Comparison Study: Cost of Electricity, Emission, and Renewable Fraction for Single Residential Load at Geelong, Victoria State- Australia using HOMER

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***Abstract*—This paper presents a comparison of change in Cost of Electricity (COE) ($), Emission (Kilogram/year-kg/yr), and Renewable Fraction (RF) for a single residential load at Geelong with five different methodologies. The National Renewable Energy Laboratory (NREL) optimization computer model for distributed power, "HOMER," is used to study the comparison. The first analysis with system 1 showed that, a 10.5 kilo-Watt (kW) Photovoltaic (PV) module (supporting 10.5 kW converter was opted, and 33 batteries (4 volts (V)), Nominal capacity 1900 Amp-hour (Ah)) is must to supply electricity for a single residential load with available solar radiation exposure, and the obtained COE, Emission, and RF are $0.35, zero, 1.00. The second analysis with system 2 showed that excess electricity generated can be sold to the grid, and the obtained COE- $ 0.30, Emission- -2250 kg/yr carbon-dioxide (CO_2), -5.41 kg/yr Nitrogen oxide (N_2O), -11.1 kg/yr sulphur dioxide (SO_2), and RF 0.85. The third analysis with system 3 showed that with an optimized number of batteries a higher RF and reduced COE can be achieved, and excess electricity produced can be sold to the grid; the obtained COE- $ 0.14, Emission- -4,386 kg/yr CO_2, -19 kg/yr SO_2, -9.1 kg/yr N_2O and RF-0.80. The fourth analysis with system 4 showed that there is a reduction in the percentage of RE factor and escalating price of COE, obtained COE- $0.18, Emission - 5055 kg/yr CO_2, -10.7 kg/yr N_2O, 21.9 kg/yr SO_2, and RF- 0.80. The fifth analysis with system 5 showed that house load connected to only grid emits significant amount of Emission, the obtained COE, 0.26$, Emission - 3691 kg/yr CO_2, 16 kg/yr SO_2, 7.83 kg/yr N_2O and RF- 0.80.**

***Index Terms*—Photovoltaic (PV) modules, primary house load, battery, grid, converter, renewable energy (RE).**

I. Introduction

Australia is the seventeenth largest in using non-renewable energy resources and ranks eighteenth on per person basis around the world. The main Non-renewable energy primary resources used in Australia are coal, oil, gas, and related products, which represents 96 per cent of total energy consumption.

The remaining 4 percent is Renewable sources with majority of Bio-energy (wood and wood waste, biomass, and biogas). However, in the recent years, RE consumption is growing strongly [1].

The majority of powers supplied in houses by state or local power authority throughout Australia are 240-volt alternating current (AC). However, few house owners find the prices of the electricity connected through grid to the houses are expensive [2]. Historically Australia had competitive and stable electricity prices, due to developed world standards in the recent years, the electricity price in the tariff has risen 70 percent nationally. This is because of the fact that the transmission and distribution lines which deliver electricity to houses are becoming older, and it's now time to replace with new ones, which over all requires a huge capital investment, and these investments are imposed on the electricity prices [3].

Australia has predicted 20 - 2020 i.e. 20 percent of RE usage by 2020 [4]. Within RE technology, by considering less moving parts, less area occupancy and easy installable devise for a typical house, PV modules are best suitable to supply electricity.

II. Background

In Australia, average house hold electricity charges in the year 2012-13 are discussed below, and is also shown in Fig. 1

1) Network charge-These charges accounts 51 percent of the bill, which mainly includes cost of building, and for maintaining electricity networks such as electric poles and wires which deliver electricity to houses.
2) Whole sale cost-These charges accounts 20 percent of the electricity bill, which mainly includes cost associated with generated electricity and for trading in whole sale market.
3) Retail and energy scheme costs - It includes 20 percent of the bill for the 'shop front' i.e. for consumer's electricity supply and costs from schemes for energy efficiency and renewable.
4) Carbon price-Around 9 percent of the cost is added to the electricity bill for carbon emission by fuel generators [3].

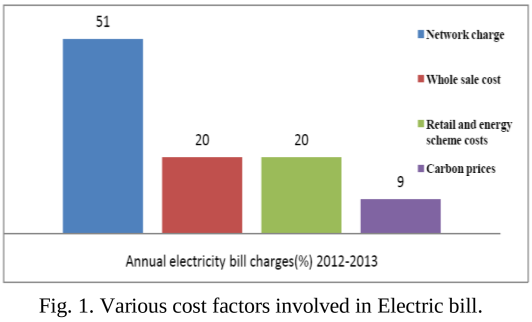

Fig. 1. Various cost factors involved in Electric bill.

However an alternate solution i.e PV modules can be used to eliminate the charges imposed on electricity bills [3]. A PV module generates direct current (DC), which is directly proportional to the available global solar radiation [5]. Hence the DC output from PV module can be calculated using (1)

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[6], and its efficiency can be calculated using (2) [4].

$$P_{PV} = f_{PV} \times Y_{PV} \left(\frac{I_T}{I_s} \right) 1 \quad (1)$$

where, f_{PV} - PV de-rating factor [percent %].

