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Research Article
Evaluation of Solar Energy Potential in Malaysia

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Abstract
Most developing countries are facing the same problem of increasing population and pollution. This has led to the increase of energy consumption that forces them to seek for alternative energy other than depleting fossil fuel such renewable energy namely solar. Located in South East Asia, Malaysia is confronting with the same situation. In this study, the evaluation of potential of solar energy for three locations in Malaysia including Pontian, Kerteh and Teluk Intan is performed using HOMER software. Based on the results, Pontian generates the highest annual solar electricity generation of 543,509 kWh year^{-1} due to the large size of 400 kW PV panel of the system. However, the cost of energy or also known as COE produced is expensive. On the other hand, with the highest solar radiation received in Kerteh, the PV stand-alone system requires lower size of 350 kW PV panel but at the same time is able to fulfil the demand with the lowest COE of $0.442 kWh^{-1} among other locations.

Key words: Solar, HOMER software, pbc system

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Malaysia is a country that is gifted with the diversity of energy resources including fossil fuel as well as various renewable energy sources. Although the development of renewable energy sources is still limited and not fully utilized, there has been a lot of new policy, fund, investment and program being implemented by the government to enhance its progress[1]. Malaysia has the advantageous values in developing its solar energy due to its location in the equatorial zone. Besides, Malaysia is blessed with natural tropical climate with average daily solar radiation of 4500 kWh m^{-2} and abundant sunshine[2] for about 12 h day^{-1}.

Figure 1 shows the solar radiation in Malaysia[3]. Kota Kinabalu records the highest solar radiation of 1900 kWh m^{-2} followed by Bayan Lepas and Georgetown with annual solar radiation of 1890 and 1785 kWh m^{-2}, respectively.

In average, Malaysia has the average annual radiation of[2] 1643 kWh m^{-2}. At present, the utilization of solar energy in Malaysia is mostly focused on water pumping, domestic water heating system and drying process of agricultural crops[4]. The solar system is usually installed at the point of use only. At the beginning of its development, a project namely.

Malaysian Building Integrated Photovoltaic Project (MBIPV) has been introduced by the government of Malaysia in 2005 in order to encourage the installation of building integrated PV system[5]. The project took a total duration of 5 years. In November 2006, Universiti Teknologi MARA (UiTM) has been selected as the Photovoltaic System Monitoring Centre (PVSMC) whereby the performance of BIPV and PV projects under the MBIPV project are monitored for 5 years until June 2011[5]. Another program implemented by Malaysian government is the SURIA-1000 program that was launched in 2007, with a specific goal on the residential and commercial sector in order to create a wider BIPV market and enhance the development of renewable energy technology[4].

Various studies have been done on the development of the projects involving solar energy in Malaysia. A study on grid-connected PV (GCPV) systems in Malaysia has highlighted the installed capacity of GCPV, the technologies involved and the performance evaluation of the systems[5]. The average price for every kWp for Malaysia Building Integrated Photovoltaic (MBIPV) has recorded a decrease of 60% from RM 31,410 in December, 2005 to RM 19,120 in March 2010[5]. Meanwhile, the photovoltaic system monitoring centre (PVSMC) has found that the total GCPV capacity

