Cost per kWh Produced and Payback Time of a PV-Solar-Thermal-Combined System at Different Locations in New Zealand

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Abstract

This study presents an economic evaluation of three types of solar applications: a) grid-connected photovoltaic system, b) grid-connected photovoltaic system combined with a solar water heating system and c) solar water heating system only. The operational data of an 1.3m^2/120-litre tank evacuated tube solar thermal collector and the data of an average1kWp grid-connected crystalline photovoltaic solar generator are taken as a basis for the calculation. The annual amount of energy produced, the incurred cost and the resulting savings over the system lifetime are used to determine the cost per kWh and the payback time of the system at different geographic locations in New Zealand.. The analysis presented in this paper for a combined solar installation including a grid-connected photovoltaic system and a solar thermal unit at a typical domestic house has shown that such a system will present realizable benefits compared to simple grid-connected photovoltaic systems operated separately. The calculations demonstrate the shortest payback time and the lowest cost per kWh for the pure solar water heating system compared to the two other alternatives, the combined system and the sole GC-PV.

1. INTRODUCTION

It is most common in New Zealand for water and space to be heated electrically. This situation is due to the fact that NZ has traditionally had an abundance of natural hydroelectricity produced, transmitted and distributed efficiently with minimal polluting effect. However, the electric energy consumption in water heating for domestic household use is considered to account for 42 % of the electricity consumption as described by Stoecklein *et al* (2002).

The recently released National Energy Efficiency and Conservation Strategy - New Zealand's Renewable Energy Target (October 2002) announces a target to provide a further 30PJ/year (around 8340GWh/year) to increase the renewable energy supply by 2012. In 2000, renewable energy supplied 133.5PJ, 29% of consumer energy. This means that by 2012 a minimum of 163.5 PJ of consumer energy should be supplied by renewable sources. The renewable energy target is intended to give effect to the required progressive transition to renewable energy.

As grid-connected photovoltaic (GC-PV) are highly recommended for urban use representing typical distributed generation to provide support to the national grid, the risk exists that the valuable high-grade photovoltaic electricity may in turn be used for heating purposes. This work is an attempt to introduce the economics of a GC-PV combined with a suitable domestic solar water heater in order to encourage the use of both types of solar energy where applicable. The use of a separate solar heater adds, as expected, advantages to the economics of the whole system. The operational data of an evacuated tube collector (ETC) representing the solar water heating (SWH) system and an average crystalline solar grid-connected photovoltaic solar generator are taken as a basis for the calculations. The annual amount of energy produced, the resulting savings over the system lifetime and the payback time are presented.

2. THE SOLAR SYSTEM

This analysis describes the economic performance of a domestic solar system consisting of an 1 kWp grid-connected photovoltaic plant (GC-PV) attached to an 700 W ac inverter and of an evacuated tube (ETC) solar water heater (SWH) of 1.37m^2 total aperture collector area attached to an 120 litre water tank. The study is based on operational data resulting from field measurements on evacuated tube solar collector of that art tested at Christchurch as described by Abdalla & Wilson (2001) and the interpreted operation data of a typical 1 kWp GC-PV system. An economic analysis of such a system, operated at Christchurch, has been previously also presented in another publication by Abdalla & Wilson (2001).

The average availability of solar irradiation at different locations in New Zealand are presented in Table 1 while the total energy gains generated by the operation of that particular solar system at the same locations in kWh/year are summarized in Table 2.

