Techno-economic analysis of PV-based power systems for Cape York, Australia

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ABSTRACT

Fossil fuels are the world's main sources of power production. Because of the huge population, the energy demand and supply gap have recently escalated, and fossil fuels will not satisfy the gigantic energy demands. Meanwhile, they have harmful environmental effects as well. Remote rural areas far from the national grid have no way of meeting their energy needs. These concerns summarize the situation facing the population living in Cape York, Australia. The solar photovoltaic (PV) off-grid system has emerged as the best energy solution for the electrification of these remote regions. However, the local electricity providers struggle with the lack of area-specific data on generation capacity and economic feasibility of solar energy. To address this problem, this study aims to deliver a comprehensive techno-economic feasibility analysis of a solar PV system for Cape York, Queensland, Australia. This study investigates the economic viability for solar PV systems by means of Hybrid Optimization Model for Electric Renewables (HOMER) software. HOMER results suggest that the total cost of electricity generation from the solar PV stands significantly cheaper than conventional electricity. Besides, the system can reduce carbon emissions and other pollutants considerably.

Keywords: *PV, Solar energy, Cape York, HOMER, Pollutants*

INTRODUCTION

With the rise in population and technological and economic growth, people need more resources to create a better living environment. However, the current power systems have created a negative environmental impact and contributing to global warming through the emission of carbon dioxide (CO_2) due to the utilisation of fossil fuel (Shafiullah et al., 2012). To date, fossil fuels have been the primary source of energy that offers a financial affordable choice; however, our globe's environment is paying an expensive price (greenhouse gas emissions) for the production and use of fossil fuels (Shafiullah et al., 2012; Commonwealth of Australia, 2011). Renewable energy is beginning to be used as a panacea for addressing climate change and global warming issues, unlike fossil fuels.

Renewable energy is inferred from natural forms that are recharged continually. In its different forms, it determines directly from the sun, or the heat created deep inside the earth. Included within the definition are power and heat created from solar, wind, hydropower, geothermal resources, and biofuels inferred from renewable resources (Shafiullah et al., 2012; Commonwealth of Australia, 2011; Department of Commerce, 2009). Renewable energy sources present the potential of energy production with a minimal impact on the environment, particularly concerning greenhouse gas emissions (Department of Commerce, 2009).

It is only possible to use three renewable sources of energy (i.e. biomass, geothermal and solar) to produce adequate heat energy for power generation. Of all three, solar energy has the most significant global potential despite being decentralised, sporadic and is continuously fluctuating solar energy turns to be promising (Holm-Nielsen and Ehimen, 2016; Sampaio and González, 2017). It offers inexhaustible availability, universality, high capacity, and environmental friendliness. The solar energy can contribute to a significant reduction in the global carbon emissions, which has been a major environmental, social, and economic issue in recent years (Kabir et al., 2018).

A range of variables is primarily responsible for determining the strength of the solar influx passing through the Earth's atmosphere (e.g. latitude, diurnal variation, temperature, and geographic variation) (Al-Tameemi and Chukin, 2016). The total amount of solar energy obtained in Earth's atmosphere is approximately 342 W/m^2, of which 30% is distributed or mirrored back into space, leaving approximately 70% for harvesting and capture (239 W/m^2) available. Figure 1 indicates the global horizonal irradiation on the surface of the earth.