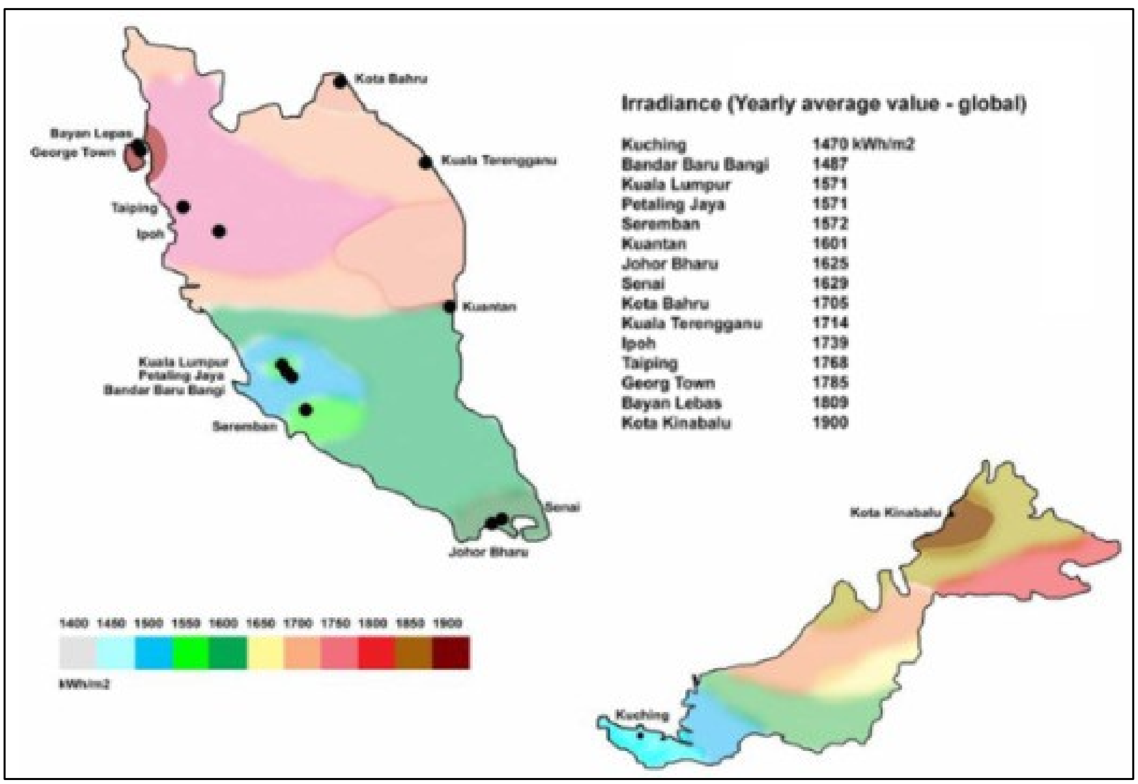


Fig. 1: Solar radiation in Malaysia[3]

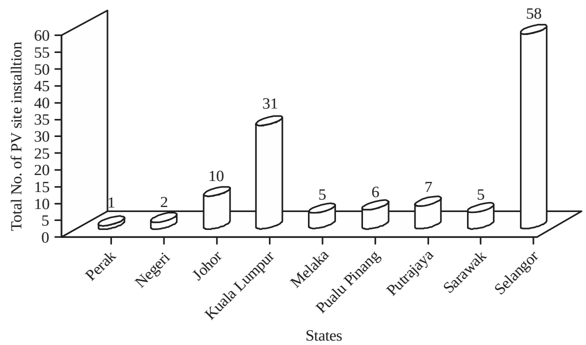


Fig. 2: Total PV site installations in Malaysia[5]. Source: PVSMC, UITM (June, 2011)

installed until June 2011 is equal to 1,605.4 kWp. The following Figure 2 shows the total number of PV site installation in Malaysia according to the states until June, 2011.

MATERIALS AND METHODS

Introduction to HOMER software: The HOMER which stands for Hybrid Optimization Model for Electric Renewables is a software invented by National Renewable Energy Laboratory (NREL) of US to assist the design process of a power system. It is able to model grid and off-grid system with various resources of energy such as PV, wind, hydro, biomass, battery, fuel cell as well as hydrogen storage[6] to fulfil either the heat or electrical loads. The modelling process is done every hour over the project's lifespan whereby the technical feasibility of a system whether the demand can be fulfilled is first determined. Consequently, the cost of installing and operating the system over its lifetime is estimated[7]. In total, there are three principle tasks modelled by HOMER which include the simulation, optimization and sensitivity analysis as presented[6] in Fig. 3.

For the purpose of clearer explanation, it is noted that a "System type" represents the combination of different types of component while "System configuration" includes variation of sizes of components in a same system type. During the simulation process, HOMER simulates the hourly performance of system configuration in order to determine the life-cycle cost and technical feasibility. Meanwhile, the optimization process models various different system configurations and determines the system configuration that fulfils the technical requirement at the lowest total net present cost. Finally, if there is a range of input set for the system, HOMER will run the sensitivity analysis process. Several examples of sensitivity inputs include range of wind speed and diesel price whereby the variation is set to check the effect of uncertainties.

