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ScienceDirect
Renewable and Sustainable Energy Reviews 13 (2009) 871–878
RENEWABLE & SUSTAINABLE ENERGY REVIEWS
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Development of an economical model to determine an appropriate feed-in tariff for grid-connected solar PV electricity in all states of Australia

A. Zahedi *

School of Engineering, James Cook University, Townsville, QLD, Australia

Received 8 January 2008; accepted 15 January 2008

Abstract

Australia is a country with a vast amount of natural resources including sun and wind. Australia lies between latitude of 10–45°S and longitude of 112–152°E, with a daily solar exposure of between less than 3 MJ/(m^2 day) in winter and more than 30 MJ/(m^2 day) in summer.

Global solar radiation in Australia varies between minimum of 3285 MJ/(m^2 year) in Hobart to 8760 MJ/(m^2 year) in Northern Territory. As a result of this wide range of radiation level there will be a big difference between costs of solar PV electricity in different locations.

A study we have recently conducted on the solar PV electricity price in all states of Australia. For this purpose we have developed an economical model and a computer simulation to determine the accurate unit price of grid-connected roof-top solar photovoltaic (PV) electricity in A$/kWh for all state of Australia. The benefit of this computer simulation is that we can accurately determine the most appropriate feed-in tariff of grid-connected solar PV energy system. The main objective of this paper is to present the results of this study.

A further objective of this paper is to present the details of the unit price of solar PV electricity in the state of Victoria in each month and then to compare with electricity price from conventional power systems, which is currently applied to this state. The state Victoria is located south of Australia and in terms of sun radiation is second lowest compared with the other Australian states.

The computer simulation developed for this study makes it possible to determine the cost of grid-connected solar PV electricity at any location in any country based on availability of average daily solar exposure of each month as well as economical factors of the country.

Keywords: Energy economics; Solar photovoltaic electricity

Contents

1. Introduction

In order to determine the price of grid-connected solar PV electricity we need to consider a number of parameters such as sun radiation data of the location, where PV is installed, capital cost of PV system (market price), level of government's financial support, interest rate on the loan obtained from a bank to purchase the PV system, period of loan payment, operation and maintenance (O&M) cost, etc. Some of these parameters have direct effect on price of PV electricity, while some others have indirect effects.

Fig. 1 shows that each Australian state experiences different solar radiation level [1]. As solar PV is an electricity generating technology that converts sun energy directly into electricity, the output energy of the PV generator depends very much on the availability of fuel, i.e. sun radiation.

* Tel.: +61 7 4781 6907; fax: +61 7 4781 5177.
E-mail address: Ahmad.Zahedi@jcu.edu.au.

1364-0321/$ – see front matter
doi:10.1016/j.rser.2008.01.012

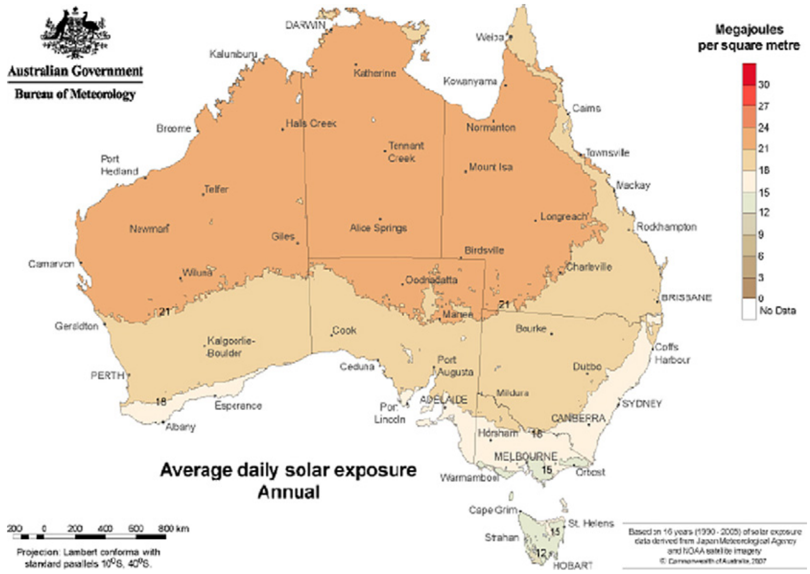

Fig. 1. Average daily solar exposure (annual) (*source*: BOM, [1]).

For the computer simulation developed for this study we have used the sun data produced by the Australian Bureau of Meteorology (BOM). In order to be able to produce accurate results, we have considered up to three radiation levels for each state. This has been shown in Table 1 and Fig. 2.

According to the BOM [1], the global solar exposure is defined as the total amount of solar energy falling on a horizontal surface. The sun data obtained from BOM give the average daily solar exposure across Australia for each month and the year. Typical values for daily global solar exposure range from 1 to 35 MJ/m^2 (mega-Joules per square meter). For mid-latitudes, the values are usually highest in clear sun conditions during the summer and lowest during winter or very cloudy days. Table 2 shows the price of PV electricity in A$/kWh for both minimum and maximum radiations and for different PV installation prices ranges from 4 to 14 $/W. Table 3 shows the same information but for the case that money to purchase the PV system is borrowed from a financial institution at mortgage of 7%. Table 4 shows the average daily solar exposure. Graphical form of this table is shown in Fig. 11.

