ASIA-PACIFIC SOLAR RESEARCH CONFERENCE

2016

Peer Reviewed
2016 Solar Research Conference

Solar Heat Below Grid Price

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Abstract
Solar Heat Worldwide (SHWW) is the International Energy Agency Solar Heating and Cooling Programme's (IEA SHC) annual market report, and has been published annually for over a decade. The latest edition covers data up to the end of 2014 and provides insights into the solar heat market. Markets in previously well-established areas including China, Europe and Australia are stagnating, whilst markets in the global south are increasing their share. A major driver in this shift to new renewables appears to be the lack of reliable conventional energy supplies in developing countries.

The current edition also illustrates that solar heat is a substantial market compared to other solar technologies. For the first time this report has included the calculated levelised cost of solar heat (LCOH) for a number of countries around the world. According to this new research, it is more cost-effective to provide hot water using solar heat than from conventional supplies. A number of parameters specific to the Australian market were not considered in the SHWW report. These will be addressed throughout this paper.

The most commonly purchased solar hot water systems in Australia are flat plate collector pumped hot water systems. Considering the full cost of this type of solar hot water system at current market prices, energy is provided as heat at between 9 - 14 cents/kWh. However, in Australia the purchasing of a solar water heater predominantly occurs to replace an existing system at the end of its life, rather than supplementing a conventional system. When this is taken into account the cost of heat from a flat plate solar water heater may be as low as 4 cents/kWh. This represents significant savings compared to both conventional electric and gas systems. Solar heating systems will continue to provide energy at this cost for their entire lifespan, whilst the rates of conventional energy sources are likely to increase.

Investigation and sensitivity checking of this and other assumptions made in the SHWW report including life span of systems, collector yield and climate differences across Australia shows significant improvement on the initial LCOH estimates of three different solar hot water technologies made in SHWW.

1) Introduction

Solar thermal heating represents the largest installed capacity of new renewables worldwide (Mauthner et al. 2016). Despite this it is often overlooked in favour of renewable power technology both in terms of visibility and public policy.

Solar thermal has been recognised by the International Energy Agency as an area with significant potential for increased use (IEA, 2012). This form of solar fills a specific need, and can do so independently of electric power grids. Rather than generating power to be fed into the grid, solar thermal removes load by providing heat directly. This eliminates the need to convert from electricity to heat with the associated losses. Whilst limited in the scope of possible end-uses compared to electricity generating renewable sources, the contribution thermal can make to reductions in greenhouse gasses and an overall greener energy landscape should not be understated. Given the ageing nature of Australia's electricity infrastructure (Bruno et al. 2015) this contribution has the potential for immediate and visible impact.

The potential for solar thermal to reduce overall energy use and subsequent emissions is enormous, as water heating represents almost one quarter of total residential household energy use (Pavia & Ryan). Additionally, Australia has the highest average solar radiation per square meter in the world, thereby providing favourable conditions for solar technology (Geoscience Australia and ABARE, 2010).

Comparing the costs of energy provided from different sources can be quite challenging. Levelised Cost Of Heat/Energy (LCOH/LCOE) is an effective and widely used method of comparing the costs of power generation between different technologies (IEA et al. 2010). It provides in depth analysis incorporating a large number of factors such as investor costs, lifespan of systems and discount rates. This method has been applied by the International Energy Agency Solar Heating and Cooling Programme (IEA SHC) in its 2016 publication Solar Heat Worldwide (SHWW) to quantify the cost of solar thermal in some major markets across the globe. This is the method employed by this paper to show the value of solar heat.

The purpose of this study is to examine the calculation of the levelised cost of heat and further refine the techniques used by the IEA SHC in its SHWW 2016 to provide a more accurate reflection of the Australian market. This has been achieved through analysing several of the assumptions and variables included in previous LCOH calculations including the cost of a new system, ongoing maintenance costs, life expectancy of systems and the solar yield of collectors in different climate zones. With the data from these refined calculations this work also illustrates the financial viability of renewable water heating compared to conventional systems.

2) Background

It is widely recognised that there is urgent need for global action on climate change (Latin, 2012) with a strong focus on embracing renewable energy and green technologies to reduce greenhouse gas emissions (IPCC, 2014).