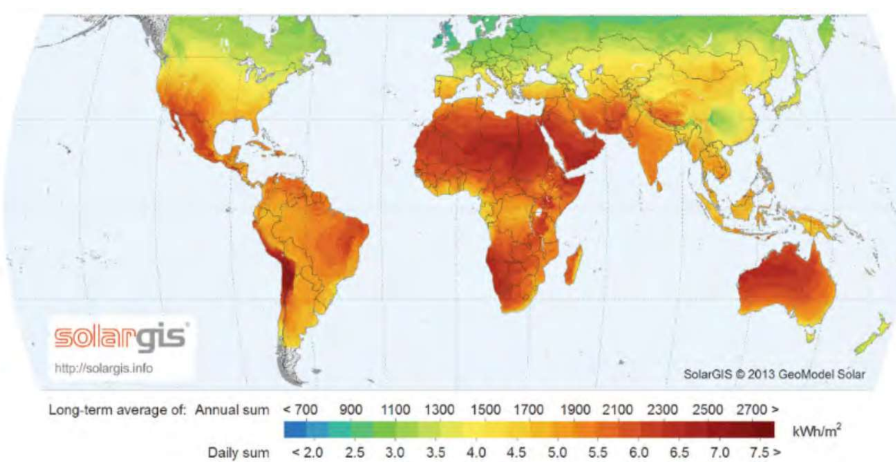

Figure 1: World map of global horizonal irradiation (Tiwari, 2016).

In the field of renewable energy, the capture of solar energy by photovoltaic (PV) panels present a promising solution. Owing to its rapid growth trend and the high level of investment involved, the photovoltaic market is getting more attention. Currently, they supply the most common technology in harvesting solar energy around the world.

Access to energy is a crucial enabler to survive and prosper in remote areas such as Cape York. The Cape York Peninsula is a remote and largely inaccessible part of Queensland, Australia. The largest town is Weipa, which runs local bauxite mining operations. This analysis focuses on the country north of Weipa (Figure 2). Energy is critical in Cape York, as in other countries, for economic and social growth and better quality of life. This paper reports a case study conducted in Cape York area, aiming to deliver a comprehensive techno-economic feasibility analysis of a solar PV system.

MATERIALS AND METHODS

In undertaking the study, Hybrid Optimization Model for Electric Renewables (HOMER) software is adopted to conduct cost analyses for different groups of solar PV to meet an electric load of 30 megawatts (MW) for a chosen site in Cape York, as shown in Figure 2. Established by the National Renewable Energy Laboratory (NREL), HOMER is one of the most broadly employed tools to examine renewable energy systems (Huang et al., 2011; Oulis Rousis et al., 2018; Abdul-Wahab et al., 2019; Khormali and Niknam, 2019; Hossain and Rahman, 2020). The software permits the end-user to explore the financial and technical options for on-grid and off-grid energy systems and to analyse various aspects of energy projects (location, system sizing, etc.), allowing assessing the feasibility of renewable energy projects while they are under the study phase.