The two important factors in cost calculation of grid-connected solar PV systems are the installation cost and the financial support, which is provided by Australian Federal Government. The current market price of grid-connected roof-top residential solar PV system in Australia varies between A$12,000 and A$15,000/kW. It is obvious that this installation price is relatively high and unlikely to encourage the Australian house owners to buy solar PV system and install of roof of their houses.

In order to make it more affordable the Australian Federal Government (Managed by Australian Greenhouse Office, AGO) provides a generous financial support of maximum A$8000/kW for house owners who wish to use solar PV electricity [3]. So, after the government support a grid-connected solar PV system will cost the house owners something between A$4000 and A$7000/kW.

Table 1
Average daily solar exposure (annual), [1]

	Minimum (MJ/(m^2 day))	Maximum (MJ/(m^2 day))
ACT	15	18
TAS1	9	12
TAS2	12	15
TAS3	15	18
VIC1	12	15
VIC2	15	18
VIC3	18	21
SA1	15	18
SA2	18	21
SA3	21	24
WA1	15	18
WA2	18	21
WA3	21	24
QLD1	18	21
QLD2	21	24
NSW1	15	18
NSW2	18	21
NT1	21	24

Fig. 2. Average daily solar exposure (annual), [1].

Table 2
Unit price of PV electricity for case 1, for minimum and maximum radiation

	Purchase price ($/W)							
	14		6		12		4	
	Minimum radiation[a]	Maximum radiation[a]	Minimum radiation[a]	Maximum radiation[a]	Minimum radiation[a]	Maximum radiation[a]	Minimum radiation[a]	Maximum radiation[a]
ACT	0.85	0.71	0.39	0.32	0.73	0.61	0.28	0.23
TAS1	1.42	1.06	0.65	0.49	1.22	0.92	0.46	0.34
TAS2	1.06	0.85	0.49	0.39	0.92	0.73	0.34	0.28
TAS3	0.85	0.71	0.39	0.32	0.73	0.61	0.28	0.23
VIC1	1.06	0.85	0.49	0.39	0.92	0.73	0.34	0.28
VIC2	0.85	0.71	0.39	0.32	0.73	0.61	0.28	0.23
VIC3	0.71	0.61	0.32	0.28	0.61	0.52	0.23	0.20
SA1	0.85	0.71	0.39	0.32	0.73	0.61	0.28	0.23
SA2	0.71	0.61	0.32	0.28	0.61	0.52	0.23	0.20
SA3	0.61	0.53	0.28	0.24	0.52	0.46	0.20	0.17
WA1	0.85	0.71	0.39	0.32	0.73	0.61	0.28	0.23
WA2	0.71	0.61	0.32	0.28	0.61	0.52	0.23	0.20
WA3	0.61	0.53	0.28	0.24	0.52	0.46	0.20	0.17
QLD1	0.71	0.61	0.32	0.28	0.61	0.52	0.23	0.20
QLD2	0.61	0.53	0.28	0.24	0.52	0.46	0.20	0.17
NSW1	0.85	0.71	0.39	0.32	0.73	0.61	0.28	0.23
NSW2	0.71	0.61	0.32	0.28	0.61	0.52	0.23	0.20
NT1	0.61	0.53	0.28	0.24	0.52	0.46	0.20	0.17

[a] Electricity price (A$/kWh).

The residential roof-top PV systems are usually connected to the grid, so they act as generators supplying electricity to the distribution network. As the cost of solar PV electricity in Australia is far above the electricity price of the distribution network, which is supplied in Australia mainly by conventional sources and in the coal-fired power stations, so the government needs to develop a fair feed-in tariff to encourage more Australian house owners to come forward with interest of using solar PV system on the roof of their houses.

Price of electricity from solar photovoltaic arrays depends very much on the location and the amount of sun energy received at the location. A 1 kW roof-top grid-connected PV system when installed on the roof of a house in Brisbane, for example, can produce twice as much as if the same was installed on the roof of a house in Melbourne, so the unit price

Table 3
Unit price of PV electricity for case 2, mortgage rate 7%, for minimum and maximum radiation

	Purchase price ($/W)							
	14		6		12		4	
	Minimum radiation[a]	Maximum radiation[a]	Minimum radiation[a]	Maximum radiation[a]	Minimum radiation[a]	Maximum radiation[a]	Minimum radiation[a]	Maximum radiation[a]
ACT	1.29	1.07	0.59	0.49	1.11	0.93	0.42	0.35
TAS1	2.15	1.61	0.98	0.74	1.86	1.39	0.69	0.52
TAS2	1.61	1.29	0.74	0.59	1.39	1.11	0.52	0.42
TAS3	1.29	1.07	0.59	0.49	1.11	0.93	0.42	0.35
VIC1	1.61	1.29	0.74	0.59	1.39	1.11	0.52	0.42
VIC2	1.29	1.07	0.59	0.49	1.11	0.93	0.42	0.35
VIC3	1.07	0.92	0.49	0.42	0.93	0.80	0.35	0.30
SA1	1.29	1.07	0.59	0.49	1.11	0.93	0.42	0.35
SA2	1.07	0.92	0.49	0.42	0.93	0.80	0.35	0.30
SA3	0.92	0.80	0.42	0.37	0.80	0.70	0.30	0.26
WA1	1.29	1.07	0.59	0.49	1.11	0.93	0.42	0.35
WA2	1.07	0.92	0.49	0.42	0.93	0.80	0.35	0.30
WA3	0.92	0.80	0.42	0.37	0.80	0.70	0.30	0.26
QLD1	1.07	0.92	0.49	0.42	0.93	0.80	0.35	0.30
QLD2	0.92	0.80	0.42	0.37	0.80	0.70	0.30	0.26
NSW1	1.29	1.07	0.59	0.49	1.11	0.93	0.42	0.35
NSW2	1.07	0.92	0.49	0.42	0.93	0.80	0.35	0.30
NT1	0.92	0.80	0.42	0.37	0.80	0.70	0.30	0.26

