Renewable Energy Systems for an Unmanned Offshore Platform

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Abstract. Offshore structures play a significant role in extracting non-renewable resources such as crude oil and natural gas. However, these facilities that drill, explore, extract, store and process petroleum and natural gas create environmental hazards and are not cost-effective. Therefore, to produce cleaner energy and mitigate anthropogenic pollution into the environment, the world is shifting towards Renewable Energy Resources (RES) and policies. This is largely subtended by the Paris Agreement and efforts of the United Nations Framework Convention on Climate Change where more countries are becoming receptive to the need to stabilize global Greenhouse Gas Concentrations. In this study, the use of renewable energy for powering an offshore structure is evaluated to determine its feasibility and practicality in real world applications. The site used was an unmanned platform with an average load of 10 kW for each hour per day, with 2.4 kWh energy per day and a peak load of 18 kW per day. The system was modeled and analyzed using the HOMER Pro software. A diesel /photovoltaic (PV) based hybrid system was designed for an unmanned offshore natural gas platform to replace the sole diesel-based electric generation. The Homer Pro simulation software was used to evaluate and select the most cost optimal PV system for the site. This optimal PV system was then compared with the business as usual diesel generator scenario using the same software. The parameters like net present cost (NPC), cost of energy (COE), renewable fraction, and diesel fuel consumption were considered to analyze the technical and economic aspects of the system. From the analysis of the results, it was found that the PV system has high initial capital but has a low net present cost as compared to diesel generation. The HOMER Pro suggests that the 4.8kW of the solar/diesel hybrid system for a 10kW average load as an optimized model because of the low NPC comparatively.

Key words: renewable energy, greenhouse gases, Homer pro, photovoltaic, small island developing states.

Introduction

There exists a global thrust by many countries including Small Island Developing States (SIDS) such as Trinidad and Tobago (TT) to reduce Greenhouse Gas (GHG) emissions related to energy generation (Seedath et al., 2021). TT is an oil and gas-based economy with an abundant, but steady decrease supply of petroleum hydrocarbons. Trinidad and Tobago is signatory to the United Nations (UN) Paris Agreement and is currently ranked third in the world in terms of carbon dioxide (CO_2) emissions and energy usage per capita UNDP (2011). Since hydrocarbon resources are mostly found in offshore areas, oil field development needs special attention in areas such as field exploration, plan implementation, and production phases (Seong and Hong, 1995). The manned development of oil fields requires enormous investments in the form of development costs. In comparison, the development of unmanned platforms for the offshore area will reduce the maintenance, operational cost, and save a lot of potential resource (Rongsopa, 2011).

Due to worldwide global awareness and a decrease in fossil fuel resources, the need for environmentally friendly alternative energy resources has become a necessity. Renewable energy utilization for offshore rigs will reduce its carbon footprints as well as decrease the drilling cost and aid in job generation thereby contributing to the economy (Tawiah et al., 2016). Currently, resources like diesel generators and natural gas turbines are mostly used to supply power to unmanned offshore platforms to power pumps, compressors, navigational equipment and communications (Khan and Iqbal, 2005). Continuous combustion of fossil fuels accounts for over 80% of total CO_2 and NO_x emissions from offshore installations and are having difficulty operating in an environmentally friendly manner as they produce high levels CO_2. In 2013, the International Petroleum Industry Conservation Association (IPIECA) estimated that on average, an offshore structure uses (20-$30\mathrm{m}^3$) or (20,000L – 30,000 L) of fuel per day IPIECA (2013). In TT, it is estimated that oil and natural gas production emitted 3.77 million metric tonnes of CO_2 equivalent of GHGs in 2018 (Ritchie et al., 2020). On utilizing current technologies, TT's upstream oil and gas production is forecasted to grow 4.4% from (2022-2027) Trinidad and Tobago Oil and Gas Upstream Market - Growth, Trends, COVID-19 Impact and Forecasts (2022-2028).