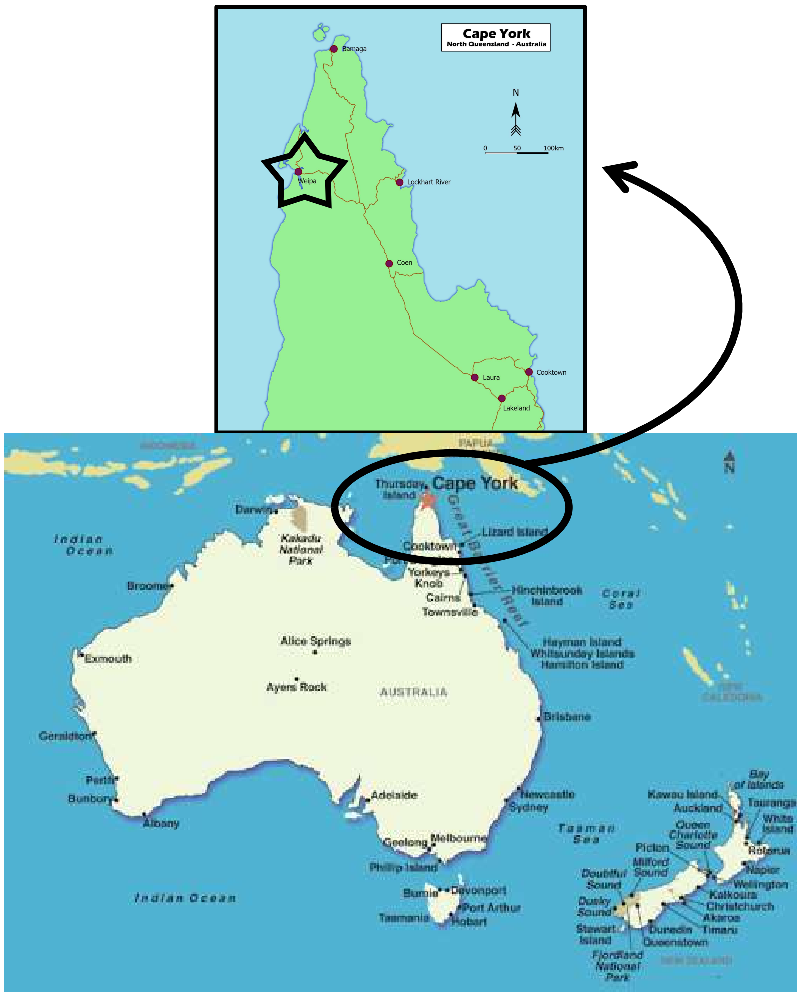

Figure 2: The geographical location under investigation.

In this assessment, the load profile was assumed to be 30 MW for all months of the year. Furthermore, ten distinct types of solar PVs, with a minimum capacity of 30 kW and a maximum capacity of 1164 kW, were decided from HOMER's accessible library. Each on from the ten solar PVs was investigated independently. Progressing to the capital and operational and maintenance costs of solar PV. the study will be based on the recent costs provided by Alarrouqi et al. (2020) (Capital cost =

1293 AUD$/kW, Operation and Maintenance (O&M) cost = 13 AUD$/kW). Additionally, solar energy requires pinpointing the appropriate resources (i.e. temperature, solar radiation, etc.) for the selected renewable energy component. The data for the monthly average solar radiation and clearness index (a measure of the atmosphere's clearness and defined as the fraction of the solar radiation that is transmitted through the atmosphere to strike the earth's surface) for every month and a duration of one year in Cape York were attained from the National Aeronautics and Space Administration (NASA) database (NASA, 2020), shown in Figure 3. As it can be seen that both the solar radiation and clearness index values vary throughout the whole year. The average daily radiation value was at its highest in October (7.45 kWh/m^2/day) and at its minimum in December (5.12 kWh/m^2/day). As for the clearness index values, the highest value was recorded in September (0.721), and October (0.709) and the lowest was recorded in February (0.466).

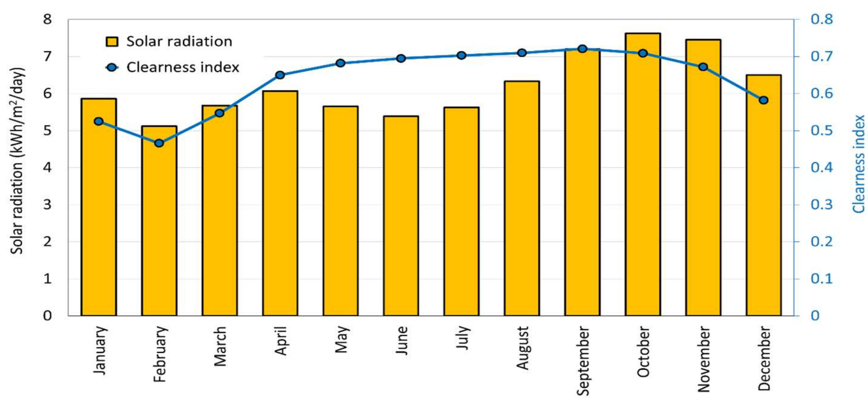

Figure 3: Average monthly solar radiation and clearness index.

The last stage was to set out the project configurations (i.e., constraints, economics, etc.). A 20-year proposed project lifetime was considered, and the solar power output was defined at 100% (to increase the yield from the solar energy). The maximum annual capacity shortage was assumed to be 100%, and the nominal discount rate was defined at 7%. After offering all the required data, HOMER simulated the system operation and computed the results based on the data provided. Considering the same load profile (30 MW), a diesel-powered generator replaced the PV systems to acquire the emissions that can be prevented by the utilization of PV. Table 1 summarizes the capital, replacement and operation and maintenance costs of the diesel generator.