[a] Electricity price (A$/kWh).

Table 4
Average daily solar exposure

	Minimum horizontal (MJ/(m^2 day))	Maximum horizontal (MJ/(m^2 day))	Tilt @ latitude (MJ/(m^2 day))
January	21	27	22.3
February	18	24	22.9
March	15	21	19.7
April	9	15	15.1
May	6	9	11.4
June	3	6	10.1
July	3	6	11.4
August	9	12	13.2
September	12	15	16.4
October	18	21	19.3
November	21	24	20.9

of PV electricity in Melbourne is almost twice as much as price of PV electricity in Brisbane. Therefore, the Federal Government should provide more financial support for house owners in Victoria who want to use solar PV energy.

2. Computer simulation for unit price of PV electricity across Australia

This part of the paper focuses on determination of unit price of solar PV electricity which will be valid for all states of Australia considering up to three radiation levels for each states.

Since the fuel is free, the cost of PV systems in Australia is determined by (a) installation cost, which is relatively high, (b) level of government financial support, and (c) maintenance cost, which is very low.

In determining the actual output power from a PV panel/array we need to consider a new factor known as performance ratio. This performance ratio is defined as the ratio between the nominal PV output power and the actual PV output power and is denoted as R_p. For small grid-connected PV systems a typical

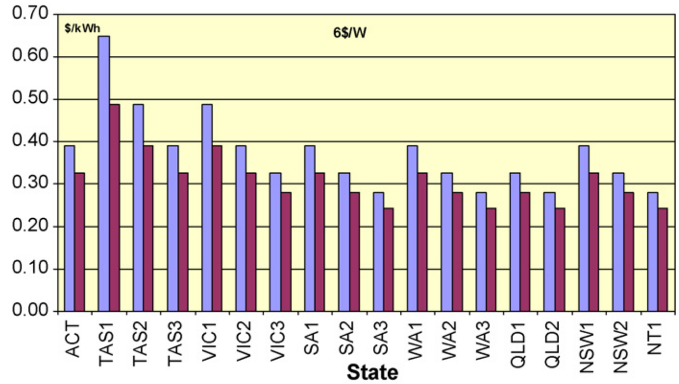

Fig. 5. Case 1, purchase price: A$14,000/kW with AGO support.

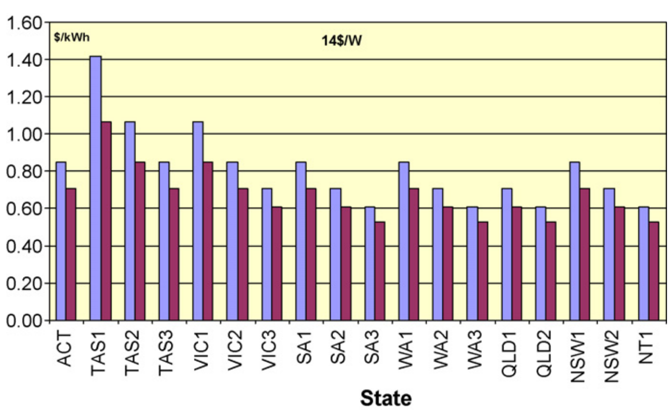

Fig. 3. Case 1, purchase price: A$14,000/kW without AGO support.

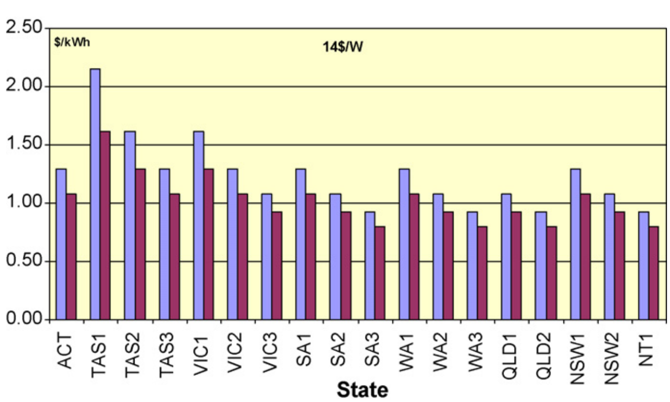

Fig. 4. Case 2, purchase price: A$14,000/kW without AGO support, mortgage rate 7%.