2.1) State of the Market

Despite being in a strong position to further advance solar based green initiatives solar water heating market growth in Australia has been in a steady decline since 2010, a trend which is consistent across most developed regions including Europe and North America and is illustrated in *Figure 1*. This decline has been attributed to withdrawal of government support amongst other factors (Epp, 2016). The majority of growth in this sector has instead been led by developing regions including the Middle East and North Africa (MENA), Sub-Saharan Africa and Latin America. It is believed that the efficiency and practicality of off grid renewables in areas with poor conventional energy sources has played a large part in solar heat's popularity in these regions (Guthrie & Hudson, 2015).

The need for more to be done to develop renewable heating has been recognised by the IEA. In releasing the World Energy Outlook in November 2016 the IEA Executive Director stated "The next chapter in the rise of renewables requires policies to push their role in heat…" (IEA, 2016)

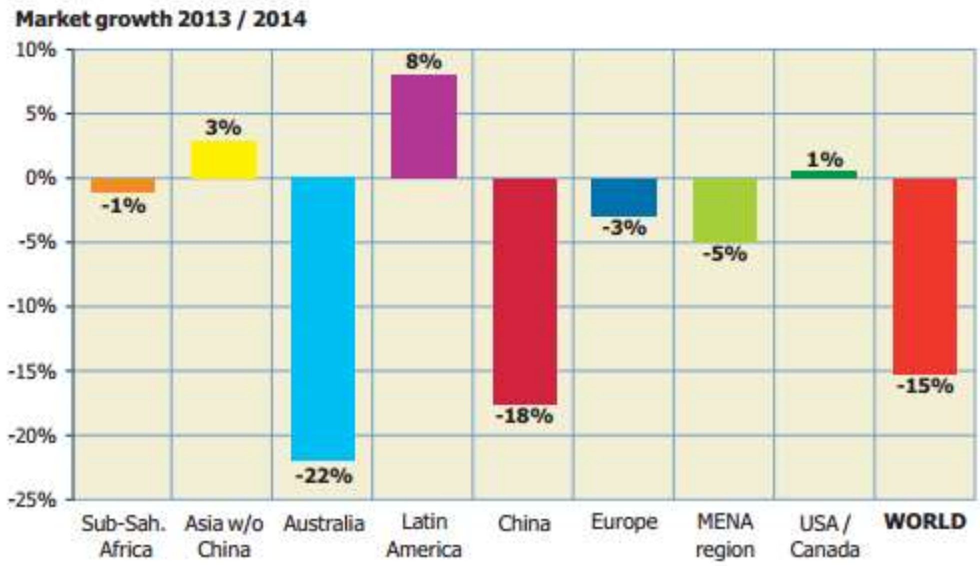


Figure 1: Market Growth for Solar Thermal 2013/2014. Source: Solar Heat Worldwide

2.2) SHWW 2016 Assumptions

The latest edition, 2016, of the International Energy Agency Solar Heating and Cooling Programme's (IEA SHC) annual market report, Solar Heat Worldwide (SHWW) presents for the first time the LCOH calculations applied to solar thermal technology. Given the global nature of this report, and the diverse markets included, the LCOH calculations are generalised. Whilst there has been a level of refinement for each region, a number of the assumptions can be further reviewed to provide a more accurate representation for Australia.

The primary assumptions that are being addressed in this paper to more accurately reflect the Australian market include the initial cost of a solar thermal system, the expected lifetime of solar and conventional water heating systems, and the solar yield ascribed to Australia in general and to each of its climate zones (AS/NZS 4234:2008). All general and system specific assumed values are listed in Tables 1 and 2 below.