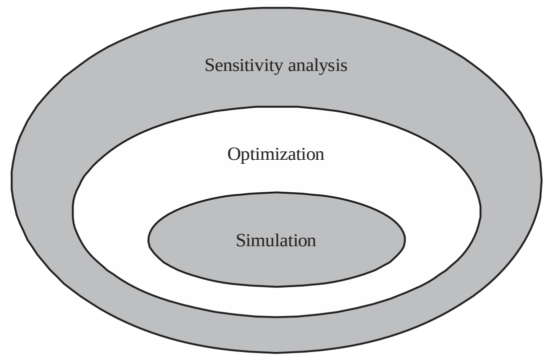


Fig. 3: Three principle tasks modelled by HOMER

From Fig. 3, it shows that a single optimization comprises of multiple simulation while sensitivity analysis consists of multiple optimizations.

PV output power: The output of PV array depends on several factors such as solar radiation, PV rating and derating factor as well as temperature parameter and it can be calculated[6] by using Eq. 1:

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\overline{G}_T}{G_{T,STC}} \right) \left(1 + \alpha_P (T_c - T_{c,STC})\right) \quad (1)$$

Where:

Y_{PV} = Rating of PV module at Standard Test Conditions (STC) (kW)
f_{PV} = Derating factor (%)
G_T = Current time step incident of solar radiation on PV module (kW m^{-2})
$G_{T,STC}$ = Solar radiation incident at STC (1 kW m^{-2})
α_p = Power temperature coefficient (%/°C)
T_c = Current time step temperature of PV cell (°C)
$T_{c,STC}$ = PV cell temperature at STC (25°C)

It is noted that the solar output power is directly proportional to the solar radiation incident on the PV array. In addition, if the effect of temperature is not taken into consideration, Eq. 1 is simplified into Eq. 2, whereby the temperature coefficient equals to zero:

$$P_{PV} = Y_{PV} f_{PV} \left(\bar{G}_T \big/ G_{T,STC} \right) \quad (2)$$

$$\text{Wind power} = 1/2\ \rho A V^3\ C_{pmax} \quad (3)$$

Economic evaluation: The HOMER arranges its optimization results in increasing order of total net present cost, NPC. Total NPC is the present value of the costs minus the revenue's present costs over the project's life time. The costs comprise of the capital, replacement, O and M as well as fuel cost. On the other hand, the revenues consist of the salvage values of the system's components. The total NPC which is the main economic output can be determined according to Eq. 4:

$$C_{NPC} = C_{ann,tot} \big/ CRF(i,\ R_{proj}) \quad (4)$$

Where:
C_{NPC} = Total annualized cost (\$ year^{-1})
CRF () = Capital recovery factor
i = Interest rate (%)
R_{proj} = Lifetime of project (year)

The capital recovery factor determines the present value of a series of equal annual cash flow and is given by Eq. 5 as follows:

$$CRF(i,\ N) = i(1+i)^N \big/ (1+i)^N - 1 \quad (5)$$

where, N is number of years.

Besides the total NPC, HOMER also calculates the leveled cost of energy, COE which represents the average cost for each kWh of useful electricity generated by the system[8]. The COE values can be calculated according to Eq. 6:

$$COE = C_{ann,\ tot} \big/ E_{served} \quad (6)$$

where, $C_{ann,\ tot}$ is system's total annualized cost (\$ year^{-1}) and E_{served} is total served electrical load (kWh year^{-1}).

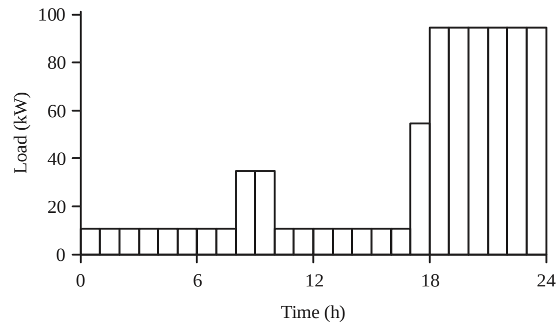


Fig. 4: Typical daily load profile of a household in Malaysia[4]

Table 1: Electricity consumption of a typical household in Malaysia[9]

Equipments	Wattage (W)	Usage (h)	Daily load demand (kWh day^{-1})	Annual load demand (kWh year^{-1})
9 V lamp	9×40	6	2.16	788.4
1 TV	80	6	0.48	175.2
1 refrigerator	100	24	2.40	876.0
4 fan	4×100	5	2.00	730.0
1 washing machine	250	2	7.54	2752.1

Load profile: Firstly, the load specification of the system is obtained. In this study, the scenario selected to represent the load for the system consists of 100 houses in a rural area or a village in Malaysia whereby there is no accessible grid nearby. Therefore, the daily load profile of a typical household in Malaysia as stated by Ismail *et al.*[9], is multiplied by 100 as shown in Fig. 4. Thus, the peak and average load demand per day for each village equals 844 kWh day^{-1} and 103 kW, respectively.