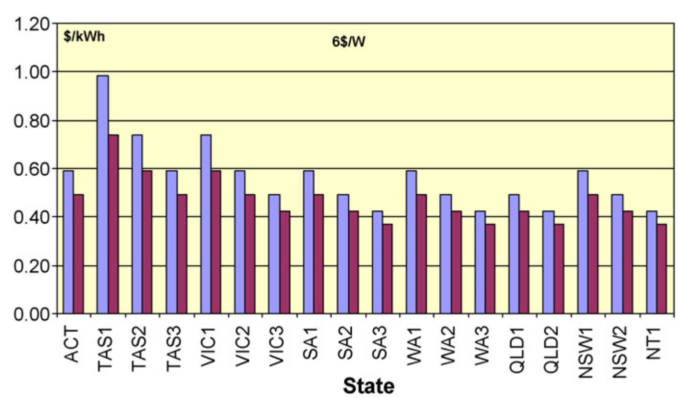

Fig. 6. Case 2, purchase price: A$14,000/kW with AGO support, mortgage rate 7%.

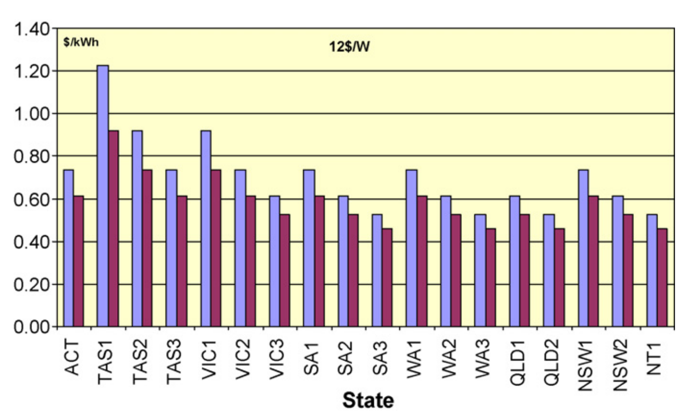

Fig. 7. Case 1, purchase price: A$12,000/kW without AGO support.

value of performance ratio is close to 75–80%. For larger PV systems with more efficient inverters this ratio may be slightly higher.

In order to present the results of this study in an understandable way, we have performed the cost calculation of unit price of PV electricity for two different cases:

1. Money to purchase the PV system is taken from a saving account;
2. Money to purchase the PV system is borrowed from a financial institution.

Obviously, when money to purchase the PV installation is available or is not available, the electricity cost in $/kWh will be different. In some events, when a bank is prepared to provide money for borrower at a very low rate, so the PV electricity will be lower compared with the case when money is available and taken from a saving account. In the cost calculations we have taken into account the time value of money, and have assumed:

- Performance ratio of PV is 75%; efficiency of inverter, 95%.
- Inflation rate (i) = 0.025; discount rate (d) = 0.05; mortgage rate (j) = 0.07;
- Present worth values: PW = (P_a) × (cost of an item, which is needed at the beginning of each year).
- Present worth factor: $P_a = (1 - X^n)/(1 - X)$, where $X = (1 + i)/(1 + d)$.
- PW = (P_{a1}) × (cost of an item, which is needed at the end of each year), where $P_{a1} = XP_a$.
- Life cycle cost (LCC) is defined as the sum of the present worth values of all the components.
- The annualized life cycle cost (ALCC) = LCC/P_a.
- Solar PV electricity price = ALCC/annual kWh energy production when money is available.

When money is borrowed from a bank: ANN-PMT = $j(\mathrm{LCC})(1 + j)^n/((1 + j)^n - 1)$, n is repayment period is the same as system's life-time; solar PV electricity price = ANN-PMT/annual kWh energy production [4].

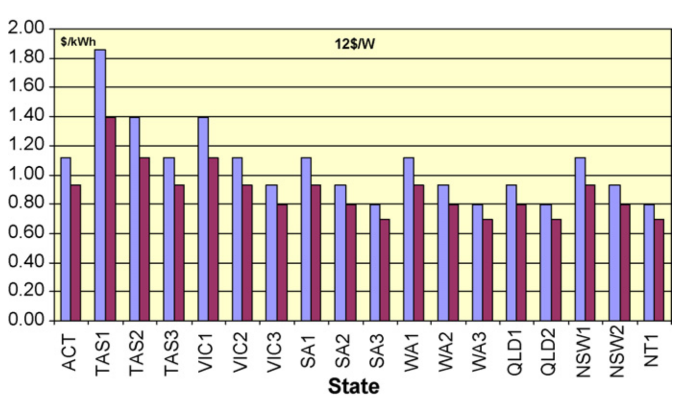

Fig. 8. Case 2, purchase price: A$12,000/kW without AGO support, mortgage rate 7%.