Table 1: General Assumptions from SHWW

Discount (interest) rate (r)	3	%
Annual Operation and Maintenance Expenditures Pumped System (At)	0.5	%
Annual Operation and Maintenance Expenditures Thermosiphon System (At)	0.25	%
Period of Use/Lifetime Pumped System	25	Years
Period of Use/Lifetime Thermosiphon System	15	Years

Table 2: System Specific Assumptions from SHWW

	Flat Plate Collector		Flat Plate Collector		Evacuated Tube Collector	
	Pumped System		Thermosiphon		Pumped System	
Reference Climate	Sydney		Sydney		Sydney	
Global Horizontal Irradiation	1674	kWh/m^{2}pa	1674	kWh/m^{2}pa	1674	kWh/m^{2}pa
Gross Collector Area	3.9	m^2	3.9	m^2	4.1	m^2
Storage Volume	250	Litre	280	Litre	290	Litre
Annual Solar Energy Yield	844	kWh/ m^{2}pa (absorber)	844	kWh/ m^{2}pa (absorber)	844	kWh/ m^{2}pa (absorber)
Net Spec. Solar Thermal System Costs incl. Labour						
Min	740	€/m^2(gross)	930	€/m^2(gross)	990	€/m^2(gross)
Max	1200	€/m^2(gross)	1240	€/m^2(gross)	1320	€/m^2(gross)
Levelised Cost of Heat						
Min	5.9	€-ct/kWh	10.4	€-ct/kWh	10.7	€-ct/kWh
Max	9.6	€-ct/kWh	13.9	€-ct/kWh	14.3	€-ct/kWh

2.3) Typical Australian Systems

There is a large array of different solar hot water systems currently in use around Australia. These vary in cost, capacity and type. Whilst all of these factors will influence the output of a system, the primary focus of this paper is on the cost of energy produced by the collector.

The two types of collector used in the Australian domestic hot water market are Flat Plate Collectors (FPC) and Evacuated Tube Collectors (ETC). These products are constructed differently and have significantly differing properties, and as such should be considered separately. Collectors are part of a system which will either be a thermosiphon system or a pumped system. Pumped systems are the most prevalent in Australia with both FPC's and ETC's common, whilst thermosiphon systems predominantly utilise FPC's.

For each common type of collector/system a set of performance characteristics were developed to represent a 'typical' system on the Australian market. These typical systems allowed TRNSYS modelling to investigate the impact of changed conditions upon the system's performance using a consistent approach.

The general assumptions and the characteristics of each system are listed in Table 3 below.

Table 3: Typical System Characteristics

	Electric boost (ET) Evacuated Tube pumped	Flat plate pumped	Flat plate Thermosiphon
Annual Solar Energy Yield	Zone Dependent	Zone Dependent	Zone Dependent
a1	0.69	0.79	0.79
a2	2.5	3.9	3.9
a3	0.011	0.025	0.025
Tank heat loss (kWh/day)	2.3	1.9	1.6
Volume (L)	325	220	180
Collector description	30 tube @0.09m^2/tube	2 collectors @1.89m^2	2 collectors @1.89m^2
Collector area (m^2)	2.8	3.78	3.78
Booster	electric	Gas	electric
tank wall thickness (mm)	2.5	2.5	3
Efficiency of gas burner		85%	
*Any variable not indicated can be assumed to align with SHWW report			

3) Method

3.1) Levelised Cost of Heat

Levelised Cost of Heat (or Energy) is a method of comparing the costs of different forms of energy production or generation over the operating life (IEA et al, 2015). This method calculates the total costs for installation and maintenance of a system and divides that by the energy provided over the lifetime. It is important to note that as this calculation covers the lifecycle of the system, all costs are discounted at a determined discount rate. The framework for the LCOH calculations in this report is taken from IEA SHC SHWW 2016 and is calculated according to Equation (1) below:

$$LCOH = \frac{\sum_t^{t_{life}} C_t * (1+r)^{-t}}{\sum_t^{t_{life}} E_t * (1+r)^{-t}}$$

This equation can be expressed in a format to more readily calculate Levelised Cost of Heat as in Equation (2) below:

$$LCOH = \frac{I_o + \sum_t^{t_{life}} A_t * (1+r)^{-t}}{\sum_t^{t_{life}} SE * (1+r)^{-t}}$$

Where

$LCOH = \ Levelised\ Cost\ of\ Solar\ Thermal\ Generated\ Heat\ [\$/kwh]$
$I_o = Specific\ Solar\ Thermal\ System\ Cost\ incl. Install\ (excl. VAT\ and\ Subsidies)\ [\$/m^2_{gross}]$
$A_t = Fixed\ and\ Variable\ O\ and\ M\ Expenditures\ in\ the\ Year\ [\$/m^2_{gross}]$
$SE = Solar\ Energy\ Yield\ in\ the\ Year\ [kwh/m^2_{gross}]$
$r = Discount\ (Interest)\ Rate\ [\%]$
$t_{life} = Period\ of\ Use/Lifecycle\ \ of\ System\ [years]$
$t = Year\ Within\ Period\ of\ Use$