Previous research involving unmanned platforms conducted by Tiong et al. (2015), provided evidence that wind derived energy can be a viable option for offshore applications, however considerations such as the space requirements on an unmanned platform as well as the intermittent gusts of the North East Trade winds that sweep over TT may not adequate for a consistent generation. The hydrodynamic performance of the tidal technologies is also not directly linked to its economics attractiveness Oliveira-Pinto et al. (2019: 556-569). On the other hand, solar energy is one of the key players among renewable energy systems being utilized to meet energy demand. Given the richness of natural sources of solar radiation, the PV system provides the clean and simple transformation of solar energy into electricity (Azimoh et al., 2017: 222-231). The solar system can be installed to replace or offset other generation sources like diesel for remote areas and other installations such as unmanned gas platform (Rahmat et al., 2022). As demonstrated by Choi et al. (2016), renewable energy technologies in the oil and gas industry especially solar thermal systems are proving to be feasible. The American Midway-Sunset Oil Field is being powered by a stand-alone 500 kW PV system being used to power the oil rigs. Solar energy is currently being used in the McKittrick Oil Field and Coalinga Oil Field in the US where solar energy is generated both offshore and onshore and connected to offshore platforms via subsea cables mitigating the negative environmental effects of previously used diesel generators (Macinnes, 2021; Swarnkar et al. 2016: 56-61; Amole et al., 2022; IEA, 2022).

Justification for a switch, the switch to renewable energy alternatives is required and suggested solutions must be able to achieve or exceed energy demands in a reliable manner and proven to have favorable economics while demonstrating the benefit of reduced emissions associated with current energy sources (Nugroho et al., 2022: 730-743). A review of the literature has revealed limited studies and information required for the adaptation and utilization of PV technologies to power offshore installations in TT. To fill this information gap, this study will evaluate the feasibility of using renewable energy to power an unmanned gas platform located 45km offshore Pt. Lisas Industrial Estate in Trinidad. The study will involve conducting an energy audit of the facility, development of an energy load profile and designing as well as optimizing a suitable renewable system to satisfy the energy needs of the platform using the Homer Pro software. The performance of possible hybrid renewable energy systems and their design architectures will be evaluated. The suitable architecture and optimum model will be based on economics with the add on benefits of reduction in GHG emissions in comparison to a standalone PV system and the diesel generation systems currently being utilized on the platform.

Material and Methods

The energy load profile for the unmanned gas platform located was built using the relevant load ratings for each electrical component matched to their average usage. The energy load profile was developed based on the calculated energy usage values. In this study, the daily unmanned offshore gas platform average load of 10kW for each hour per day was considered. The electric load profile day was generated synthetically by HOMER Pro software by using random calculations. The total energy needed for this load was 24kWh/day, and the peak load was 18kW with a load factor of 0.55.

The normalised energy load profiles were then inputted into the HOMER Pro software as the electric base load for the models built. Alternative models were also built by adding/removing components to/from the base case system model built and then simulated using the 'HOMER Pro' software. For this project, diesel generators and PV-based solar systems were considered and the designed model consisted of PV panels, AC/DC converter, batteries for storage, diesel generator and load. Relevant information on the diesel generator specifications were supplied by the Operator of the unmanned platform.

System optimisation was conducted using the ‘HOMER Pro’ Optimiser option within the software to study the most favourable performance outcomes. The simulation and optimisation results were analysed and the most appropriate system was chosen based on the lowest LCOE obtained taking into consideration other economic factors and CO_2 emission reduction values.

Results and Discussion

The energy load profile for the unmanned gas platform located was built using the relevant load ratings for each electrical component matched to their average usage. The energy load profile was developed based on the calculated energy usage values. In this study, the daily unmanned offshore gas platform average load of 10kW for each hour per day was considered. The electric load profile day was generated synthetically by HOMER Pro software by using random calculations. The total energy needed for this load was 24 kWh/day, and the peak load was 18 kW with a load factor of 0.55 being utilized.

