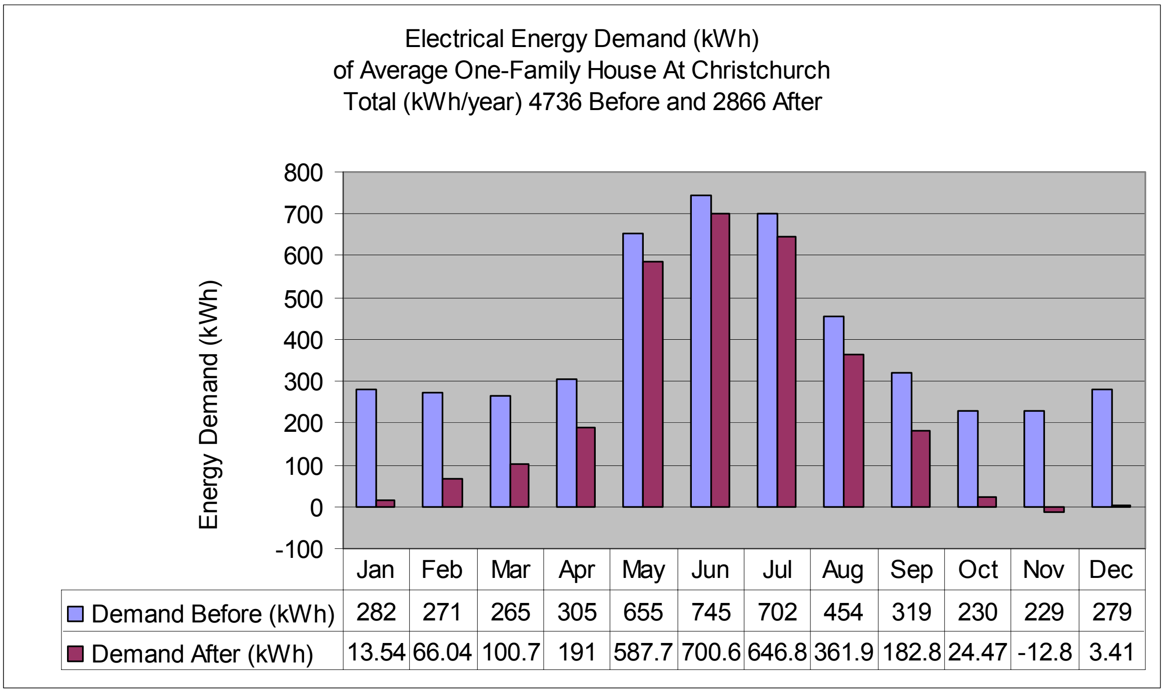
The total model system cost interpreted according to present New Zealand market data is shown in Table1.

Table 1: System Costs

Item	No. Units	Total cost range NZ $
PV module	1	8,000
Modules installation, Wiring & Cabling		1,500
Inverter (PCU) 700 W-ac	1	2,500
Evacuated tube solar thermal 1.37 m^{2}unit	1	2,500
Total Initial Capital Investment		14,500

3. RESULTS

The electric energy demand of a typical average household in Christchurch has been implemented in the calculation in order to demonstrate the impact of the installed combined solar system on the energy consumption. The assumption made in this analysis is that the energy provided by the solar water heater entirely replaces the electricity otherwise used for heating water. The contribution made by the PV system added to that of the solar thermal system results in the total reduction in the energy demand from the utility grid. Fig. 3 shows the resulting electric energy savings for one-family household implementing the proposed combined solar system at Christchurch. At other locations in New Zealand the energy yield of an identical system will vary according to the availability of solar radiation. It is expected that in northern parts of the country a considerable increase in energy yield could be achieved.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
□ Demand Before (kWh)	282	271	265	305	655	745	702	454	319	230	229	279
■ Demand After (kWh)	13.54	66.04	100.7	191	587.7	700.6	646.8	361.9	182.8	24.47	-12.8	3.41

Figure 3. Realisable electric energy savings from the proposed solar system.

4. ECONOMIC ANALYSIS

The life-cycle analysis is used in order to evaluate the economic performance of the proposed solar system. The life-cycle cost of a solar system is its initial cost plus the lifetime cost of maintenance and operation discounted to the present time. The life-cycle benefit of the solar system is the total value of all the energy produced over the system lifetime similarly discounted to the present time. The methodology used in this report is comprehensively reported in [3] and [4]. Costs and benefits for each operational year are projected and then discounted back to the year of installation to obtain the "present value". The present value of the benefits is then compared to the present value of the costs. In order to carry out the economic calculation the following assumptions are made:

r	interest rate 7% p.a.
N	Lifetime of the system in year
t	marginal tax bracket 0 %
g	savings escalator 0.10, ie 10% p.a.
CI	Initial Capital of investment NZ$14500.
OM&TI	Operation, Maintenance & Insurance first year 0.2% of invested capital

Maintenance & Insurance increase at 5%/year
Total energy savings/ year 1870 kWh/year

The economic viability of the system will be determined by the comparison of costs to benefits. The net present value (NPV) is the difference between the present value of the system lifetime resulting benefits (PV_B) and the present value of the cost (PV_C) generated by acquiring and operating the system over its entire lifetime.

$$NPV = PV_B - PV_C$$

An economically viable system is one that generates benefits over its lifetime that exceed the resulting total cost over the same period, and the NPV is positive. In cases where the benefits equal the cost the system is in break-even conditions. At negative NPV the system is uneconomic in the sense that all the benefits generated over the entire lifetime will not cover the invested cost. In the following the Net Present Value of Lifetime System Cost PV_C and the Net Present Value of Lifetime System Benefit PV_B will be calculated and compared.