3.2) Actual Cost

One of the major considerations not taken into account by the IEA SHC SHWW 2016 report in regards to LCOH calculation is the types of systems and the purchase process in the Australian market. In many other major markets worldwide solar hot water systems are often installed as a supplementary preheater to existing conventional systems. This is rarely the case in Australia. The predominant driver of installing new water heating systems is the need to replace a failing system or in a new house. As such a portion of the initial cost of installation of a solar hot water (SHW) system would have been required to purchase and install a conventional system regardless. Therefore this cost should be subtracted from the initial installation costs of a new SHW system. The evaluation in SHWW used the full cost of the solar water heater, not the marginal cost, which is appropriate in the Australian market.

The cost of a conventional system including installation and labour costs is estimated at $1500. Sensitivity testing including higher and lower incremental cost changes from $1200 to $2000 is presented in Section 4.

The cost of a SHW system including installation and labour costs was given in SHWW as a cost per square meter of collector gross area. SHWW gives collectors prices for FPC systems from approx. $2800 to $4700, and ETC systems from approx. $4000 to $5400[1]. The data used for Australia by the IEA SHC in this publication came from the Victorian rebate data from 2010-2013 and as such reflects the Victorian market from this time.

3.3) Annual Solar Energy Yield

Annual Solar Energy Yield is the amount of energy provided by the collector over a year. This is the amount of heat delivered to the tank. It takes into account that at times the water in the tank will be hot and so there will be no more heat delivered despite there being solar radiation on the collector. It can be compared with the cost of a conventional fuel source delivering heat to the hot water store, which for gas should include the efficiency of combustion as the combustion occurs after the meter.

The IEA SHC SHWW 2016 publication gives an annual solar energy yield of 844 kwh/(m^2a) for the whole of Australia. This is problematic in two respects, firstly in that the conditions vary greatly around the different regions of Australia and secondly in that it represents a reasonably conservative value for many regions and systems.

[1] Prices initially in € in Solar Heat Worldwide were converted to $AUD using same exchange rate as SHWW used initially: 1$ AUD to 0.669 €

As stated in section 2.3 of this paper, representative characteristics were created to model typical flat plate and evacuated tube collector systems on the Australian market. These systems were modelled using TRNSYS software to provide the annual outputs under load size 2 of AS/NZS 4234 in each of the climate zones typically used for analysis of systems across Australia. These include Rockhampton, Alice Springs, Sydney and Melbourne. From the resulting output the solar yield was calculated using the equations below

Equation 3a) Total Energy Output

$$Qut_{Annual} = \sum Qut_{monthly}$$

Where

$$Qut = Energy\ Output\ from\ .out\ TRNSYS\ File\ \text{(GJ)}$$

Equation 3b) Conversion to output per area (m^2)

$$b = \frac{Qut}{A_g}$$

Where

$$A_g = Gross\ Area\ of\ Collector\ (m^2)$$

Equation 3c) Conversion to kWh/m^2

$$Solar\ Yield = \frac{b}{3.6}\ kWh * 10^3/m^2$$

This provided annual solar yield figures for the climate zones across Australia for comparison to the data in SHWW. These are used in the revised LCOH calculation and are shown in Table 5.

3.4) Lifetime of System

SHWW 2016 assumes a life expectancy of a SHW system is 25 years for a pumped system and 15 years for a thermosiphon. In Australia a number of regulatory impact statements have used the lifetime of a SHW system as 15 years (Plumbing Industry Commission and Department of Planning and Community Development, 2008), with a conventional system considered to have a lifetime of 10 years (Zero Waste SA, 2004),(Commonwealth of Australia Department of Industry, 2013). Additionally, Morrison and Wood (1999) reviewed the lifetime of solar water heater system components and found that mean collector life was 19+/-5 years.