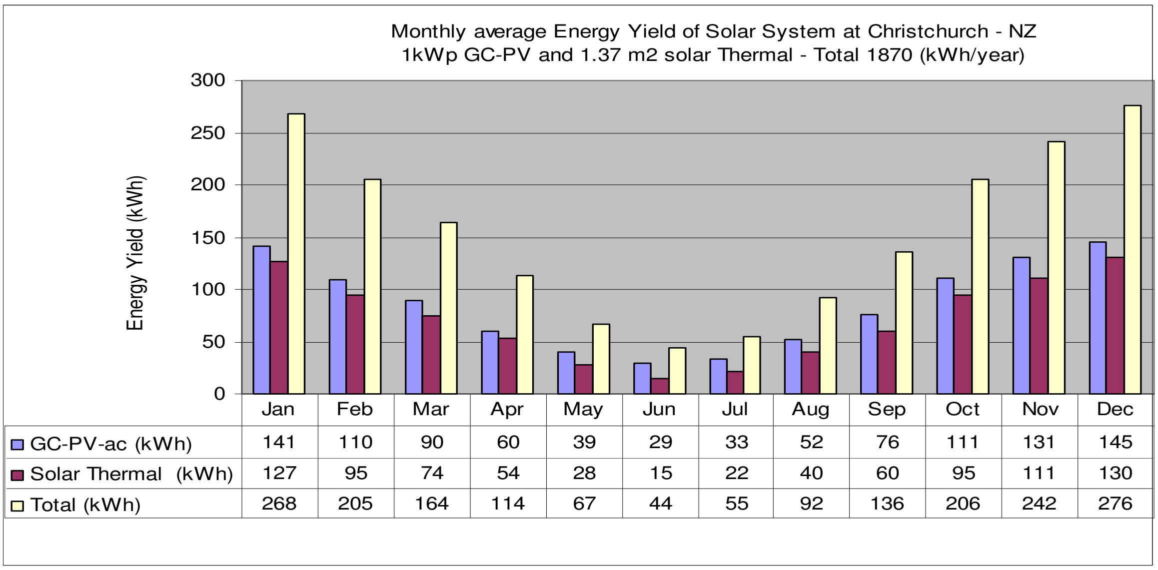
Table 1: Average solar irradiation availability at different locations in New Zealand

	Auckland	Wellington	Christchurch	Dunedin
Total mean solar irradiation (kWh/m^2 year)	1575	1422	1357	1252

Table 2: Forecasted energy production of a 1-kWp GC-PV and a 1.37m^2 ETC solar heater at different locations in New Zealand

	Auckland	Wellington	Christchurch	Dunedin
Energy Yield 1kWp-Grid-connected PV (kWh/year)	1182	1067	1019	940
Energy Yield Evacuated Tube SWH (kWh/year)	999	878	851	759
Total Energy Yield of a combined system (kWh/year)	**2181**	**1945**	**1870**	**1699**

Figure 1 shows the average monthly energy yield of the combined system at Christchurch.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
GC-PV-ac (kWh)	141	110	90	60	39	29	33	52	76	111	131	145
Solar Thermal (kWh)	127	95	74	54	28	15	22	40	60	95	111	130
Total (kWh)	268	205	164	114	67	44	55	92	136	206	242	276

Figure 1. Average monthly Energy yield of the proposed combined solar system at Christchurch, New Zealand.

The total model system initial cost interpreted according to present New Zealand market data is shown in Table 3.

Table 3: System initial cost

Item	No. Units	Total cost range NZ$
Mono-Crystalline 1 kWp PV modules	1	8000
Modules installation, Wiring & Cabling		1500
Inverter 700 W-ac	1	2500
Evacuated tube SWH 1.37m^2/120 Litre including installation cost	1	2500
Total Initial Capital Investment		**14500**

The electric average energy demand of a representative domestic of a volunteer user (4-person household) at Christchurch has been implemented in the calculation in order to demonstrate the impact of the installed combined solar system on the energy consumption. The contribution made by the GC-PV system added to that of the solar thermal system results in the total reduction in the energy demand from the utility grid**.** Figure 2 shows the resulting electric energy consumption for one-family household implementing the proposed combined solar system at Christchurch.