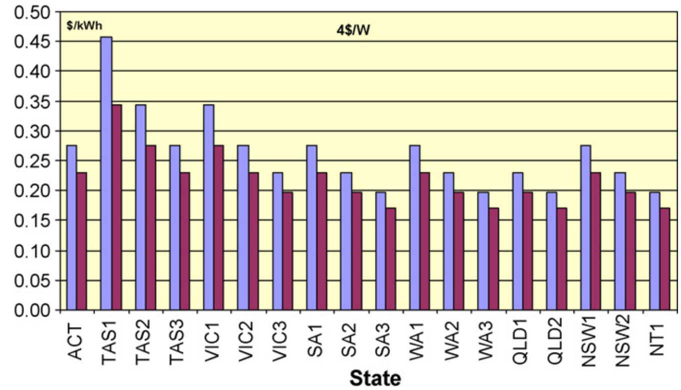

Fig. 9. Case 1, purchase price: A$12,000/kW with AGO support.

Figs. 3–10 show the unit price of electricity for minimum and maximum sun radiation for two different cases and two different prices before and after government subsidies.

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3. Unit price of PV electricity in Victoria

This part of the paper focuses on unit price of solar PV electricity when the PV system is installed in the state of Victoria. For the computer simulation used in this part of the study we have used the sun data produced by the Australian Solar Radiation (AUSOLRAD) Handbook developed by the Australian company Energy Partners on behalf of the

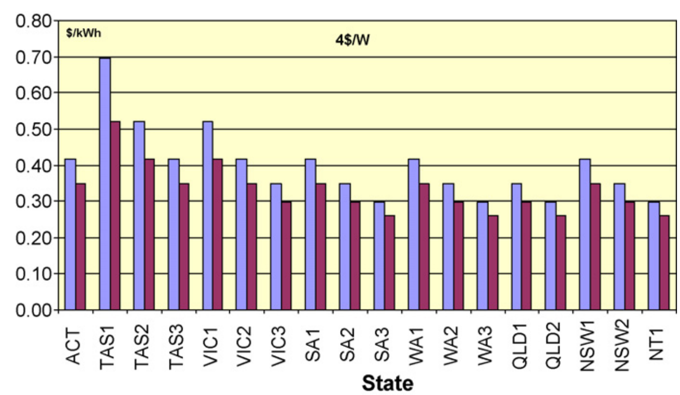

Fig. 10. Case 2, purchase price: A$12,000/kW with AGO support mortgage rate 7%.

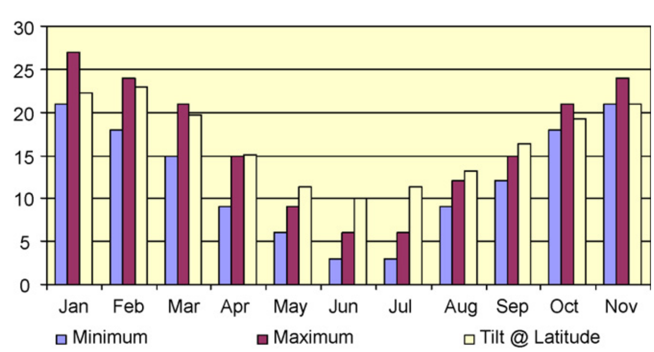

Fig. 11. The average daily solar exposure in MJ/m^2/day.

Table 5
Unit price of PV electricity in each month of the year for case 1

A$/W	LCC	ALCC	January (A$/kWh)	February (A$/kWh)	March (A$/kWh)	April (A$/kWh)	May (A$/kWh)	June (A$/kWh)	July (A$/kWh)	August (A$/kWh)	September (A$/kWh)	October (A$/kWh)	November (A$/kWh)	December (A$/kWh)
8	8784	547	0.32	0.36	0.38	0.51	0.65	0.76	0.65	0.56	0.47	0.39	0.37	0.33
7	7784	496	0.29	0.33	0.34	0.46	0.59	0.69	0.59	0.51	0.43	0.35	0.33	0.3
6	6784	433	0.25	0.28	0.3	0.4	0.52	0.6	0.52	0.44	0.37	0.3	0.29	0.26
5	5784	369	0.21	0.24	0.25	0.34	0.44	0.51	0.44	0.38	0.32	0.26	0.25	0.23
4	4784	305	0.18	0.2	0.21	0.28	0.36	0.43	0.36	0.31	0.26	0.21	0.2	0.19
3	3784	241	0.14	0.16	0.17	0.22	0.29	0.34	0.29	0.25	0.21	0.17	0.16	0.15
2	2784	178	0.1	0.12	0.12	0.17	0.21	0.25	0.21	0.18	0.15	0.13	0.12	0.11
1	1784	114	0.07	0.07	0.08	0.11	0.14	0.16	0.14	0.12	0.1	0.08	0.08	0.07

Table 6
Unit price of PV electricity in each month of the year for case 2

A$/W	LCC	ANN-PMT	January (A$/kWh)	February (A$/kWh)	March (A$/kWh)	April (A$/kWh)	May (A$/kWh)	June (A$/kWh)	July (A$/kWh)	August (A$/kWh)	September (A$/kWh)	October (A$/kWh)	November (A$/kWh)	December (A$/kWh)
8	8784	829	0.48	0.55	0.57	0.77	0.99	1.16	0.99	0.85	0.71	0.58	0.56	0.51
7	7784	735	0.43	0.48	0.51	0.68	0.88	1.02	0.88	0.75	0.63	0.52	0.49	0.45
6	6784	640	0.37	0.42	0.44	0.60	0.76	0.89	0.76	0.66	0.55	0.45	0.43	0.39
5	5784	546	0.32	0.36	0.38	0.51	0.65	0.76	0.65	0.56	0.47	0.38	0.37	0.33
4	4784	452	0.26	0.30	0.31	0.42	0.54	0.63	0.54	0.46	0.39	0.32	0.30	0.28
3	3784	357	0.21	0.23	0.25	0.33	0.43	0.50	0.43	0.37	0.31	0.25	0.24	0.22
2	2784	263	0.15	0.17	0.18	0.24	0.31	0.37	0.31	0.27	0.23	0.19	0.18	0.16
1	1784	168	0.10	0.11	0.12	0.16	0.20	0.23	0.20	0.17	0.14	0.12	0.11	0.10