Consequently, for this analysis a range of solar system life of 15-25 years was chosen to cover the range of studies undertaken, the base case being 20 years, and the conventional system lifetime was modelled at 2/3 of that in most cases.

Given the shorter lifespan of conventional hot water systems, there is an unavoidable cost of replacement at more regular intervals than a SHW. For the present work, this cost difference was incorporated into the LCOH calculations (which require all systems to have the same t_{life} for the purposes of comparison) by multiplying the capital cost by a replacement factor *R*, representing proportional difference in lifespan in calculating the marginal cost of the solar water heater installation.

Factoring for the replacement factor and calculating the marginal Levelised Cost Of (solar) Heat calculation now becomes Equation (4) below:

$$LCOH = \frac{[I_{o,solar} - RI_{o,conventional}] + \sum_t^{t_{life}} A_t * (1+r)^{-t}}{\sum_t^{t_{life}} SE * (1+r)^{-t}}$$

Where $R = 1.5$ represents the solar:conventional system lifetime ratio of 15:10. This was determined to be a conservative estimate of savings over time when accounting for inflation, whilst also assuming like-for-like replacement and neglecting potential advancements in efficiency.

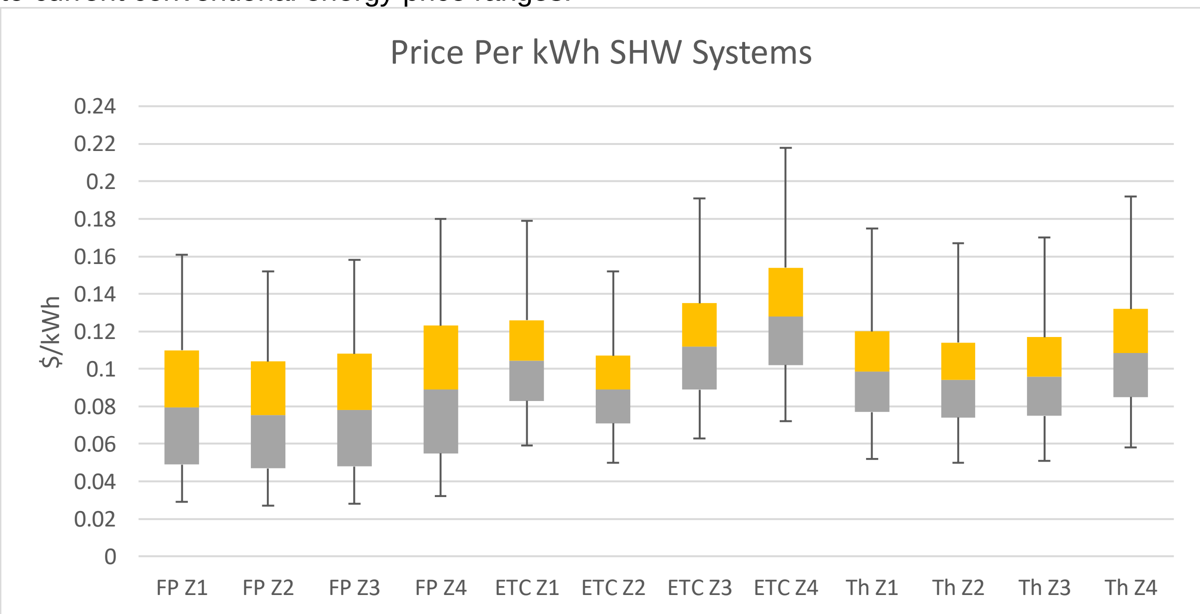
3.5) Prices of conventional fuels
The Australian Energy Market Commission (AEMC,2015) report that residential electricity prices average 28 -29 cents per kWh nationally. Electricity prices range from 19.46 c/kWh in ACT to 31.5 in South Australia. Prices in all states apart from ACT and Tasmania are above 27c/kWh and three are above 30 c/kWh.