4.1.1. Net Present Value of Lifetime System Cost

System cost includes the initial investment capital (CI) needed to acquire and install the system plus Insurance (TI) and Operation & Maintenance (O&M) Costs. The present value of lifetime system cost, PV_C is given by:

$$PV_C = CI + \frac{OM\&TI \ x \ CI}{CRF}$$

OM&TI = Sum of the Maintenance, Property Tax & Insurance percentage multiplier for annual payments;

CRF = Capital Recovery Factor

The Capital Recovery Factor (CRF) is used to discount future payments to the present and is expressed as:

$$CRF = \frac{r(1+r)^N}{(1+r)^N - 1}$$

Table 2 gives CRF and Present Value of lifetime system Costs PV_C at different system lifetimes accounted at an annual interest rate of 7%.

Table 2 Cost Recovery Factor CRF at different system lifetimes

System Lifetime (Year)	CRF at r=7%	Present Value of Lifetime System Cost ($)
5	0.243891	14618.91
10	0.142378	14703.68
15	0.109795	14764.13
20	0.094393	14807.23
25	0.085811	14837.95
30	0.080586	14859.86

5. NET PRESENT VALUE OF LIFETIME SYSTEM BENEFIT

Lifetime system benefits can be calculated foremost by defining the First Year Benefits (X_O) which is the price of the energy produced by the system at its first year of operation. To calculate the present value of X_O, is then calculated considering the electricity price escalation and the inflation.

By using a constant rate to represent long-term escalation, it is possible to obtain the present value of the lifetime benefits (PV_B) by multiplying the First Year Benefit X_0 by a single calculated parameter M_B, the benefits present value multiplier.

$$PV_B = M_B X_0$$

Net First Year Energy Savings X_0 will be used to determine the lifetime benefit of the system.

$$X_0 = 1^{st} \text{ Year Energy Savings - Maintenance \& Insurance Cost}$$

The benefit present value multiplier M_B is used to calculate the Present Value Benefit PV_B . It can be accounted using the following expression:

$$M_B = \begin{cases} \dfrac{1+g}{r-g}\left[1-\left(\dfrac{1+g}{1+r}\right)^N\right]; & r \neq g \\ N; & r = g \end{cases}$$

Present Value Multiplier at different system lifetimes taking into account a fixed interest rate of 7% and an escalation rate for energy cost of 10% is shown in Table 3.

Table 3 Benefit Present Value Multiplier at different system lifetime.

Lifetime (Year)	Benefit Present Value Multiplier M_B at r =0.07 and g=0.1
5	5.436617
10	11.67933
15	18.84766
20	27.07884
25	36.53047
30	47.38351

The relation describing the energy price capable to allow operating the system at break-even conditions for predefined system life-time is presented in Figure 4. The system proposed in framework of this study usually covers a lifetime of 30 years for both the photovoltaic system and the solar thermal collector. The calculations demonstrate that the system is economically viable for the operation under Christchurch climate conditions for all cases where the energy price is higher than 0.16 ($/kWh), see Figure 4.

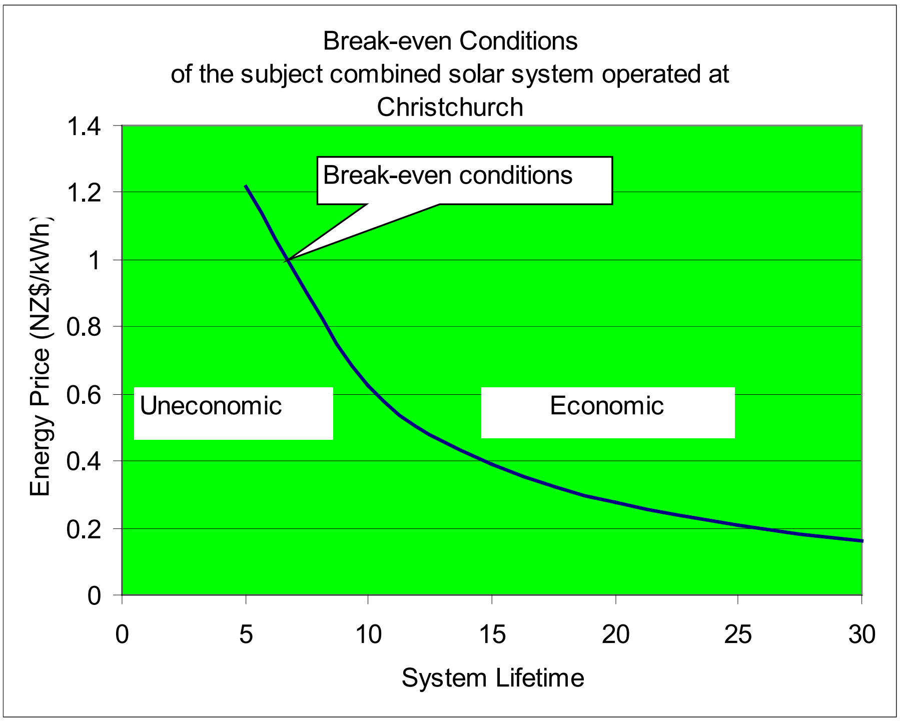


Figure 4 Energy price vs. system lifetime – with break-even conditions.

In the drought conditions of 2001 the spot price for electricity has varied between 0.12 and 0.35 $/kWh and did, for short periods, reach in excess of 0.45 $/kWh.

6. CONCLUSIONS

The analysis presented in this paper for a combined solar installation at typical domestic house has shown that such a system will present realisable benefits within the expected lifetime of the system.

With the current uncertainties surrounding future electricity pricing and the requirements for a move to an increased use of renewable energies, the time has never been more opportune for an increased uptake of such systems in New Zealand.

7. REFERENCES

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