The unmanned offshore platform being considered in this study is currently being powered by a marine diesel generator with a power rating of 13.5kW being used to deliver power for the 10-kW system at full load capacity. Based on information supplied by the operators of the platform, the generator consumes 4.5 Liter of diesel per hour at full load with a fuel cost of US$1/Liter. The output of the engine is mechanical energy which rotates the rotor of the connected electrical machine through a rotating shaft. The electrical machine operates at a constant speed provided by the diesel engine to produce the rated output voltage at a defined frequency.

The theoretical efficiency of this type of diesel generation is about 30% at a nominal operating load. The diesel generator consumes about 25% of fuel even if no output power is being produced. A 10kW diesel generator was simulated using the HOMER PRO software and the relevant specifications, performance data and cost parameters generated shown in Table 1. Based on the data outlined above, once can see that thought the generator is not competitive from an economic viewpoint, it is a requirement to provide power to the platform at a marginal generation cost of 0.273US$/kWh.

Table 1. The specifications and cost parameters associated of a Diesel system

Capacity	10.0 kW
Capital Cost	US $5,000
Marginal Generation Cost	0.273 US$/kWh
Generator Fuel	Diesel
Generator Fuel Price	1.00 $/L
Simple payback:	N/A
Return on Investment:	-0.100 %
Internal Rate of Return:	N/A
Capital Investment:	$5,000
Electrical Production	75,582 kWh/yr
Fuel Consumption	23,458 L
Hours of Operation	8,557 hrs/yr
Maintenance Cost	2,567 $/yr

An alternative 10kW PV system to the diesel generator was designed and optimized using the HOMER Pro software by defining initial variables in the modeling tool. The generic flat plate PV panels were selected because of their efficiency and easy accessibility in different locations. Table 2 and 3 shows the detailed specifications of the panel and the AC/DC Converter used to design the 10kW PV system.

Table 2. PV Panel Specifications

Rated Capacity	10.0 kW
Capital Cost	$7,000
Specific Yield	1,433 kWh/kW
PV Penetration	16.4 %
Total Production	14,329 kW
Maintenance Cost	100 $/yr

Table 3. AC/DC Converter specifications

Capacity	7.00 kW
Mean Output	1.53 kW
Minimum Output	0 kW
Maximum Output	7.00 kW
Capacity Factor	21.9 %
Hours of Operation	4,350 hrs/yr
Energy Out	13,412 kWh/yr
Energy In	14,117 kWh/yr
Losses	706 kWh/yr

After designing, the simulations were run repeatedly to get an optimized result. Optimized results were displayed and categorized by determining the most reasonable combination of resources to meet the required load demand. The results were determined based on the least cost considering the combined cost of all equipment. Mostly that power system is selected which provides less net present cost. The system can be selected based on the high fraction of RES, low shortage of capacity, less excessive electricity generation, or low fuel consumption. Comparison can be made among different power generating schemes to check the technical feasibility of the system.

The economic parameters associated with the alternative renewable system to the marine diesel generator considered is the 10 kW PV system which is described in Table 4. In this case and unlike with the generator, this system does have an associated payback and ROI (though the initial capital cost is higher), proving to be more economically competitive than the former.

Table 4. The economic parameters associated with a 10 kW PV system

Project Lifetime	25 years
Simple payback	7.35 yr
Return on Investment	9.00%
Internal Rate of Return	12.4%
Capital Investment	$7,000
Annualized Savings	$111.68

The optimized system has a connected load with a peak value of 18kW and energy of 24kWh/day. The annual energy produced by the solar system is 14,329kWh/yr. Fig. 1 shows the trend of energy production throughout the year and highlights energy production during daylight hours generally between 6am and 6pm.