A review for the Department of Industry, Innovation and Science in 2016 (DIIS, 2016) of gas price trends indicated that "In 2015, the average residential gas price ranged from 1.84c/MJ in Victoria to 6.00c/MJ in Queensland. " Prices in all other states were between 3.2 and 4.5 c/MJ. When burned with an efficiency of 85% these prices are equivalent to paying 7.8-25.4 c/kWh for heat from Gas

4) Results and Discussion

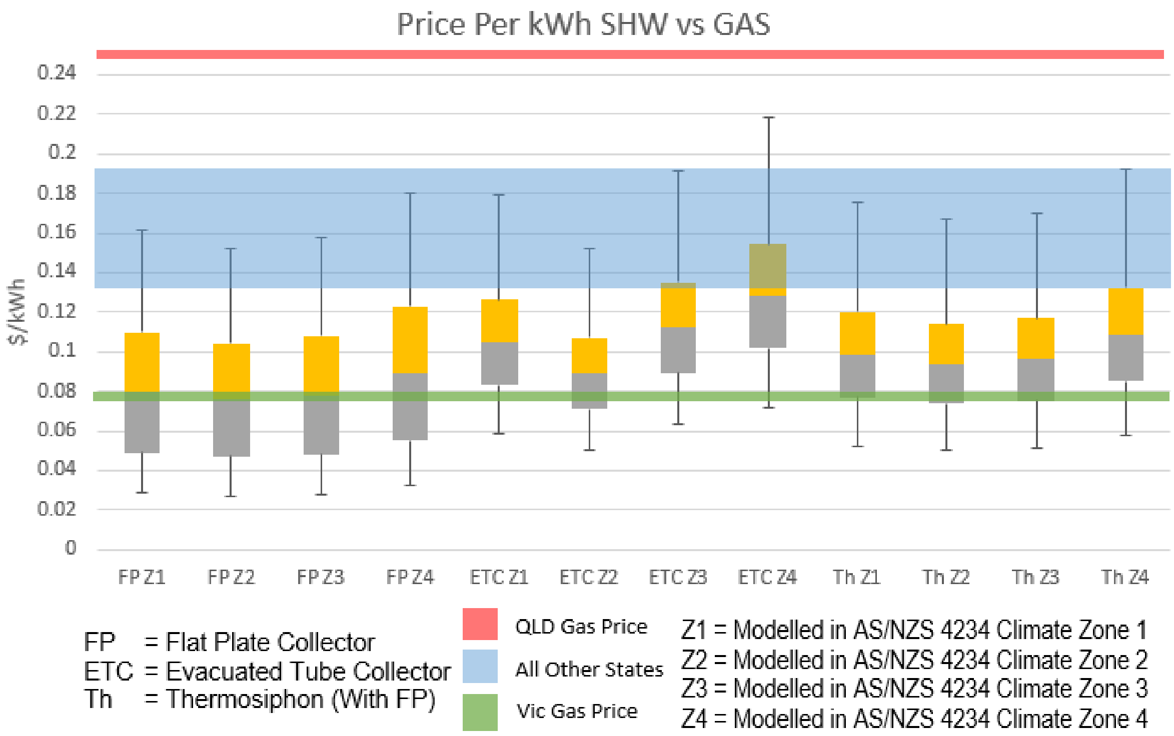
4.1) Effect of revised assumptions on LCOH

After applying assumptions based on the Australian market the LCOH was significantly reduced (compared to the SHWW 2016 estimate). In **Error! Reference source not found.** below we can see the expected price of heat for each system in each climate zone across Australia; compared to current conventional energy price ranges.



FP = Flat Plate Collector
ETC = Evacuated Tube Collector
Th = Thermosiphon (With FP)

Z1 = Modelled in AS/NZS 4234 Climate Zone 1
Z2 = Modelled in AS/NZS 4234 Climate Zone 2
Z3 = Modelled in AS/NZS 4234 Climate Zone 3
Z4 = Modelled in AS/NZS 4234 Climate Zone 4