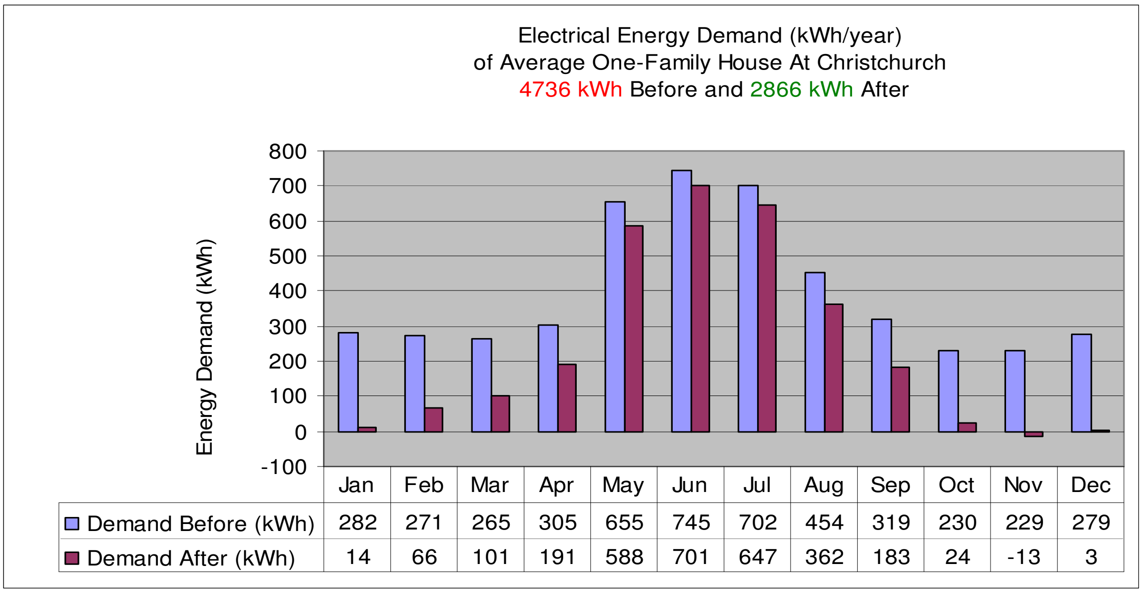


Figure 2. Realisable electric energy savings from the proposed solar system.

3. COST PER KWH PRODUCED

In a lifecycle cost analysis the cost of the produced energy has been calculated as a result of the Net Present Value of Lifetime System Cost divided by the energy produced over the system lifetime. Figure 3 illustrates the cost per produced kWh generated from the system at four locations in New Zealand (Auckland, Christchurch, Wellington and Dunedin) for three different cases: a) the grid-connected photovoltaic system, b) the combined system and c) just the evacuated tube SWH system.