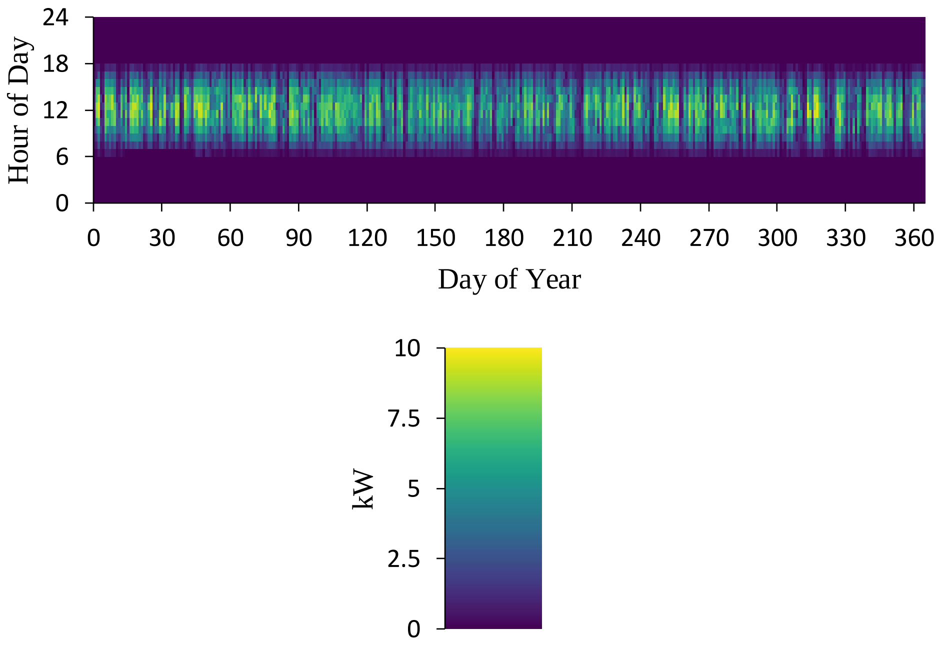


Fig. 1. Annual Energy Production Behavior

From the data shown in Fig. 1, it can be inferred that solar energy alone cannot be used to power offshore rigs. Since an offshore structure requires consistently high-quality power to ensure stability and efficiency along with limitations with space and weight restrictions, renewable PV energy sources alone cannot fulfil all the requirements. of powering the structure for now, due to and power requirements. A comparison of the economic factors associated with the 10 kW of solar PV and the diesel generation systems are shown in Table 5. The comparisons validate the earlier point that the PV would be a more preferred system to the diesel generator using a least cost objective function. However, it should be noted that without batteries to provide power in the low solar availability hours, this system would incur more capacity shortage than the generator. As such, the generator would still be required but should be used to increase energy reliability during these capacity shortage periods.

Table 5. Comparison of economic parameters of the 10kW Solar and Diesel Generation Systems

Parameters	PV	Diesel
Net Present Cost (NPC)	$123,262	$135,272
Cost of Energy (COE)	$0.0945	$0.103
Operating cost	$7,579	$8,648
Initial Capital	$9,100	$5000
Renewable factor	15.3%	0
Project Lifetime	25 years	Undefined (need scheduled repairs)
Simple payback	7.35 years	N/A
Return on Investment:	9.00 %	NA
Internal Rate of Return:	12.4 %	-0.100%
Capital Investment:	$9,100	$5,000
Fuel Consumption	NA	23,458 L

Another alternative system for the connected load with a peak value of 18 kW and energy of 24 kWh/day is a PV system of 4.8 kW capacity. The NPC associated with this system is $112,999 dollars as compare to 10 kW NPC which is $123,262.

By adding the 4.8kW solar system, the operating cost will reduce up to $4,663 per year, the payback period of investment will be 9.84 years, and an IRR of 8.34%. Table 6 shows the cost specification of a 4.8 kW PV system.

Table 6. Cost Specification of 4.8 kW PV

Simple payback:	9.84 yr
Return on Investment:	5.60 %
Internal Rate of Return:	8.34 %
Net Present Value:	$18,955
Capital Investment:	$42,761
Annualized Savings:	$4,097

The input from the PV system of 4.8 kW capacity is more compared to the 10 kW PV system as seen in Fig. 2.