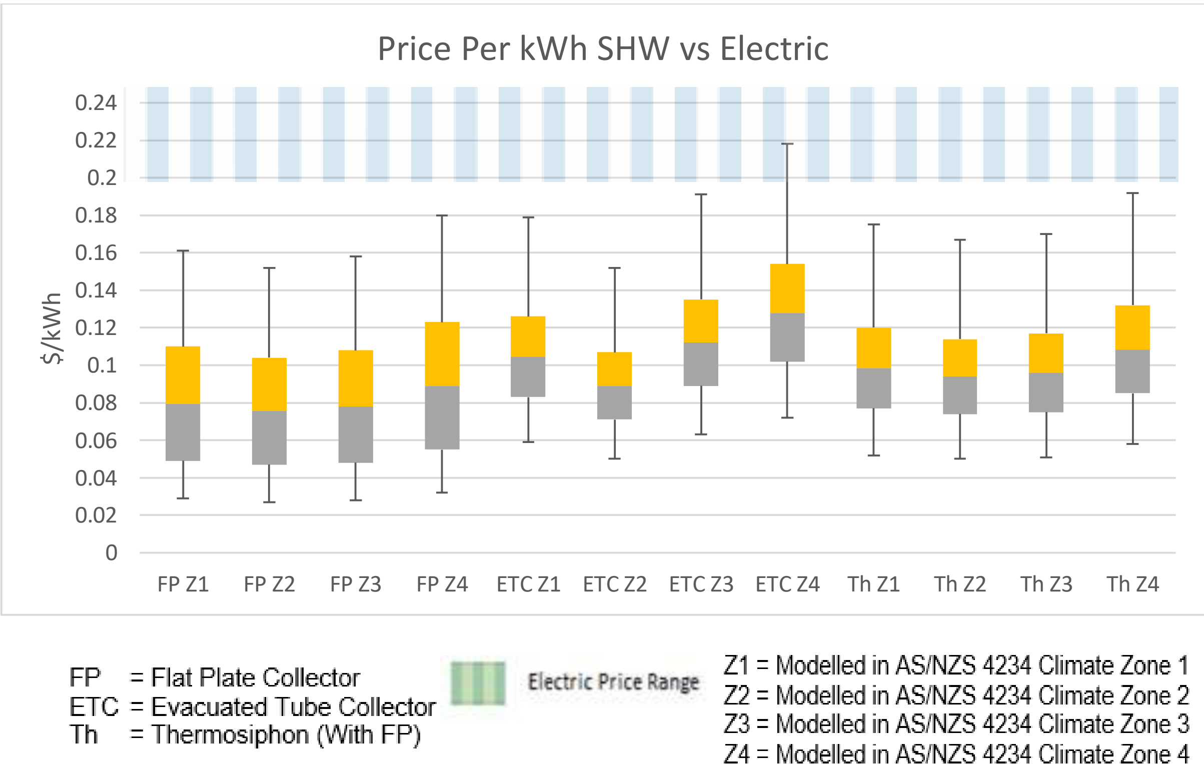


Figure 2: Price Comparison

Notes:

1. *Base Cases (Boxes) are calculated with a 20 year solar system life, R =1.5 and Conventional system cost of $1500. The upper and lower bound of the boxes are based on the maximum and minimum solar water heater prices from SHWW (Table 2 above)*
2. *Best Cases (lower 'Whisker') are calculated with a 25 year solar system life, R =1.5, Conventional system*

cost of $2000 and minimum solar water heater prices from SHWW.

3. *Worst Cases (upper 'Whisker') are calculated with a 15 year solar system life, R =1.0, Conventional system cost of $1200 and maximum solar water heater prices from SHWW.*

This illustrates that when more realistic assumptions for the Australian market are made the results show that the LCOH of a solar water heater in Australia are below electricity costs everywhere in Australia and generally below or competitive with gas at current prices across Australia.

4.1.1) Reduced Initial Cost

The initial change made to LCOH calculations in this paper was to offset the price of a conventional system including installation from that of a SHW system, providing an estimate of the marginal cost of solar heat. Even with conservative estimates of $1200 for a conventional system significant improvements in cost per kWh were seen. A full array of cost improvements for this factor in isolation when applied to the base case model may be seen below in Table 4. Table four shows the sensitivity to conventional water heater costs avoided when a solar water heater is installed. The calculation shown is for systems in Zone 3 with a 20 year solar system life and R =1.0.