Y_{PV} - Rated capacity of the PV panel Kilowatt [kW],

I_T - Global solar-radiation [W/m^2], and

I_S - 1000 Watt per square meter [W/m^2], standard amount of radiation:

$$Solarefficiency(\%) = \left(\frac{Powerout}{Powerin} \right) inkW \times 100 \quad (2)$$

The most important factor is identifying the value of a PV system, and is calculated using equation (3) [4].The simple payback time/year of PV module can be calculated using (4) [4].

$$\$ / \mathrm{W} = \left(\frac{Upfront\ cost\ of\ the\ PV\ system(\$)}{2\ Rated\ Peak\ Power\ of\ the\ PV\ system\ avoided\ electricity\ purchase} \right) \quad (3)$$

$$\$ / \mathrm{W} = \left(\frac{Capital\ cost(\$)}{Savings\ from\ avoided\ electricity\ purchase} \right) \quad (4)$$

Before installing a PV module, PV sizing is must, as it allows identifying the required PV module wattage to supply electricity to the house load, and is calculated using (5) [4], [7]

Watts-hour per day= Solar Irradiance kWh/m^2 $\times$ (Panel Wattage $\times$ de-rating factor) (5)

Carbon-dioxide is a very important factor for energy intensity of an economy. Emission intensity is defined as the amount of green house gases emitted per unit of energy used. Per Capita is defined as the measure of the amount of energy used per unit of economic activity generated, and is calculated using (6) [8].

GDP per capita is gross domestic product divided by midyear population.

$$Per\ capita\ = GDP\ per\ capita \times\ Energy / GDP\ \times\ CO_2 / Energy \quad (6)$$

By considering above all factors finally COE plays a vital role, as people are concerned with the payments made for Electricity bills, and is calculated using (7) [9].

$$\mathrm{COE}(\$) = \frac{C_{ann.tot}}{E_{IS} + E_{grid}} \quad (7)$$

where, $C_{ann,\ tot}$ is the annual total cost, ($).

E_{Is} - Electrical energy supplied by the grid system [kWh/yr] and E_{grid} -Amount of electricity sold to the grid [kWh/yr], and the electricity sold to grid can be calculated using "(8)

$$Gridsales(\$) = Sell\ Back\ rate \times Gridsales \left(\frac{kwh}{yr} \right) \quad (8)$$

III. Approach Methodology

Various feasible approaches were looked upon to identify optimum COE, Emission, and RF, which are listed in Table I. In total, 5 systems were designed to understand and identity the optimum system model for Geelong location. System 1, 2, 3, and 4 were designed to achieve majorly with PV RE source. System 2, 3, 4 and 5 were modeled with an assumption that a grid connection is available near the house location.

TABLE I: Approach Methodology

System	Grid	PV+ Converter	Battery
1		✓	✓
2	✓	✓	✓
3	✓	✓	✓
4	✓	✓	
5	✓		

IV. Primary House Load

The hourly, daily, monthly and annual load profile for a typical house is as shown in the Fig. 2. From Fig. 2. it can be noticed that the load varies at each different time in a day; the maximum demand occurs during the day time i.e. only between 7 am to 10 am, the reasons is all family members get ready to office and school, and return home after 5 pm, after which the peak demand starts and electricity load reduces eventually when the day gets over.

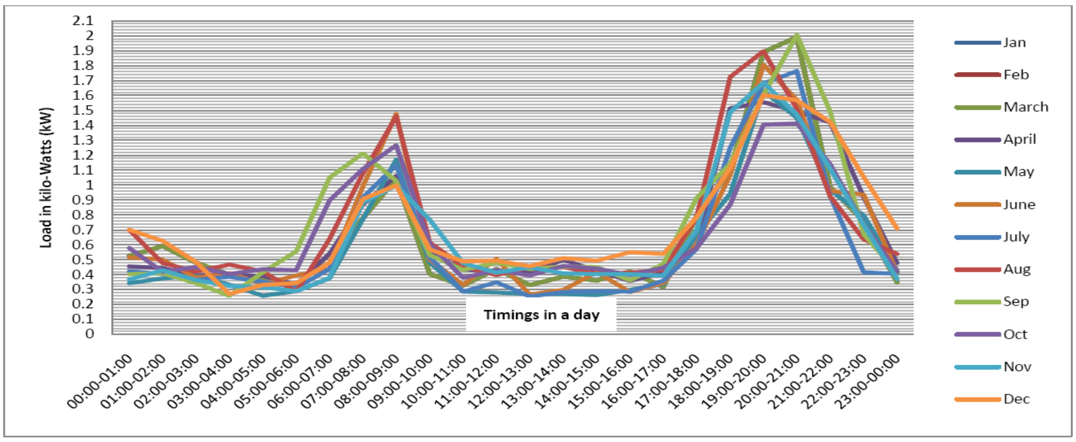


Fig. 2. Primary house load recorded at Geelong.