Three selected case studies are located in Pontian (A), Teluk Intan (B) and Kerteh (C) which are located at the south, east coast and west coast of peninsular Malaysia respectively as shown in Fig. 5. The electricity consumption electrical appliances in a typical medium household in Malaysia can be seen in Table 1.

Solar radiation: The solar radiation data can be directly accessed from the NASA surface meteorology and solar energy website by inserting the location's coordinates. The data obtained consists of daily solar radiation, clearness index and air temperature. Based on the data the daily solar radiation in all three locations in Malaysia is similar and considerably high with the lowest is recorded in Pontian followed by Teluk Intan and Kerteh with annual average values of 4.998, 5.389 and 5.445 kWh m^{-2} day^{-1}, respectively.

By simply inserting the coordinates of each location, HOMER directly imported the solar radiation data into the solar resource window and created a solar radiation graph as shown in Fig. 5 which is for Pontian.

Fig. 5: Location of case studies in Malaysia[7]

PV modules: The total rating, area and number of PV modules needed for the whole system is calculated. The total PV module area required for the system is as follows:

$$\text{PV area} - \frac{E_L}{G_{ev} \times \eta_{pv} \times \text{TCF} \times \eta_B \times \eta_{inv}} \quad (7)$$

Where:

EL = 844 kWh day^{-1} average daily load demand
Gav = 4.998 kWH m^{-2} day^{-1} average solar input per day
TCF = 0.578 temperature coefficient factor[8]
η_{PV} = 13.7% PV efficiency[10]
η_B = 80% battery efficiency[8]
η_{inv} = 95% inverter efficiency[8]

After the total PV area is calculated, the PV peak power is obtained according to Eq. 8:

$$\text{PV area} = \frac{844 \text{ kWh day}^{-1}}{4.998 \text{ kWh m}^{-2} \text{ day}^{-1} \times 0.137 \times 0.578 \times 0.8 \times 0.95} = 2806 \text{ m}^2 \quad (8)$$

$$\text{PV peak power} = \text{PV area} \times \text{PSI} \times \eta_{PV}$$

$$\text{PV peak power} = 2806 \text{ m}^2 \times 1000 \times 0.137 = 384 \text{ kWp}$$

Table 2: PV sizing in all location

Measurements	Pontian	Teluk Intan	Kerteh
Average solar input per day (kWh m^{-2} day^{-1})	4.998	5.389	5.445
PV power rating (kW)	384	357	353
Area of modules (m^2)	2806	2603	2576
Number of modules (U)	1707	1587	1569

Finally, by selecting the PV module with a rating of 225 Wp, the total number of PV modules needed is:

$$\text{No. of PV module} = \frac{384 \text{ kWp}}{225 \text{ Wp}} = 1707 \approx 1710 \text{ modules}$$

The calculation is for a system in Pontian. By using the same calculation steps, the PV sizes for Teluk Intan and Kerteh are obtained by changing the input value of average solar input per day, Gav according to Table 2. The final calculated PV power rating and number of modules are as follows:

The selected PV module is multicrystalline Trina Solar PC-05 PV manufactured by Thailand Company[10]. It is rated at 225 Wp with a relatively high module efficiency of 13.7% for better energy conversion. The capital cost of a PV system consists of the PV module cost and the balance of system, BOS cost[11]. Basically, the BOS of a PV system includes the cost for installation, mounting, racking, wiring works, inverter and battery. However, since PV module and inverter as well as battery are treated separately in the HOMER software, the cost of inverter and battery are excluded from the BOS cost.