Cost type	**Value**
Capital cost (AUD$/kW)	1000
Replacement cost (AUD$/kW)	900
Operation and maintenance cost (AUD$/op. hr)	0.025
Fuel price (AUD$/L) (GlobalPetrolPrices.com, 2020)	1.195

Table 1: Capital, replacement, and operation and maintenance costs for diesel generator (Jamal et al., 2016).

RESULTS AND DISCUSSION

HOMER simulation results for the ten dissimilar types of solar PVs with a range of capacities are summarized in Table 2. For all the PVs, the net present cost was determined to be around AUD$ 49.3 M. The results show that the highest cost of electricity was attained from type 9 (SMA Sunny Tripower 60-US with Generic PV) at AUD$ 0.05666/kWh. Type 5 (Studer VarioTrack VT-80 with Generic PV), on the other hand, demonstrated the lowest cost of electricity (approximately AUD$ 0.05606/kWh).

No.	Type	Capacity (kW)	Cost of Electricity (AUD$/kW)	Net Present Cost (AUD$)	Unmet electric load (%)	No. of PV
1	Ingeteam (1164kVA) with Generic PV	1164	0.05636	43.9 M	77.4	26
2	Schneider ConextCoreXC 680kW with Generic PV	680	0.05632	43.9 M	77.4	44
3	Studer VarioString VS-120 with Generic PV	680	0.05659	43.9 M	77.5	44
4	Studer VarioTrack VT-65 with Generic PV	680	0.0561	43.9 M	77.3	44
5	Studer VarioTrack VT-80 with Generic PV	680	0.05606	43.9 M	77.3	44
6	Schneider ConextCoreXC 630kW with Generic PV	630	0.05622	43.9 M	77.4	48
7	Schneider ConextCoreXC 540kW with Generic PV	540	0.05643	43.9 M	77.5	56
8	SolarMax 500RX A with Generic PV	500	0.05659	43.9 M	77.5	60
9	SMA Sunny Tripower 60-US with Generic PV	60	0.05666	43.9 M	77.5	500
10	Huawei SUN2000 30kW with Generic PV	30	0.05634	43.9 M	77.4	1000

Table 2: HOMER results for different types of solar PVs.

The cost of electricity and the unmet electric load of the assessed 10 PV systems are illustrated in Figure 4 and Figure 5, respectively. The results notably illustrate that the unmet electrical load results were approximately the same and fluctuated between 77.3% and 77.5%. On the other hand, the cost of electricity results was notably different across the examined PVs. From the results, and taking into account that the operation and maintenance costs are strongly reliant on the number of PVs necessary for electricity generation, and the reality that it has the lowest cost of electricity, the ideal PV type suitable for Cape York's requirements and meets the targeted demand of 30 MW is type 5 (Studer VarioTrack VT-80 with Generic PV) (the properties of this type are listed in Table 3).

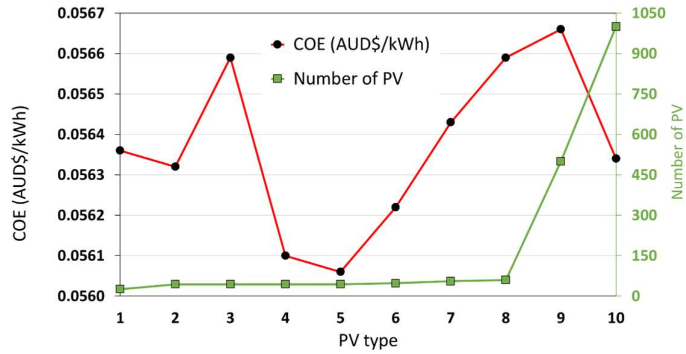

Figure 4: Cost of the energy of the studied PVs. 1 Ingeteam (1164kVA) with Generic PV. 2 Schneider ConextCoreXC 680kW with Generic PV. 3 Studer VarioString VS-120 with Generic PV. 4 Studer VarioTrack VT-65 with Generic PV. 5 Studer VarioTrack VT-80 with Generic PV. 6 Schneider ConextCoreXC 630kW with Generic PV. 7 Schneider ConextCoreXC 540kW with Generic PV. 8 SolarMax 500RX A with Generic PV. 9 SMA Sunny Tripower 60-US with Generic PV. 10 Huawei SUN2000 30kW with Generic PV.