Australian and New Zealand Solar Energy Society (ANZSES), [2]. Fig. 11 shows the average daily solar exposure in MJ/m^2/day for minimum horizontal, maximum horizontal, and tilt at latitude angle exposure.

In order to determine the actual unit price of monthly solar PV electricity, we need to determine the actual output power from the PV panel/array. Table 5 shows the unit price of solar PV electricity for case 1, while Table 6 shows the unit price of PV electricity for case 2. Numbers in the first column in both tables represents the house owner's contribution to the PV installation cost.

Figs. 12–19 show the unit price of solar PV electricity for case 1, while Figs. 20–27 show this price for case 2. The last bar

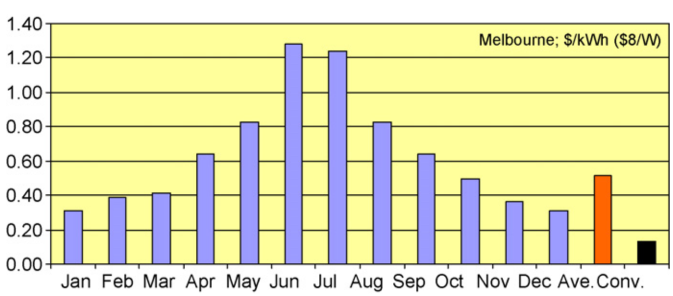

Fig. 12. Solar PV electricity price for the case of A$8/W.

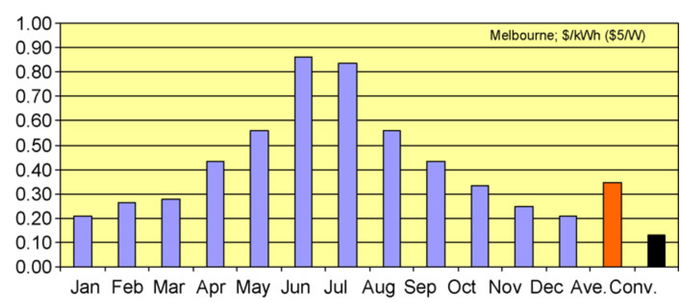

Fig. 14. Solar PV electricity price for the case of A$5/W.

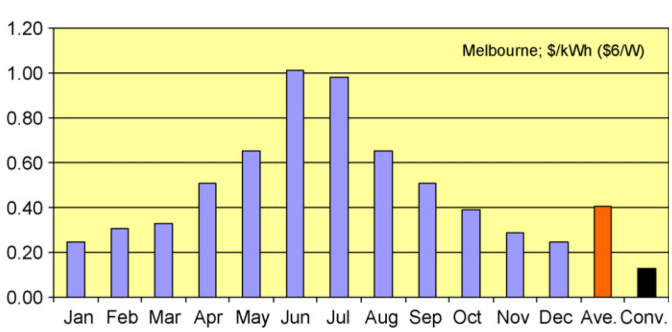

Fig. 13. Solar PV electricity price for the case of A$6/W.

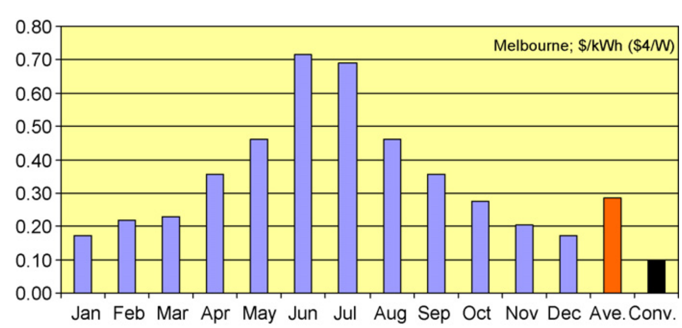

Fig. 15. Solar PV electricity price for the case of A$4/W.

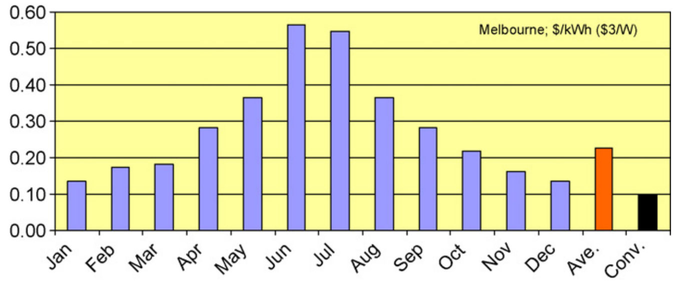

Fig. 16. Solar PV electricity price for the case of A$3/W.