According to Ismail *et al.*[9], in Malaysia, the capital cost for each kW produced by a PV array equals US $2600. The replacement cost is assumed to be the same as the capital cost[8]. Besides that, the operation and maintenance, O and M cost for PV system is taken[9] to be US $4 year^{-1}. The selected Trina Solar PV module has a lifetime of 25 years[10]. Meanwhile, according, to NREL[7], the ideal tilt angle for Malaysia ranges from 2-8° looking South and the PV should tilted at about 15° and face True South. Therefore, the slope is chosen to be 5°. On the other hand, the derating factor and ground reflectance are 80 and 20%, respectively[12].

Inverter: Some papers simply chose the rating of the inverters to be the same as the PV module rating[13]. In this study, the required inverter rating is computed according to the load. The size of inverter is 20% higher than the total wattage of AC loads[14]. By referring to Table 1, the total wattage of appliances is as follows:

Total wattage of appliances:

$$(9\times40)+80+100+(4\times100)+250 = 119 \text{ kW}$$

$$\text{Size of inverter (kW)} = 1.2\times119 \text{ kW} = 143 \text{ kW}$$

In this study, a solectria renewable 100 kW inverter, a product from Thailand is selected for the system[15]. The inverter has the maximum operating input current of 351A. At the output side, it produces a continuous output power of 100 kW and a continuous output current of 240 A for a 240 VAC system in Malaysia. In addition, the peak efficiency is very high reaching 96.5%. The selected solectria 100 kW inverter costs US $28224 per unit resulting in a capital cost[8] of US $282.24 kW^{-1}. Meanwhile, the replacement cost is assumed to be the same as the capital cost[10]. Besides, the O and M cost for the inverter is US $10 year^{-1} is stated[8].

Battery: The storage capacity of the battery required by the system is computed by using Eq. 9. The number of continuous cloudy day is assumed to be half of the entire week:

$$\text{Battery storage capacity} - \frac{N_C \times E_L}{DOD \times \eta_{out} \times V_B} \quad (9)$$

Largest number of continuous cloudy day = 3.5 days. Maximum permissible depth of discharge of battery, DOD = 80%. Battery nominal voltage = 6V:

$$\text{Battery storage capacity} - \frac{3.5 \times 844 \text{ k}}{0.8 \times 0.8 \times 0.95 \times 6} = 809759 \text{ Ah}$$

With a total storage capacity of 809759 Ah and a rating of 1156 Ah each, the number of batteries needed is equal to 16 U.

$$\text{No. of battery} = \frac{809759}{1156} = 700.5 \approx 700 \text{ U}$$

With a nominal voltage of 6V, a 6CS25P battery was chosen for the system[8]. It is made in Canada by the Rolls Battery Company and the capacity reaches 1156 Ah at 100 h rate. A single unit of 6CS25P Rolls battery comes in dimension of 22×11.25×18.25 inch and weight 115 kg. According to IRENA[11], a single unit of 6CS25P Rollsbattery costs US $1000. In this project, the replacement cost for inverter is assumed to be the same as the capital cost. An annual O and M cost of US $10 year^{-1} is considered for each battery unit[8].

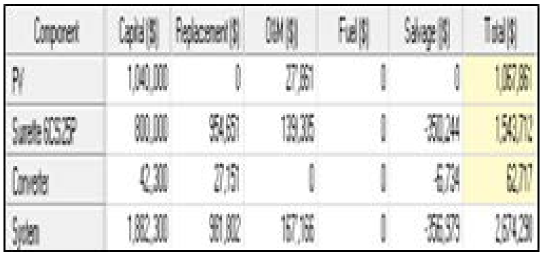
RESULTS AND DISCUSSION

Stand alone PV system (Pbc): The third system type discussed in this section is the stand-alone PV system, Pbc that consists of PV module, battery and converter. Figure 6 tabulates the detail fractions of total NPC for Pbc system in Pontian that is used in the analysis of the total NPC allocation presented in the Fig. 7. From Fig. 7, it is noted that a total of 58% which is more than half of the total NPC for Pbc system in Pontian is contributed by battery storage. It is 18% greater than PV module's total NPC. It is known that PV module comes with very high initial capital cost.

However, once installed, it is very cheap to maintain and operate. Figure 8 shows that, although PV module takes the highest capital cost of US $1040000 in the beginning of the project, the long lifetime duration of 25 years which is equal the project's lifetime cause no PV replacement to be made. Besides requiring zero fuel cost, PV module also has the advantage of low O and M cost, which in this system only equals to US $27861 that is 5 times cheaper compared to the O and M cost for battery, US $139305. In the 12th and 24th year of the project lifetime, with an expected life of 12 years, a total of US $954651 is spent for twice battery replacements, contributing a large amount to the total NPC of battery. Meanwhile, converter has small impact on the total NPC of the system with low initial capital cost and only a replacement made in the 15th year, after its lifetime ends.