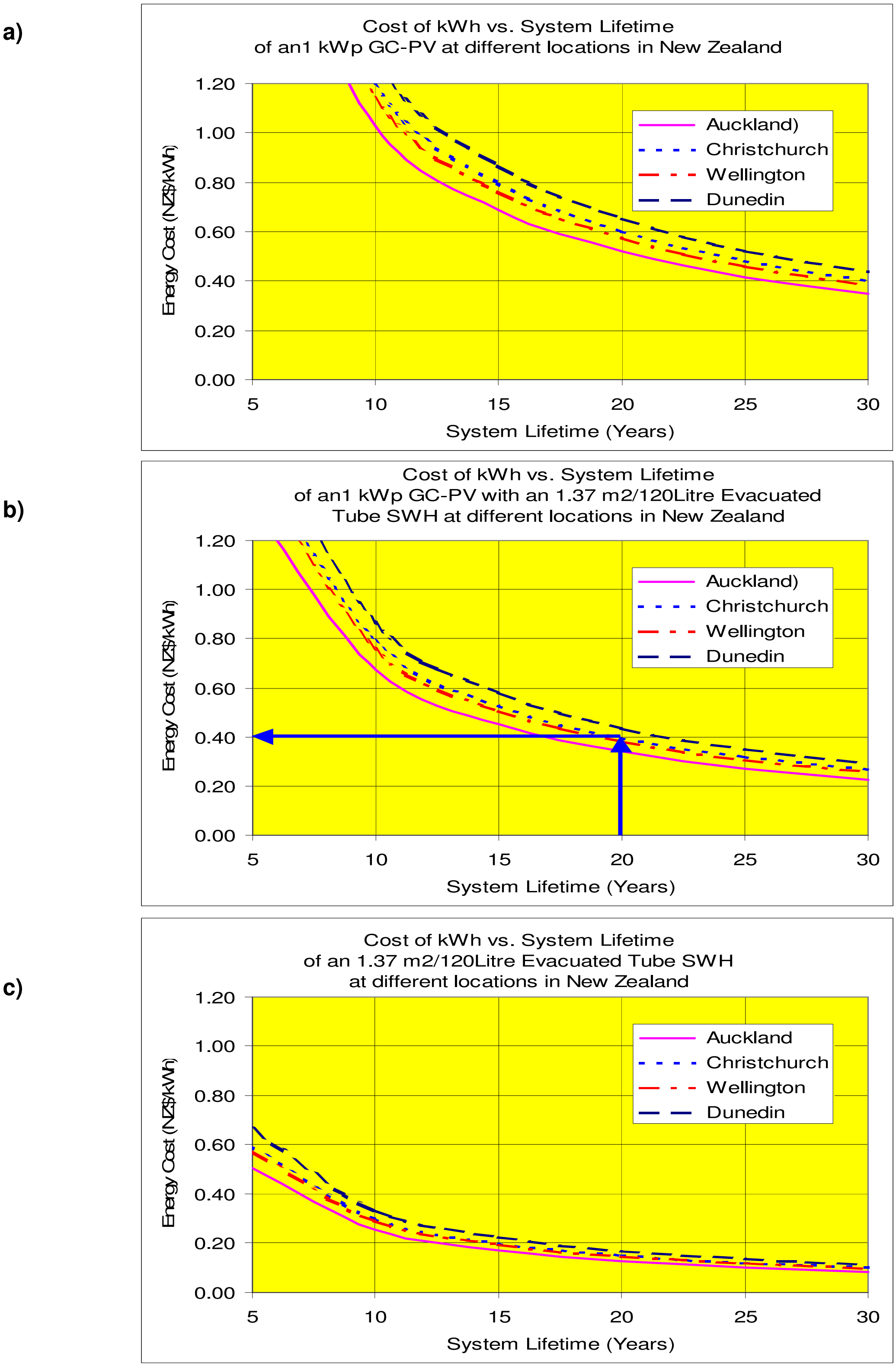


Figure 3. Cost per produced kWh generated for three different cases: a) the grid-connected Photovoltaic system, b) the combined system and c) just the Evacuated tube SWH system.

4. PAYBACK TIME

The lifecycle analysis has been used here as described by Doane *et al* (1976) and lately by Merzeiewski (1998) to evaluate the payback time of the proposed system. In this technique cost and benefits for each operational year are projected and then discounted back to the year of installation to obtain the "present value".

Usually, as described by Boer (1978), the payback time is computed as the time at which first cost and annual expenses with compounded interest equal the total savings of energy cost with compounded interest. In the following the Net Present Value of Lifetime System Cost and the Net Present Value of Lifetime System Benefit will be calculated and compared. A lifecycle cost of zero represents a "break-even" investment, i.e. the system capital cost is exactly met by the savings or benefits generated over its lifetime.

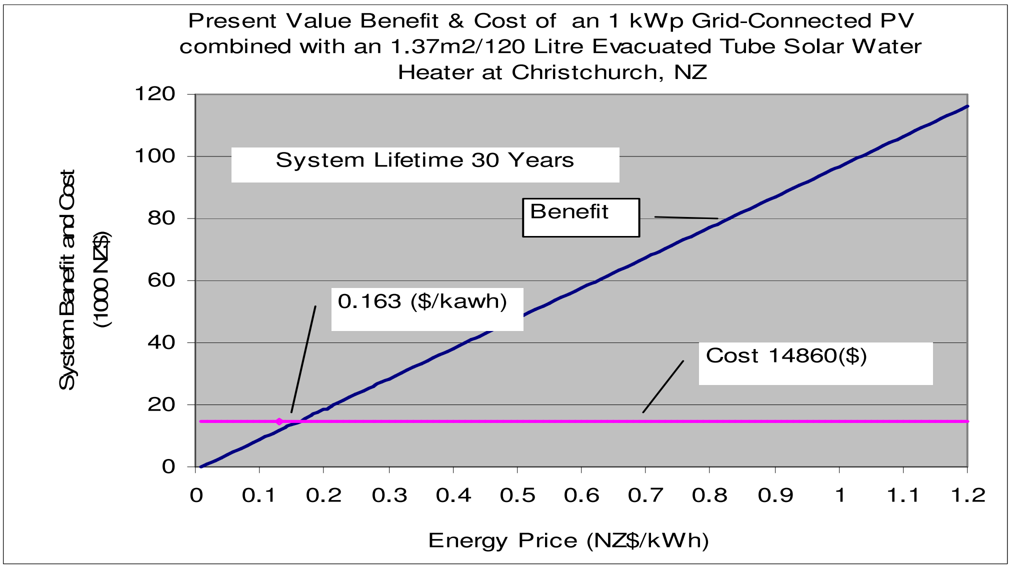
Following assumptions have been made to calculate the Net Present Value of Lifetime System Cost and the Net Present Value of Lifetime System Benefit:

- Interest rate 7% p.a.
- Lifetime of the system in year 5-30 years
- Marginal tax bracket 0 % (no governmental subsidies)
- Savings escalator 0.10, i.e. 10% p.a.
- Operation, Maintenance + Insurance first year = 0.2% of invested capital
- Operation, Maintenance + Insurance increase = 5%/year

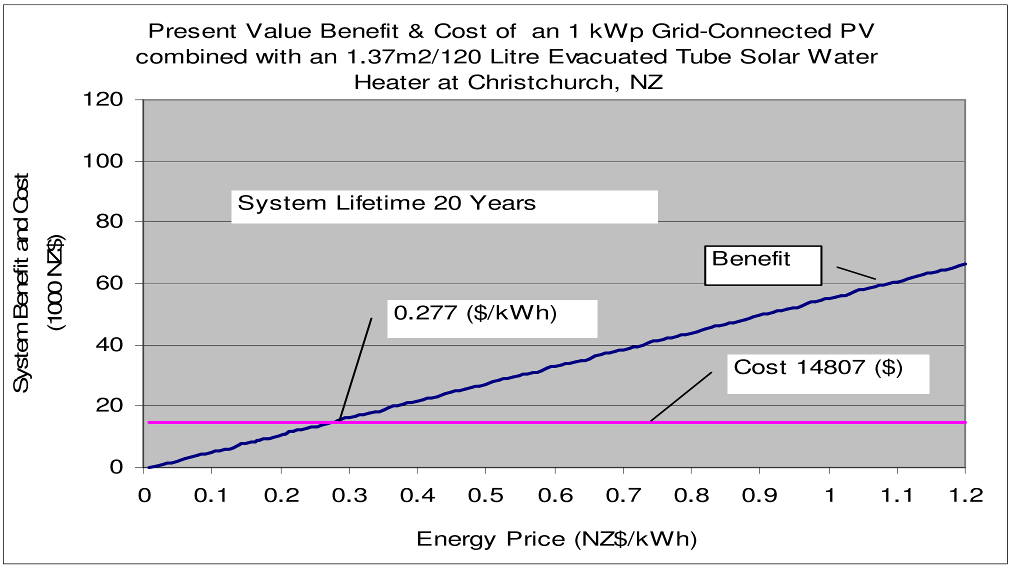
Figure 4 shows the results of the lifecycle cost analysis for the combined system at Christchurch. The points of intersection between the system cost and benefits represent the situation at which the total system cost equal the total benefits generated by the system operation during its entire expected lifetime ensuring so a rewarding investment. At energy prices below that level the expected benefits are lower than the system cost and consequently, on just immediate economic considerations, the system might not be justified. At higher energy prices the economic benefits generated are higher than the incurred cost i.e. the system is paying back itself before the expected lifetime. The higher the energy prices the shorter the payback period.