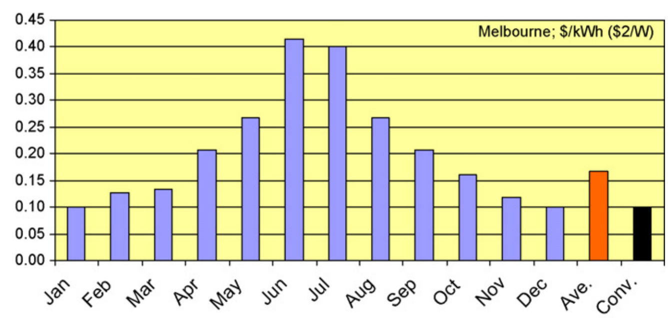

Fig. 17. Solar PV electricity price for the case of A$2/W.

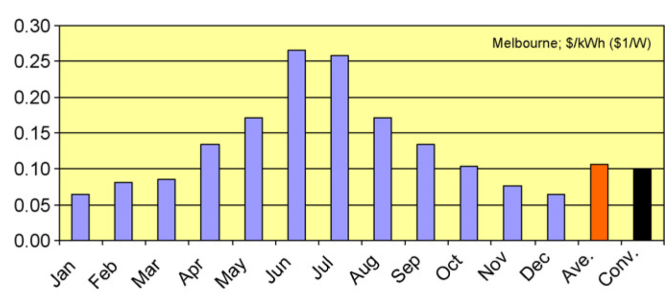

Fig. 18. Solar PV electricity price for the case of A$1/W.

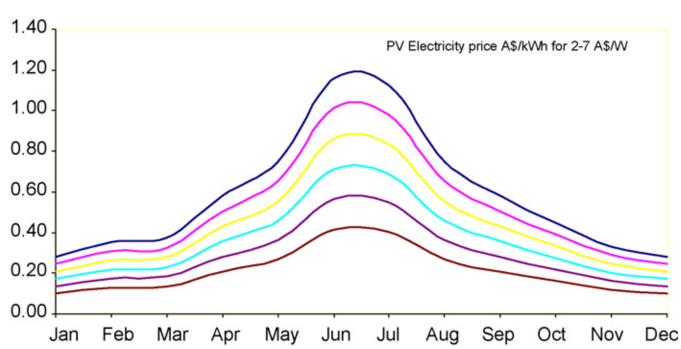

Fig. 19. Solar PV electricity price for the case of A$2–7/W.

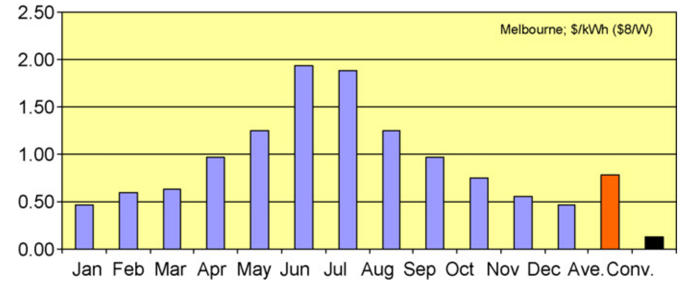

Fig. 20. Solar PV electricity price for the case of A$8/W.

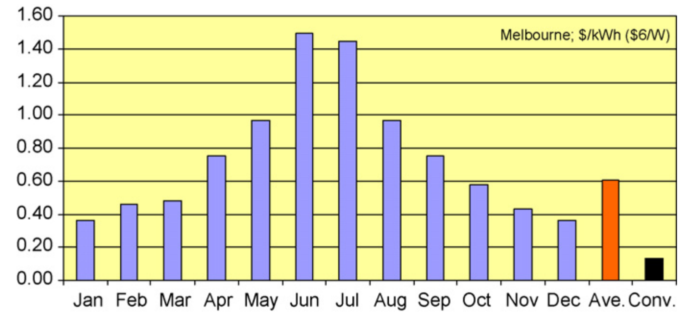

Fig. 21. Solar PV electricity price for the case of A$6/W.

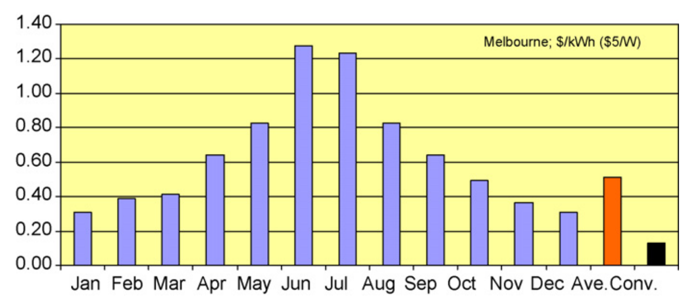

Fig. 22. Solar PV electricity price for the case of A$5/W.