The amount of electricity generated by the PV modules as displayed in Fig. 9 depends directly on the solar radiation received. With a total capacity factor of 15.5% utilized, the 400kW PV array in a stand-alone PV system in Pontian generates a total of 543509 kWh year^{-1} which is sufficient enough to fulfil a village total demand of 308060 kWh year^{-1} and results in zero unmet load.

The final categorized optimization results for stand-alone Pbc system type for all locations are summarized in Table 3. The COE ranges from as low as \$0.442 kWh^{-1} in Kerteh to \$0.499 kWh^{-1} in Pontian. In overall, a clearer comparison of stand-alone PV system feasibility between Pontian, Teluk Intan and Kerteh can be seen in Fig. 10. It is noted that Pontian has the highest average COE of \$0.499 kWh^{-1} followed by Teluk Intan and Kerteh with average COE of \$0.466 kWh^{-1} and \$0.442 kWh^{-1}, respectively.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	1,040,000	0	27,861	0	0	1,067,861
Surrette 6CS25P	800,000	954,651	139,305	0	-350,244	1,543,712
Converter	42,300	27,151	0	0	-6,734	62,717
System	1,882,300	981,802	167,166	0	-356,979	2,674,290

Fig. 6: Detail fractions of total NPC for Pbc system in pontian

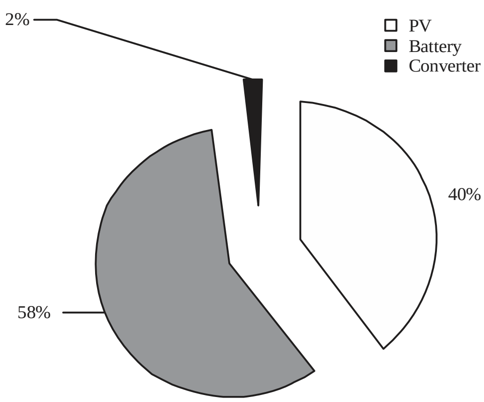


Fig. 7: Cost breakdown for Pbc system in pontian

The major factor that distinguishes the COE value is undoubtedly the main source of energy in this system which is the solar radiation level presented in Fig. 11. The stand-alone PV in Pontian has the highest COE since the solar radiation received is the lowest among other locations with a value of 4.998 kWh m^{-2} day^{-1}, not even reach 5 kWh m^{-2} day^{-1}. As the result, the biggest size of PV which is 400 kW is utilized and the number of battery string required is also 100 strings higher than in Teluk Intan and Kerteh, causing a greater COE value per kWh.

Meanwhile, although Pbc in Teluk Intan uses the same size of PV as in Pontian, with much higher solar radiation received as shown in Fig. 11 which equals 5.389 kWh m^{-2} day^{-1}, less amount of battery is needed in the system reducing the COE cost to a smaller value of

Table 3: COE and component sizes for Pbc system

Location	Pontian	Teluk Intan	Kerteh
PPV (kW)	400	400	350
Battery (string)	800	700	700
Converter (kW)	150	200	200
COE (\$ kWh^{-1})	0.499	0.466	0.442