Table 4: LCOH with Offset for conventional water heater cost

	Flat Plate Collector pumped			
Assumed Price of Conventional System	**$0**	**$1,200**	**$1,500**	**$2,000**
LCOH with Minimum Install Cost ($/kWh)	0.092	0.071	0.064	0.054
LCOH with Maximum Install Cost ($/kWh)	0.149	0.131	0.124	0.114
	Evacuated Tube Collector			
LCOH with Minimum Install Cost ($/kWh)	0.167	0.112	0.105	0.094
LCOH with Maximum Install Cost ($/kWh)	0.223	0.158	0.151	0.14
	Flat Plate Thermosiphon			
LCOH with Minimum Install Cost ($/kWh)	0.163	0.12	0.112	0.098
LCOH with Maximum Install Cost ($/kWh)	0.218	0.17	0.162	0.149

This illustrates that the LCOH is quite sensitive to the cost of a conventional water heater that is avoided in the purchase decision, and that not accounting for this will significantly underestimate the real LCOH of a solar water heater.

4.1.2) Increased Solar Yield

The solar yield was analysed for each climate zone and is summarised in Table 5 below. It can be seen that SHWW's assumption of 844 kWh pa /(m^2absorber area) represented the flat plate collector technology reasonably well across all of Australia. As expected the solar yield is slightly higher in Northern zones and slightly lower in Southern, but overall the SHWW figure is a good representation of the average across Australia for FPCs.

However, the Evacuated Tube Collector (ETC) technology has a lower absorber area to gross area ratio but gives higher yield when referenced to absorber area. As a result, the 844 kWh pa/m^2 solar yield assumption in SHWW understated the output by between 25% and 85%, representing a significant improvement in value to the ETC's LCOH from initial estimates.

Table 5: Calculated Annual Solar Yield

	Zone	Gas boosted (kWh pa/m^2)	%Change	Elec. boosted (kWh pa/m^2)	%Change
ETC	1	1233	46 %	1306	55%
ETC	2	1458	73%	1539	82%
ETC	3	1200	42%	1223	45%
ETC	4	1053	25%	1069	27%
		Pumped	**%Change**	**Thermosiphon**	**%Change**
FPC	1	839	-0.5%	781	-7%
FPC	2	889	5%	818	-3%
FPC	3	856	1.5%	802	-5%
FPC	4	753	-11%	710	-16%

Consequently, the improvement in solar yield for ETCs needs to be accounted for to avoid significant understating of the calculated LCOH.

4.1.3) Comparison of lifespan to that of a conventional system
The lifespan ratio of 3:2 for Solar vs Conventional water heaters (R=1.5) as discussed in section 3.4 shows a significant reduction in the LCOH of SHW systems when applied in the calculation, so it also should be taken into account where the solar water heater is installed as an alternate to purchasing a new conventional water heater.

4.2) Comparison with the price of conventional fuels: Electricity and Gas.
Comparison between the prices per kWh from the LCOH calculations and market prices for conventional fuels presents a challenge due to the fixed nature of the first and the variable nature of the second.

At the current market prices outlined in section 3.5, all the SHW systems analysed in this study achieve or surpass price parity; as can be seen in Figure 2. Realistically the price of both gas and electricity are likely to fluctuate over time. However solar has a significant price advantage over electrical systems and according to market experts the price of the lowest cost conventional fuel, gas, is expected to continue its upward trend (Deloitte Access Economics, 2014).

5) Conclusions

Solar Heat Worldwide has provided a significant advance in the understanding of the true cost of solar heat by publishing the Levelised Cost of Heat (LCOH) of a number of different solar heater types supplying heat to a range of load types.

This study has reviewed the assumptions made, and results reported, in Solar Heat Worldwide. We find that:

- The analysis reported in Solar Heat Worldwide indicates that solar water heaters are likely to provide heat at a competitive price in Australia.
- The analysis reported in Solar Heat Worldwide doesn't accurately represent the LCOH from solar water heaters in Australia. Many of the assumptions are too conservative for the Australian situation so the actual LCOH is lower than reported by Solar Heat Worldwide.
- When more realistic assumptions are used in the LCOH calculations for Australia, the analysis shows that the cost of supplying heat through solar water heaters is below the cost of electricity everywhere in Australia and lower than or competitive with current gas prices across Australia.
- Despite this the market trend is away from solar water heaters and the IEA Executive Director has pointed out that policies necessary to support the increased deployment of renewable heat.

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