The baseline anual average is 15.9 kilo-Watt hour/day (kWh/d) and HOMER scaled anual average is 16 kWh/d. The average baseline load is 0.664 kilo-Watt (kW), and HOMER average scaled load is 4.15 kW, and both the baselins, scaled input HOMER load factor is 0.16.

V. Costs And Information

The current prices of Grid connected COE (without any discounts) for peak (3 pm-9 pm), shoulder (7 am-3 pm, 9 pm-10 pm), and off peak (10 pm-7 am) timings, and sell back rate are listed in the Table II. The input cost and information in HOMER for PV module, Converter, and Battery are listed in Table III, Table IV, and Table V.

TABLE II: Grid Electricity Prices-Victoria State

Description	Timing	Days	⋯	Cost inc GST ($/kWh)
Peak	3 pm-9 pm	Mon-Fri	⋯	0.3878
Shoulder	7 am-3 pm 9 pm-10 pm	Mon-Fri	⋯	0.2724
Off peak	10 pm-7 am	Mon-Sun	⋯	0.1775
Sellback rate	All time	All day	⋯	0.08

TABLE III: PV Module Cost and Information

Channels	Cost/Information
Capital cost	$ 1000.00 per KW
Replacement cost	$ 800.00 per KW
Operation and Maintenance cost	$ 50.00 per year
Life time	25 years
PV tracking system	No tracking
De-rating factor	85%
Slope	38.2833°
Azimuth	180°
Ground reflectance	20%

TABLE IV: Converter Cost and Information

Description	Cost/information
Capital cost	$ 200.00
Replacement cost	$ 170.00
Efficiency	90%
Life time	15

TABLE V: Battery Cost and Information

Description	Cost/information
Capital cost	$ 170.00/ 4 V 1900 AH
Replacement cost	$ 130.00/ 4V 1900 AH
Batteries per string	1
Float life	12 years

VI. Results and Discussion

A. Solar Radiation and Clearness Index

The solar radiation of each month for the year 2012 was collected from Bureau of Metrology (BOM) [10], and the data was imported in HOMER NREL tool. With the solar data, the regions Latitude and Longitude i.e. 38°.17′ South, and 144°.38′ East and the time zone as "GMT + 10:00 Melbourne, Sydney, Guam, Port Moresby" was selected. The HOMER tool automatically simulates clearness index as shown in the Fig. 3. An average of 4.378 kilo-Watt hour/square meter (kWh/m^2/d) horizontal solar radiation and a clearness index of 0.538 are available in the selected Geelong location. The clearness index can be calculated using (8) [11].

$$Clearnessindex(k)=\frac{H_g}{H_o} \tag{8}$$

where, H_g Measured Solar Radiation

H_0 Extraterrestrial Solar Radiation, in eq. (9) [11].

$$H_0=\frac{24}{\pi}\mathrm{Isc}\left(1+0.33\frac{360}{365}n\right)(\omega\frac{\pi}{180}\sin\phi\sin\delta+\cos\phi\cos\delta\sin\omega \tag{9}$$

where ϕ is the latitude (radiance),

δ - Solar declination angle (radiance), calculated using (10) [12]

ω - Sunset hour angle for typical day, and calculated using (11) [11]

n - The day of the year. Example: for January first, n = 1 i.e. number of days in a year (1 to 365)

$$\delta=23.45+\sin\left[(284+n)\times\frac{360}{365}\right] \tag{10}$$

$$\omega=cos^{-1}\left[-tan\phi\times tan\delta\right] \tag{11}$$

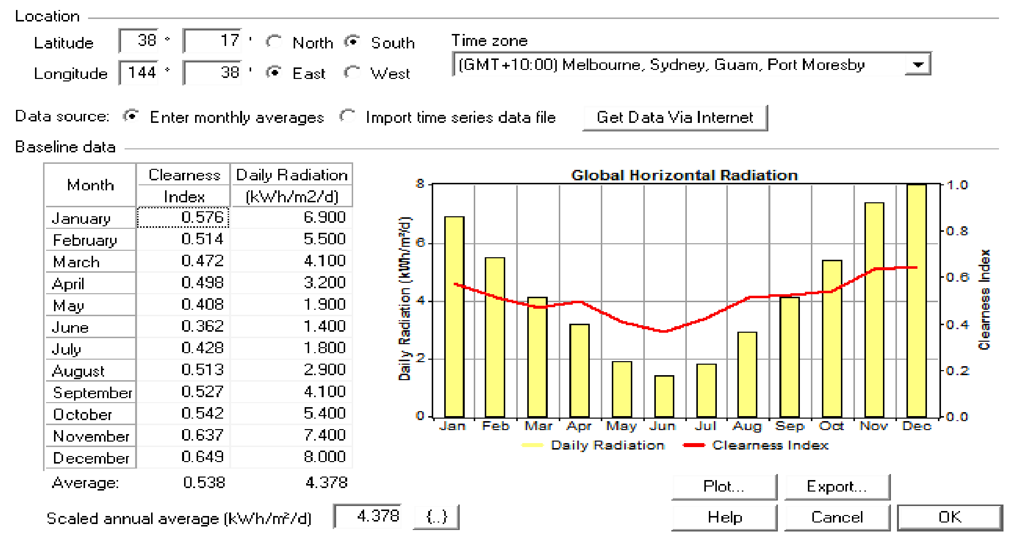


Fig. 3. Input solar radiation and simulated clearness index.