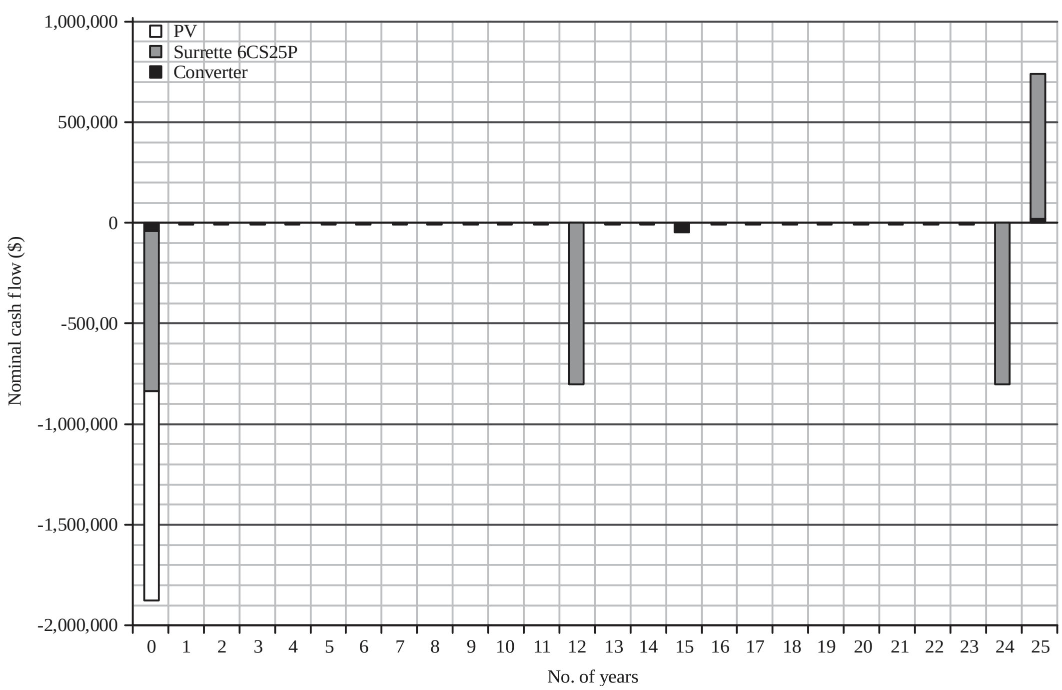


Fig. 8: Cash flow for Pbc system in pontian

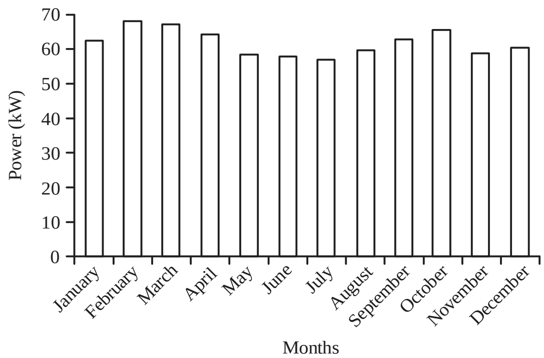


Fig. 9: Monthly electricity productions for Pbc system in Pontian

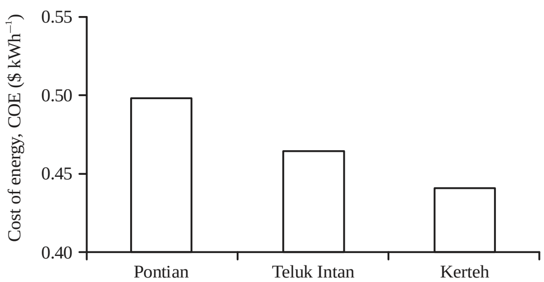


Fig. 10: COE comparison for Pbc system in all location

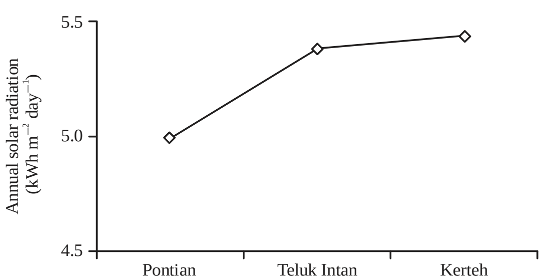


Fig. 11: Solar radiation in all location

\$0.466 kWh^{-1}. Finally, as the solar radiation is inversely proportional to the PV size needed, Kerteh has the smallest required PV size of 350 kW for its Pbc system type as it is supplied with the highest annual average solar radiation of 5.445 kWh m^{-2} day^{-1}. Consequently, as the PV size reduces, the final COE becomes cheaper which only costs \$0.442 kWh^{-1}.

CONCLUSION

With HOMER software, the evaluation of potential of solar energy for all three locations; Potian, Kerteh and Teluk Intan can be performed. Based on the results obtained, Pontian generates the highest annual solar electricity compared to other two locations. This is due to the PV panel used for the system. However, the COE produced is expensive. Kerteh uses lower size of panel but still managed to fulfill the demand with lowest COE compared to other two locations.

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