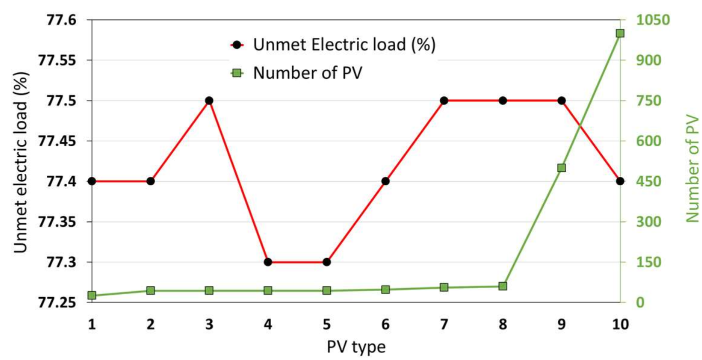

Figure 5: The unmet electrical load of the studied PVs. 1 Ingeteam (1164kVA) with Generic PV. 2 Schneider ConextCoreXC 680kW with Generic PV. 3 Studer VarioString VS-120 with Generic PV. 4 Studer VarioTrack VT-65 with Generic PV. 5 Studer VarioTrack VT-80 with Generic PV. 6 Schneider ConextCoreXC 630kW with Generic PV. 7 Schneider ConextCoreXC 540kW with Generic PV. 8 SolarMax 500RX A with Generic PV. 9 SMA Sunny Tripower 60-US with Generic PV. 10 Huawei SUN2000 30kW with Generic PV.

Name	**Studer VarioTrack VT-80 with Generic PV**
Dimensions [height (mm)/width (mm)/length (mm)]	120 / 220 / 310
Rated capacity	680.08 kW
Efficiency	17.3%
Operating temperature	45 °C
Derating factor	96%
Temperature coefficient	-0.41

Table 3: Properties of the ideal PV.

Figure 6 illustrates the monthly average electric production in the selected location of the study. The maximum solar electricity generation levels take place amongst the months August and October, with higher values occurring in October. This high electricity generation levels can be explained by the fact that the site experiences the highest amounts of solar radiation and clearness indices compared to the remaining months. On the other hand, the electric production is at its lowest during the period between January and March, attributed to the low clearness index.

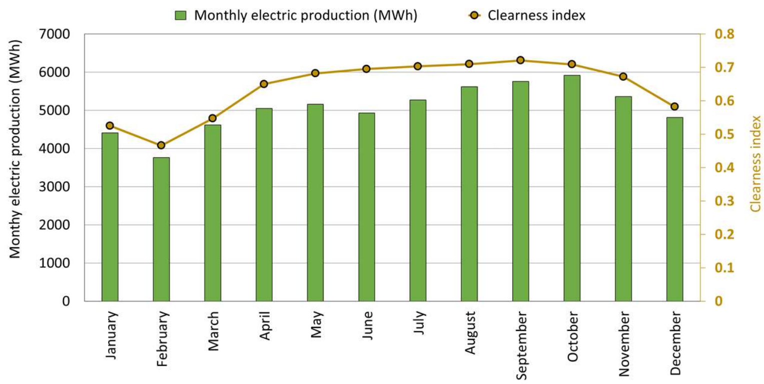

Figure 6: Monthly average electric production and clearness index profile.

Furthermore, it is crucial to identify the economic performance of the recommended solar PV system over the conventional diesel-powered generator system and to highlight the emissions that can be prevented by the utilization of PV. Starting with the economic comparison, the costs of electricity for the two systems are as follows: AUD$ 0.5051/kWh for the diesel-powered generator system and AUD$ 0.05606/kWh for the solar PV system. This clearly shows that executing a solar PV system will provide a cost of electricity savings of around AUD$ 0.44904/kWh. Worth to mention that the comparison mentioned above was based on a fixed diesel fuel price (AUD$ 1.195/Litre). The Covid-19 pandemic and global economic recession strongly impacted the global energy demand and disintegrated fossil fuel prices (Yoshino et al., 2020). With such a decrease in prices, there might be a situation where PV systems lose against conventional diesel generators. Therefore, it is vital to understand the influence of diesel fuel price on the cost of electricity savings. As can be notably observed in Figure 7, the endorsed solar PV system demonstrated superior economic performance over the conventional diesel-powered generator system, illuminating the opportunity for solar PV to act as a critical contributor to all sectors of the global energy system in a cost-effective manner, and reflects its sustainability to the instabilities of diesel fuel price.