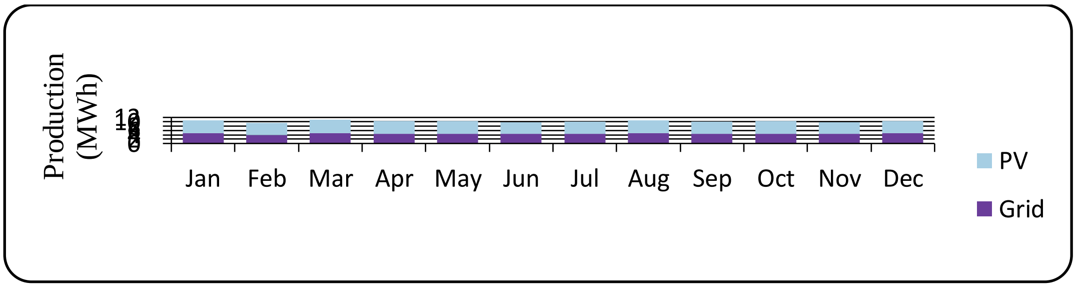


Fig. 2. Monthly Input of Different Sources

The annual output energy using this PV system is 69,003 kWh/yr. Fig. 3 shows the power out behavior of the 4.8kW PV system which was higher compared to the 10kW PV system.

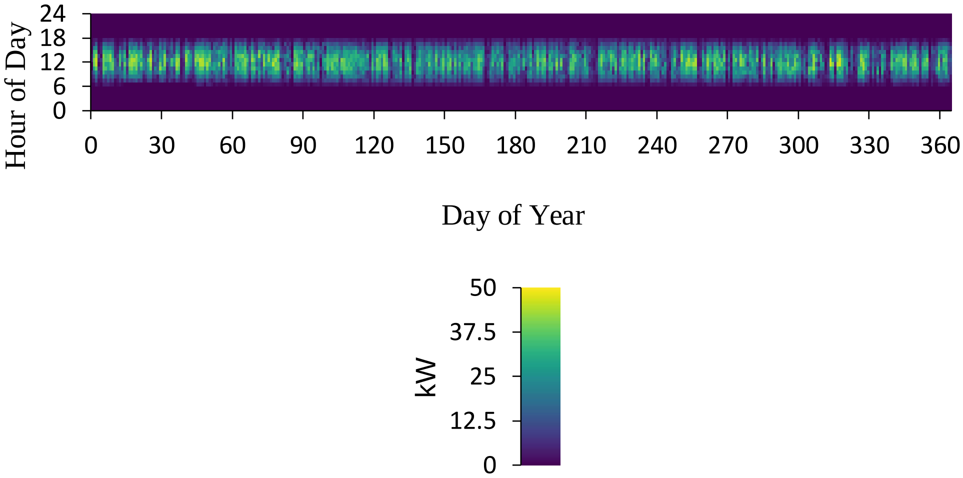
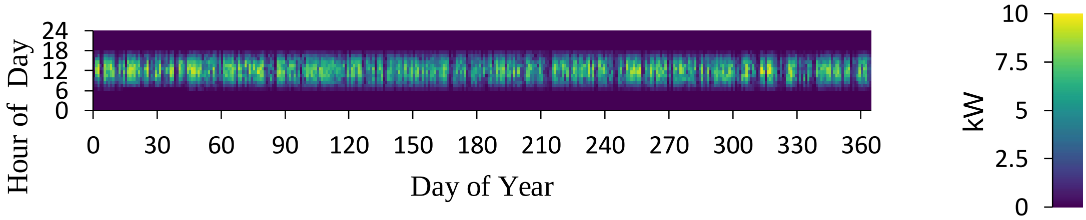
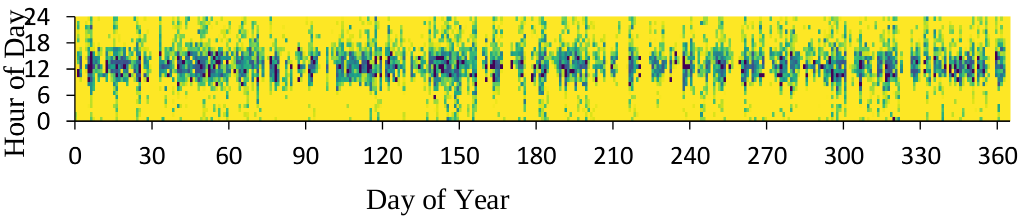