The relation describing the payback time of the proposed system at different energy prices and locations in New Zealand is presented in Figure 5 for a) the 1kWp grid-connected photovoltaic system, b) the combined system GC-PV and evacuated tube SWH and c) just the evacuated tube SWH.

a)



b)



c)

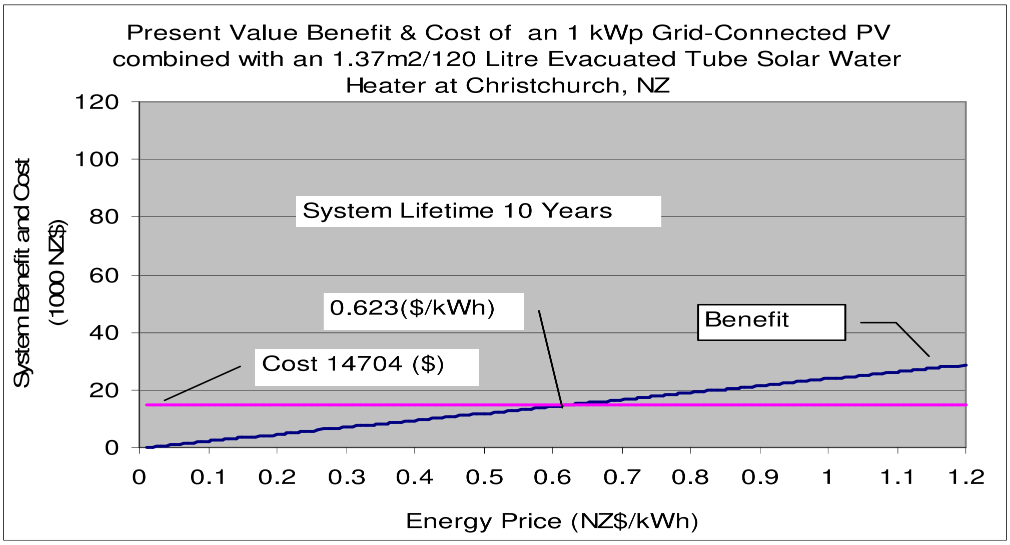


Figure 4 System benefit and cost vs. prevailing present energy price at Christchurch.