B. Electricity Price Distribution

The current 2012-2013 electricity prices of Victoria State are equally distributed in HOMER i.e. peak, off peak, shoulder periods, sell back rate, and was enabled in the scheduled prices to the grid connected primary house load as shown in the Fig. 4.

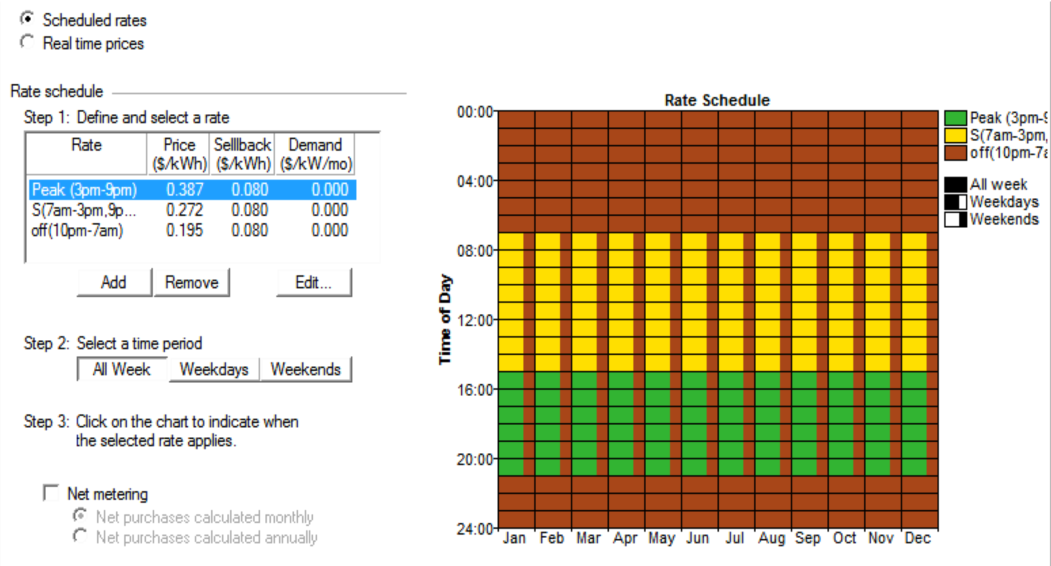


Fig. 4. Grid connected COE distribution for whole year, and timings.

C. 1ST Approach (PV- Converter- Battery)

The design of system 1 is as shown in the Fig. 5. System 1 was modeled with an attempt to achieve 100 % RE with PV modules, and was sized by considering various system losses and with the available solar radiation.

System 1 was designed in HOMER tool for recorded primary house load. The output from PV is not always same at each time, day and month as it majorly depends on the solar radiation. Hence, with these reasons an extra watts PV was designed by conducting multiple iterations in HOMER in order to meet the required load all the time i.e. a 10.5 kW PV module, 10.5 kW converter, and 33 batteries was sized instead of the actual house load 16 kWh/d (4.2 kW) peak as shown in the Fig. 6. The 10.5 kW annually generates 15,337 kWh/yr direct current (DC), however the primary alternative current (AC) house load is only 5837 kW, i.e. an excess electricity after converter losses of 7860 kWh/yr AC is unused and increasing the levelized COE. With the designed system an Initial capital cost of $ 18,210, operating cost of $225, $ 21,091 Net Present Cost (NPC), levelized COE $ 0.283/kWh and RF 1 was obtained as shown in the Fig. 7.

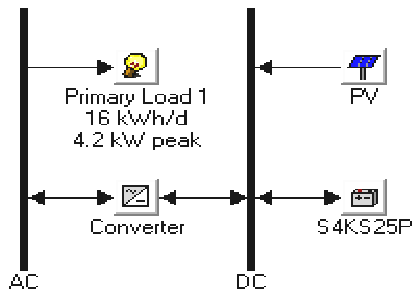


Fig. 5. System 1: PV stand alone system.