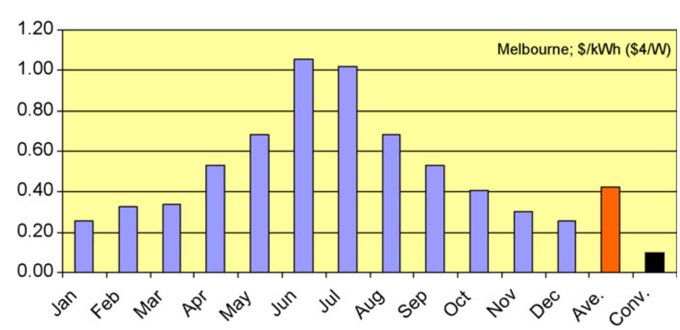

Fig. 23. Solar PV electricity price for the case of A$4/W.

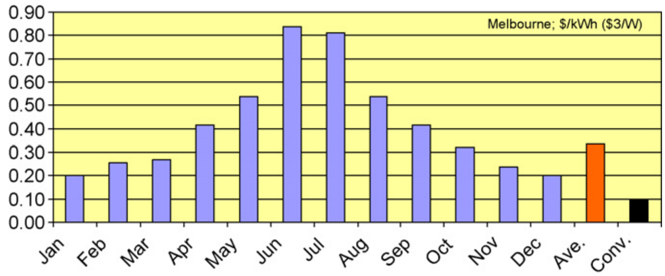

Fig. 24. Solar PV electricity price for the case of A$3/W.

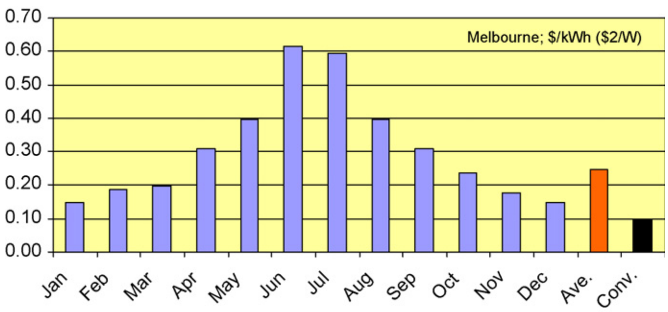

Fig. 25. Solar PV electricity price for the case of A$2/W.

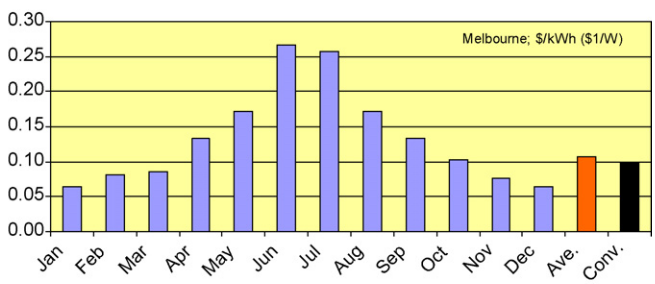

Fig. 26. Solar PV electricity price for the case of A$1/W.

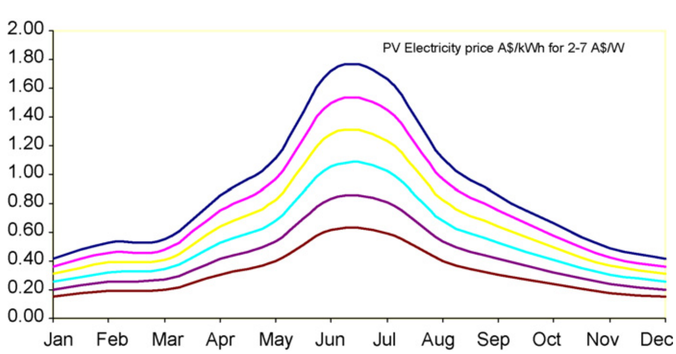

Fig. 27. Solar PV electricity price for the case of A$2–7/W.

on each figure represents the electricity price from conventional sources in Australia, which is mainly from fossil fuel. This is intentionally added to the figures for comparison purpose.

Please note that the installation cost/Watt appearing in these tables is the installation cost after the financial support from government.

4. Conclusions

This paper has presented the results of a study conducted to determine an accurate unit price of solar PV electricity (A$/kWh) in all states of Australia. The PV electricity prices obtained in this study are based on the location-dependent sun radiation data as well as country's-dependent economical factors.

This paper has also presented the monthly unit price of PV electricity systems installed in the state of Victoria and compares with electricity price currently applied to residential customers.

The results of this study show that in order to have a successful solar PV support program, there must be a link between the financial support provided by the Australian Government and the location where the PV system is installed.

And also these results show that a single feed-in tariff of solar PV electricity is not appropriate. Different states need different feed-in tariff. Therefore, feed-in tariff must be linked with location where PV system is installed.

Australian Government is currently providing a generous financial support for roof-top PV systems. But there are evidences suggesting that this program was unsuccessful and was not well accepted by the public. There are many reasons including lack of appropriate feed-in tariff for unpopularity of this program. The results of this study may be used to determine an appropriate feed-in tariff applicable across Australia.

This simulation program developed for this study can be used for calculation of unit price of electricity from roof-top solar PV system anywhere across Australia as well as anywhere across the globe, provided the location's irradiation data is available.

Appendix A

States abbreviations

1	ACT	Australian Capital Territory
2	TAS	Tasmania
3	VIC	Victoria
4	SA	South Australia
5	WA	Western Australia
6	QLD	Queensland
7	NSW	New South Wales
8	NT	Northern Territory

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