Fig. 3. Energy Behavior of 4.8 kW PV

One of the scenarios analyzed to satisfy the energy requirements of the facility is a hybrid combination of a 10kW PV and a 10kW capacity diesel generator system with an additional battery storage capacity of 88kWh. The total operating cost of this system was found to be $31,360 per year. The energy output through the PV system is 14,329 kWh/year which along with other specifications are shown in Table 1. The energy produced by diesel generators is 75,582 kWh/year and along with other cost parameters are shown in Table 2. The output power behavior of a hybrid combination of a 10 kW PV and a 10kW capacity diesel generator system based on the days and hours is shown in Fig. 4.



(a) The output power behavior of a 10kW PV system



(b) The output power behavior of a 10kW diesel system

Fig. 4. The output power behavior of (a)10 kW of the PV system and (b) 10kW diesel system

An alternative hybrid system of 4.8kW PV with a 10kW diesel generator coupled with a 50kwh battery capacity was designed and the system had an improved operating cost of $22,839 per year. In this hybrid design, the energy produced by the PV system component is greater and will be 68,780 kWh/year while the energy produced by diesel generation component will be less significant at 53,941 kWh/year.

The source input to meet load demand is shown in Fig. 5 and it shows that input for PV is almost 50% of total energy which is better than the 10kW PV system previously described.

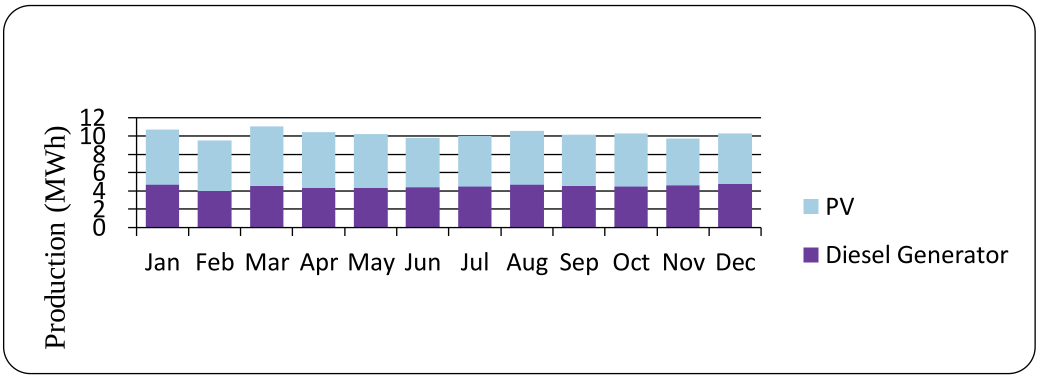
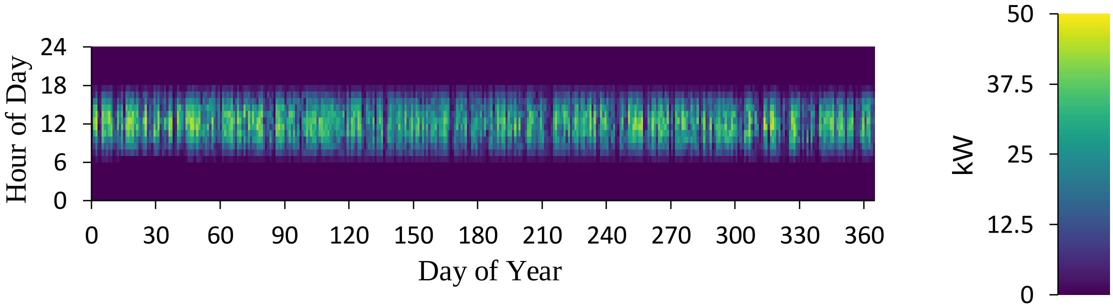
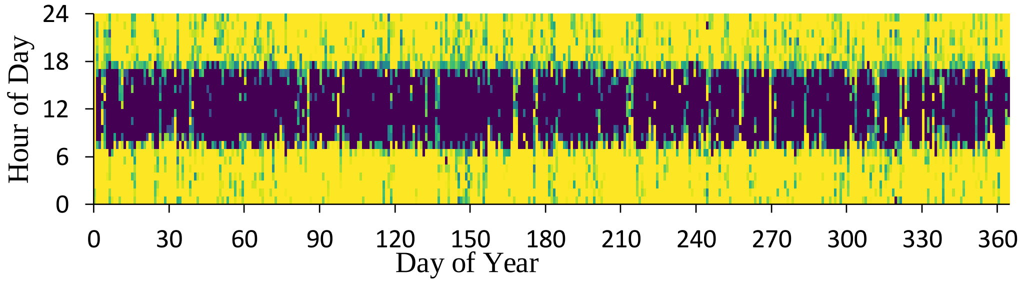