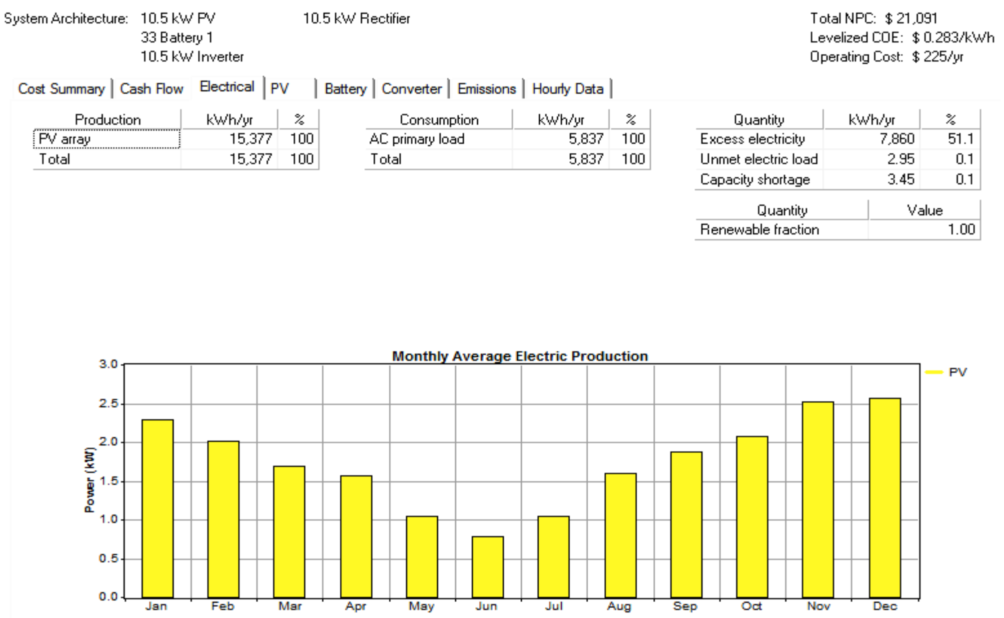


Fig. 6. Monthly average electricity production.

Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

	PV (kW)	S4KS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
	10.5	33	10.5	$ 18.210	225	$ 21.091	0.283	1.00

Fig. 7. System 1 optimized COE.

D. 2nd Approach (PV-Converter-Battery-Grid)

By considering the unused electricity and escalating levelized COE, a second approach was designed as show in the Fig. 8. The modeled System 2 is similar as system 1, but the system is connected to grid. The system connected to the grid has an advantage of using the grid connected electricity whenever the electricity is un-met to the house load from PV, and the unused electricity can be sold to the grid.

86 percent of the PV output is used to supply house load, where as the remaining i.e. AC 6, 523 kWh/yr electricity is sold to the grid, and the unmet electricity during the demand hours is purchased from the Grid. Still an excess electricity of AC 1,661 kWh/yr is stored in the battery as shown in Fig. 9. With the designed system an Initial capital cost of $ 18,210, operating cost of $332, $22,450 NPC, levelized COE $ 0.30/kWh 1 and RF 0.86 was obtained as shown in the Fig. 10.

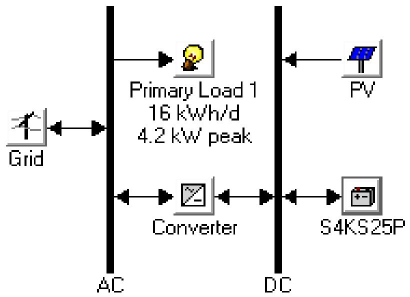


Fig. 8. System 2: Grid connected PV-converter- battery.

System Architecture: 1,000 kW Grid, 10.5 kW PV, 33 Battery 1; 10.5 kW Inverter, 10.5 kW Rectifier

Total NPC: $ 22,450
Levelized COE: $ 0.301/kWh
Operating Cost: $ 332/yr

Cost Summary | Cash Flow | Electrical | PV | Battery | Converter | Grid | Emissions | Hourly Data

Production	kWh/yr	%
PV array	15,377	86
Grid purchases	2,488	14
Total	17,864	100

Consumption	kWh/yr	%
AC primary load	5,840	47
Grid sales	6,523	53
Total	12,363	100

Quantity	kWh/yr	%
Excess electricity	1,661	9.30
Unmet electric load	0.00000441	0.00
Capacity shortage	0.00	0.00

Quantity	Value
Renewable fraction	0.861

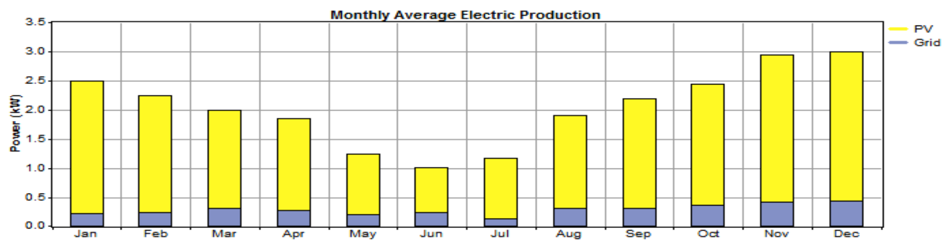


Fig. 9. Monthly average electricity production of system 2.

Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

	PV (kW)	S4KS25P	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
	10.5	33	10.5	1000	$ 18,210	332	$ 22,450	0.301	0.86

Fig. 10. System 2 optimized COE.