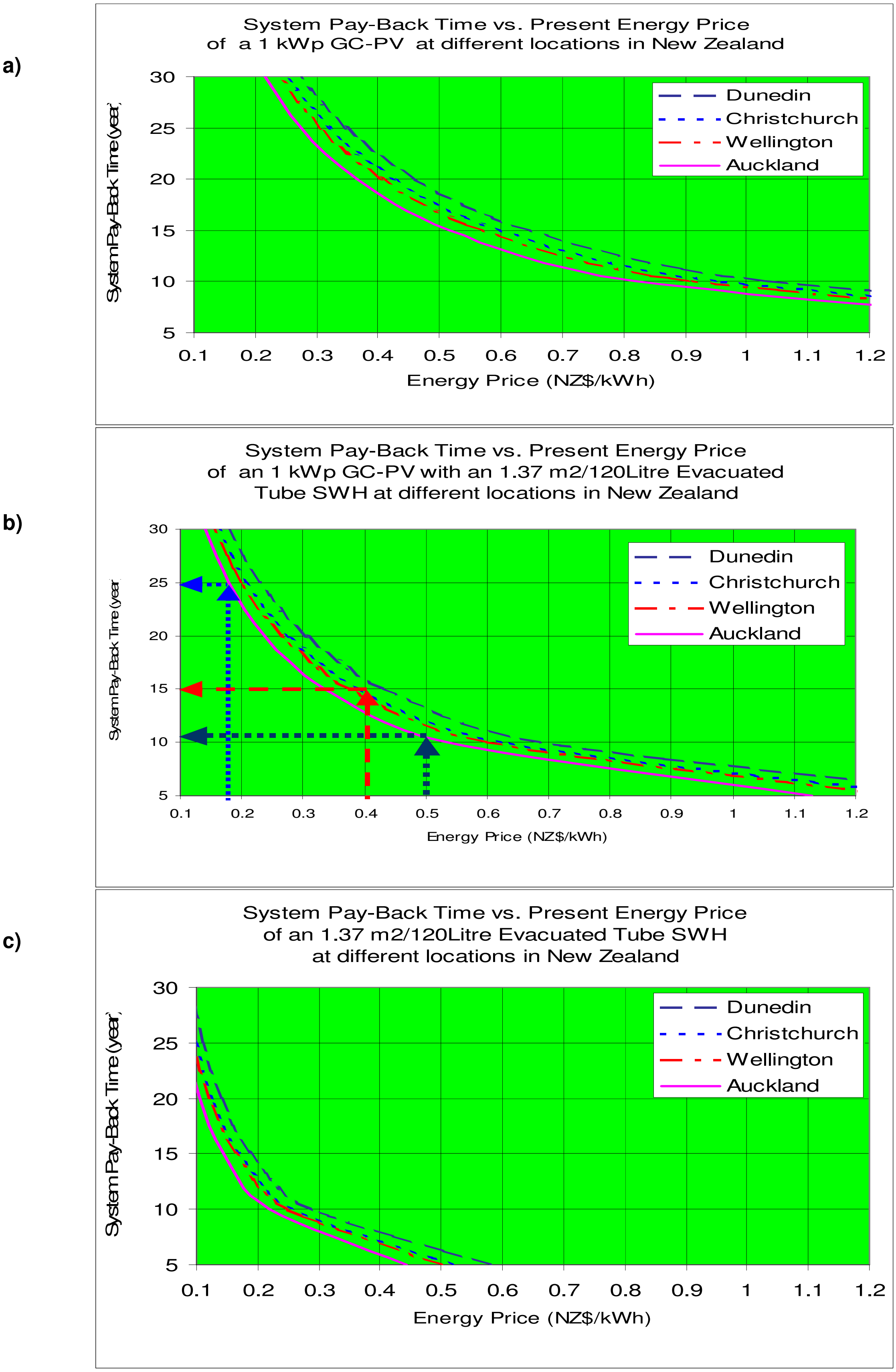


Figure 5 System payback time vs. prevailing energy prices at different locations in New Zealand for a) grid-connected photovoltaic system, b) combined system GC-PV with the evacuated tube SWH and c) just the evacuated tube SWH.

5. DISCUSSION

The calculations demonstrate that the system consisting of just the solar water heater provides the shortest payback time and the lowest kWh cost compared to the two other alternatives, the combined system and the GC-PV-only system. However the combination of both the GC-PV with the SWH still gives economic advantages in terms of lower c/kWh and shorter payback time compared to the GC-PV-only system.

Solar favorable locations such as Auckland demonstrate better economics with lower cost of energy and shorter payback time.

The cost of the produced energy is calculated, as described above, from the total present cost of the system divided by the total energy expected to be produced from the system over its lifetime, e.g. the cost of energy from the system at Christchurch for an expected lifetime of 20 years is 40 c/kWh as shown in Figure 3b. The payback time, in contrast, is calculated taking into consideration the total present cost of the system as well as the total revenues created from the system during its lifetime (discounted to the present). The point at which the cost equals the benefits is considered the break-even point as illustrated in Figure 4.

By considering Figures 3 and 5 a comparison can be drawn between the system lifetime and the payback time. As the example shows in Figure 3b the combined system at Christchurch provides an energy cost of 40 cents at a system lifetime of 20 years while the payback time for this same energy price (40 cents) is 15 years according to Figure 5b. This is obviously because the benefits generated by the system over its lifetime exceeded the incurred cost. In other words, once the generated benefits are higher than the incurred system cost the payback time will be shorter than the projected lifetime of the system. The higher the energy prices at the site of operation the higher the benefits and consequently the shorter the payback time.

The payback time for the combined system based on a current averaged price of 18c per kWh in Auckland is approximately 25 years as illustrated in Figure 5b. If the price should rise beyond this the payback time is as little as ten years in Auckland at electricity price of 50c per kWh.

6. CONCLUSIONS

The analysis presented in this paper for a combined solar installation including a grid-connected photovoltaic (GC-PV) system and a solar thermal unit at a typical domestic house has shown that such a system will present realizable economic benefits in each of the four main population centers in New Zealand compared to simple GC-PV systems operated separately. The calculations demonstrated that a system consisting of just a solar water heater provides the shortest payback time and the lowest cost per kWh compared to the two other alternatives, the combined system and the GC-PV-only system. Once the generated benefits over the system lifetime are higher than the incurred system cost the payback time will be shorter than the projected lifetime of the system. The higher the energy prices at the site of operation the higher the benefits and consequently the shorter the payback time.

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