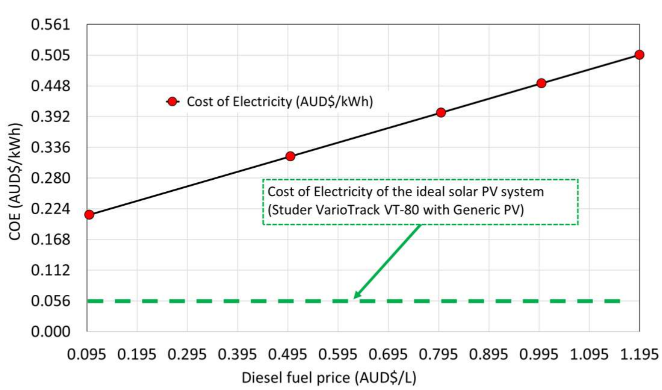

Figure 7: Impact of diesel fuel price on the cost.

Moving to the emissions, and given that solar PV is a clean, environmentally friendly source of energy that has no emissions unlike fossil fuels, Table 4 lists the quantities of greenhouse gases expelled from a diesel generator with a met electric load percentage of 22.7% (similar to the met electrical load of the ideal PV). The employment of a PV system will prevent the generation of a total of approximately 42,220,653 kg of pollutants every year. However, having said that, end-of-life solar panels may become a source of hazardous waste although there are enormous benefits globally from the growth in solar power generation. Due to the presence of hazardous substances like cadmium and lead in PV technology, landfilling of end-of-life panels is not advisable. The aforementioned harmful chemicals can leach into the ground causing drinking water contamination (Chowdhury et al., 2020). Given that the average panel lifetime is between 20-25 years, the worldwide solar PV waste is anticipated to reach between 4%-14% of total generation capacity by 2030 and increase to over 80% (around 78 million tonnes) by 2050 (Chowdhury et al., 2020). In this sense, the disposal of PV panels will become a vital environmental issue in the upcoming years.

The long-term sustainability of PVs will be mostly reliant on the effectiveness of the process solutions that will be embraced to recycle the unprecedented volume of end-of-life PV panels anticipated to be generated in the near future (Padoan et al., 2019). Therefore, and in order to certify the sustainability of PV in large scales of deployment, it is essential to establish low-cost recycling technologies for the developing PV industry in parallel with the rapid commercialization of these innovative technologies.

Pollutant	**Amount (kg/year)**
Carbon monoxide (CO)	262,206
Carbon dioxide (CO_2)	41,597,239
Particulate matter (PM)	1,589
Unburned hydrocarbons (UHC)	11,442
Nitrogen oxides (NO_x)	246,315
Sulfur dioxide (SO_2)	101,862
Total	42,220,653

Table 4: Pollutant emissions by a diesel generator with a met electric load percentage of 22.7%.

CONCLUSION

The objective of this study was to explore the solar PV systems available in the market and find a viable option that could meet an electric load of 30 megawatts (MW). Studer VarioTrack VT-80 with Generic PV because made to the top of the list with the lowest cost of electricity (AUD$ 0.05606/kWh) and a minimal number of PVs needed. Additionally, the results depicted that realizing a PV power plant rather than conventional diesel-based generators will contribute in cost of electricity savings of approximately AUD$ 0.44904/kWh and will prevent the generation of a total of approximately 42,220,653 kg of pollutants every year. Despite the current instabilities in diesel fuel price due to the Covid-19 pandemic and global economic recession, the endorsed solar PV system showed superior economic performance over the conventional diesel-powered generator system, illuminating the opportunity for solar PV to act as a critical contributor to all sectors of the global energy system in a cost-effective manner, and reflects its sustainability.

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