E. 3rd Approach (PV- Converter- Battery- Grid)

The design of system 3 is as shown in the Fig. 11. The modeled system 3 is similar to system 2, but instead of 33 batteries 5 batteries were used. The system 3 was an attempt to decrease the COE by reducing the number of batteries to 5 instead of 33, and the attempt was successful.

89 percent of the PV output is used to supply house load, where as the remaining 8,807 kWh/yr AC is sold to the grid, and the unmet electricity is purchased from the Grid. A negligible quantity of excess electricity i.e. AC 36.3 kWh/yr is stored in the battery as shown in Fig. 12. With the designed system an initial capital cost of $ 13,450, operating cost of $ -193, $10,979 NPC, levelized COE $ 0.147/kWh 1, and RF 0.89 was obtained and shown in the Fig. 13.

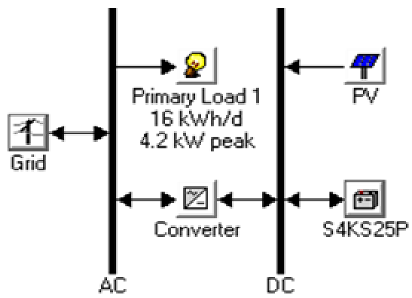
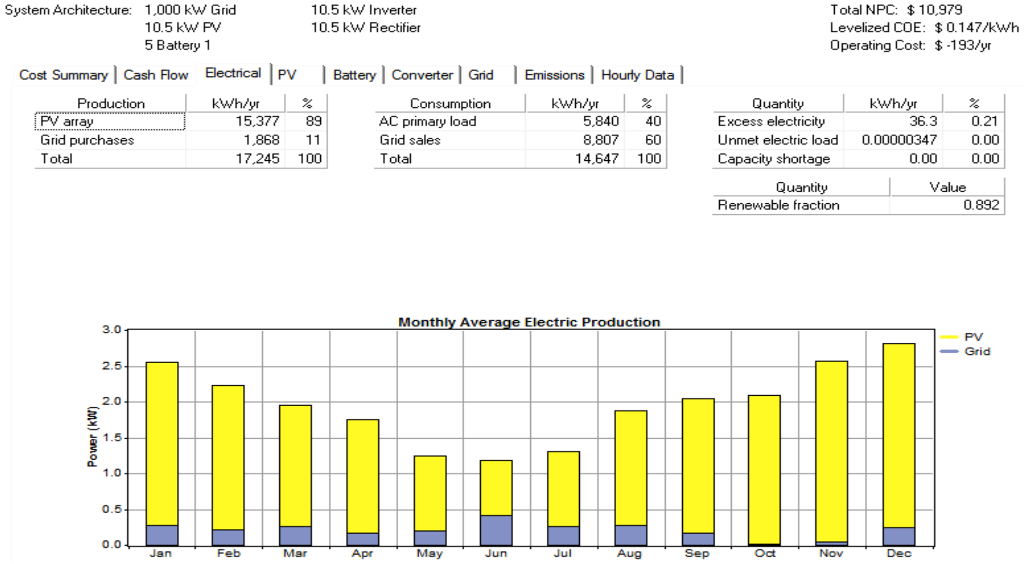


Fig. 11. System 3: PV- Converter- Grid.



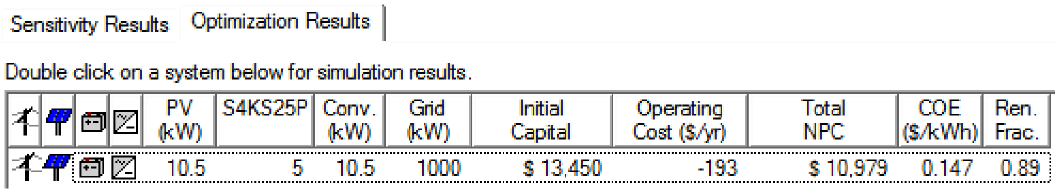
Production	kWh/yr	%
PV array	15,377	89
Grid purchases	1,868	11
Total	17,245	100

Consumption	kWh/yr	%
AC primary load	5,840	40
Grid sales	8,807	60
Total	14,647	100

Quantity	kWh/yr	%
Excess electricity	36.3	0.21
Unmet electric load	0.00000347	0.00
Capacity shortage	0.00	0.00

Quantity	Value
Renewable fraction	0.892

Fig. 12. Monthly average electricity production of system 3.



PV (kW)	S4KS25P	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
10.5	5	10.5	1000	$ 13,450	-193	$ 10,979	0.147	0.89

Fig. 13. System 3 optimized COE.

F. 4th Approach (PV- Converter- Grid)

To overcome the escalating COE, battery was eliminated during the Power system design, and a fourth approach was designed as shown in the Fig. 14. System 4 is similar to system 2 and 3, whereas battery is eliminated.

Only 80 percent of the electricity produced from PV is used to supply electricity, where as the remaining electricity is purchased from Grid. The excess electricity of 11,770 kWh/yr is sold to the grid as shown in the Fig. 15. From the designed system 4, an Initial capital cost of $ 12,600, operating cost of $332, $13, 4760 NPC, levelized COE $ 0.184/kWh, and RF 0.80 was obtained and shown in the Fig. 16.

A total of 14,096 kwh/yr of AC was produced from the RE systems after various system losses. Among the overall generated AC, only 5840 kwh/yr was used for the primary house load and the excess electricity was sold to the grid, and can be calculated using (13)

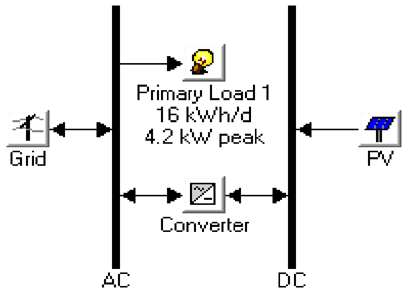
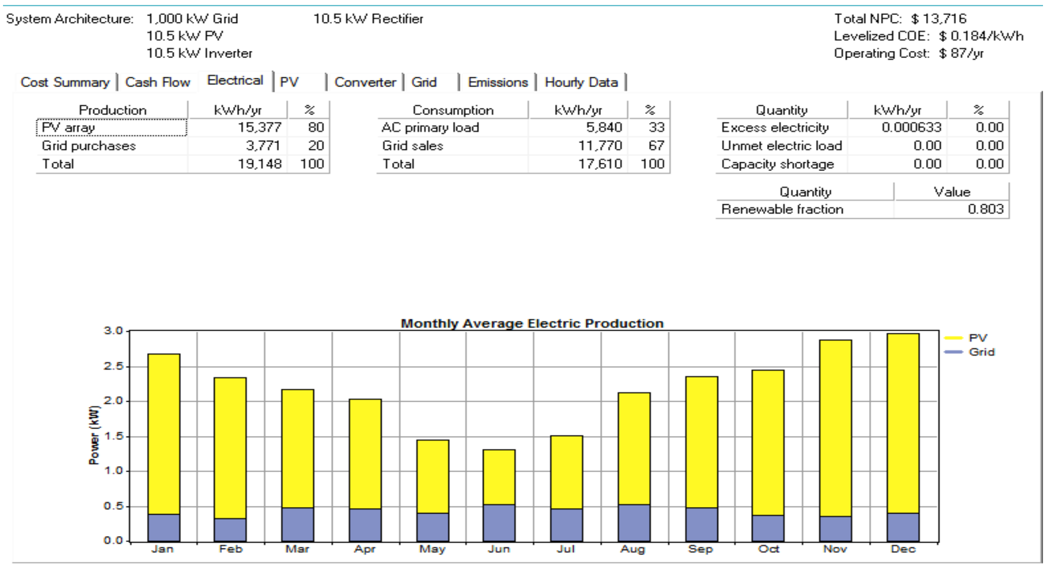


Fig. 14. System 3: Grid- PV- Converter.



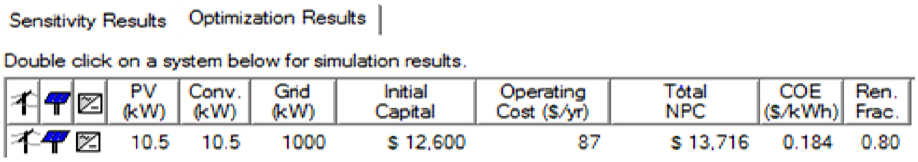
Production	kWh/yr	%
PV array	15,377	80
Grid purchases	3,771	20
Total	19,148	100

Consumption	kWh/yr	%
AC primary load	5,840	33
Grid sales	11,770	67
Total	17,610	100

Quantity	kWh/yr	%
Excess electricity	0.000633	0.00
Unmet electric load	0.00	0.00
Capacity shortage	0.00	0.00

Quantity	Value
Renewable fraction	0.803

Fig. 15. Monthly average electricity production of system 4.



Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

	PV (kW)	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
	10.5	10.5	1000	$ 12,600	87	$ 13,716	0.184	0.80

Fig. 16. System 4 optimized COE.

G. 5th Approach (Grid)

The design of system 5 is as shown in the Fig. 17. The system 5 was modeled with an attempt to identify the current COE applicable to the house load at Geelong-Victoria state.

The entire house load was connected to the Grid system. The total AC house load i.e. 5,840 kWh/yr was supplied with the grid as shown in the Fig. 18. From the designed system 5 an initial capital cost of $ 0, operating cost of $ 1,535, $19, 624 NPC, levelized COE $ 0.263/kWh, and RF Zero was obtained as shown in the Fig. 19.

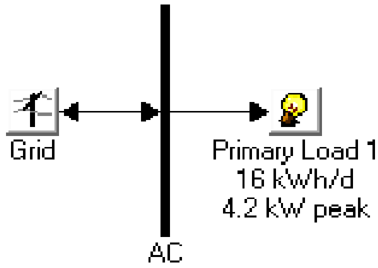


Fig. 17. System 5: Grid connected.

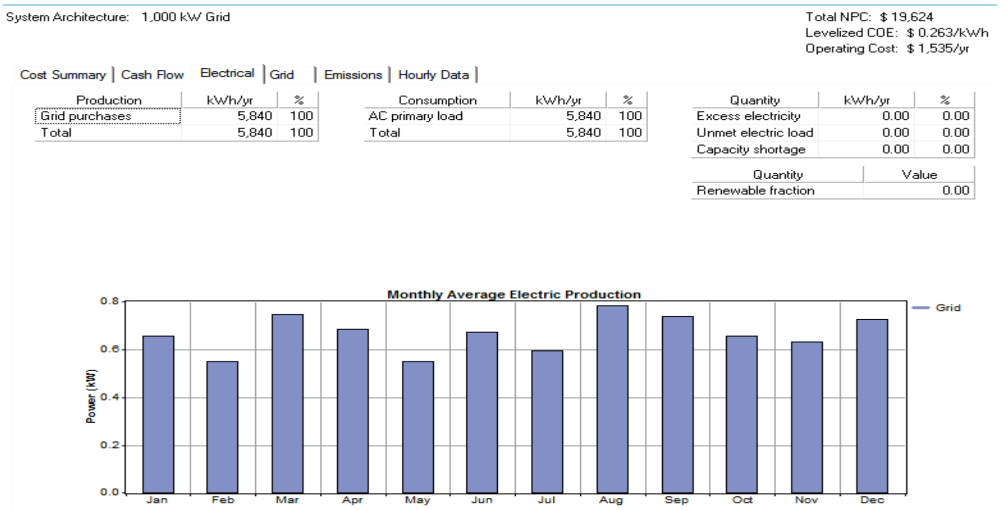
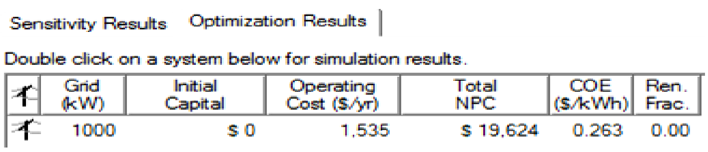


Fig. 18. Monthly average electricity production of system 5.



Sensitivity Results | Optimization Results

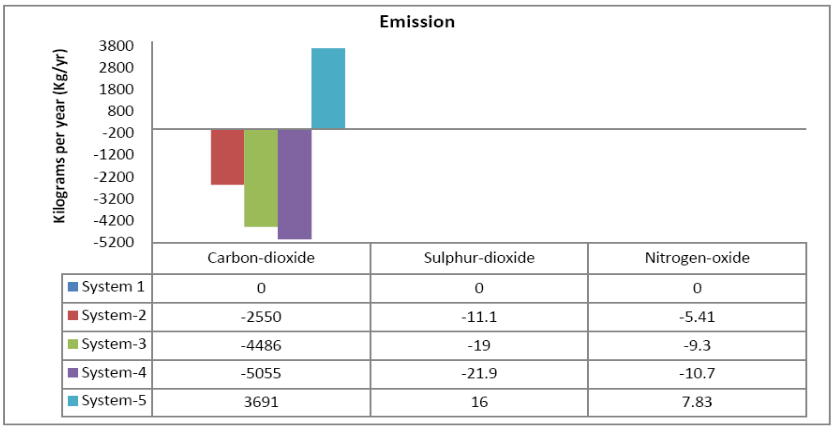
Double click on a system below for simulation results.

	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
	1000	$ 0	1,535	$ 19,624	0.263	0.00

Fig. 19. System 5 optimized COE.

H. Emission

The Emission released from system 1, 2, 3, 4, and 5 is as shown in the Fig. 20. System 1 emits zero emission, and system 5 emits significant emission, whereas system 2, 3, and 5 emits minimum quantity of emission when compared to system 5. Therefore system 1, 2, 3, and 4 are considered to be environmental friendly power systems for future sustainability, as more than 80 percent of the electricity supplied to the house load is through RE source.



	Carbon-dioxide	Sulphur-dioxide	Nitrogen-oxide
System 1	0	0	0
System-2	-2550	-11.1	-5.41
System-3	-4486	-19	-9.3
System-4	-5055	-21.9	-10.7
System-5	3691	16	7.83

Fig. 20. Comparison of emission.

VII. Future Work

The pre-analysis study with HOMER for single residential load at Geelong has given an understanding and comparison of the proposed five systems. With the analytical analysis, it was revealed that system 3 is economical, emits less emission with 80 percent RF. However to validate the analytical results an experimental set up has to be implemented to investigate further.

VIII. Conclusion

Using HOMER software computer model, the comparison study was conducted. The analytical analysis of 5 systems gave an understanding of change in COE, Emission, RF parameter. Among the 5 systems I determined that system 3 has optimum COE, and emits considerably less emission in the atmosphere. In conclusion with the future target of 20-2020, electricity price increase, depletion of non renewable energy sources, environmental concerns and for future sustainability, it is now time to take an initiation to overcome these issues with a promising solution of using PV RE source with optimum batteries connected to grid in all residential and commercial buildings.

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