Fig. 5. Energy Contribution of Sources

The output power behavior of a hybrid combination of the 4.8kW PV with a 10kW diesel generator coupled with a 50kWh based on the days and hours is shown in Fig. 6 and reflects the more even distribution of power generation from the both sources and the expected power generation during daytime hours from PV while the consumption during night hours from diesel generation.



(a) The output power behavior of a 4.8 kW PV system



(b) The output power behavior of a 10kW diesel system

Fig. 6. The output behavior of (a) 4.8kW PV system (b) 10kW diesel system

As expected, the incorporation of the PV component of energy generation and the resulting increase in the renewable fraction will have a consequential decrease in CO_2 emissions. According to literature CO_2 and some other gasses are also produced during solar plates which in effect equals 50g of CO_2 per kWh which is almost 20 times less than a fuel-based generation (WRI, 2023). Table 7 shows the produce gasses associated with the diesel generation system.

Table 7. Pollutants emission associated with the Diesel system

Pollutants	Emissions (kg/yr)
Carbon Dioxide	43,744
Carbon Monoxide	273
Unburned Hydrocarbons	12
Particulate Matter	1.64
Sulfur Dioxide	107
Nitrogen Oxides	257

Conclusion

In this study two solar systems were studied with a grid, one is of 10kW and the other is of 4.8kW. The HOMER Pro software was used to design, simulate to optimize these systems (along with the diesel only base case) and it was found that a Solar (PV) - Diesel Hybrid system was the best option with the analyses suggesting that a 4.8 kW of the solar/diesel hybrid system for a 10kW average load as an optimized model because of the low NPC.

This can initiate the start of the reduction of the platform's carbon footprint, while still being competitive on the market. As technology develops, the utilization of fully-powered solar offshore rigs may become the norm as globally solar panels become more efficient and cheaper as compared to diesel in the long term.

Despite the low initial capital for the diesel generator, it is recommended to rely on a solar system that has more initial capital investment but has better long terms benefits and a high return rate per year. The stability of the solar system is unreliable because of the unpredictability of weather conditions and also it cannot generate electricity at night so the PV system requires a storage system that can meet load demand for a long period.

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References

Amole, A. O., Adeyeye, A. O., Akinyele, D. O., Makinde, K. A., & Oladipo, S. (2022). Journal of Renewable Energy and Environment. Techno-Environmental Analysis of Hybrid Energy System for Offshore Oil Rig Black Start. https://doi.org/10.30501/jree.2022.350408.1402

Azimoh, C. L., Klintenberg, P., Mbohwa, C., & Wallin, F. (2017). Replicability and scalability of mini-grid solution to rural electrification programs in Sub-Saharan Africa. Renewable Energy, 106, 222-231. https://doi.org/10.1016/j.renene.2017.01.017

Choi, Y., Lee, C., & Song, J. (2017). Review of Renewable Energy Technologies utilized in the oil and gas industry. International Journal of Renewable Energy Research, 7(2). https://doi.org/10.20508/ijrer.v7i2.5460.g7034

IEA. (2022). World energy outlook – topics, IEA. Available at: https://www.iea.org/topics/world-energy-outlook

IPIECA. (2013). Saving energy in the oil and Gas Industry (2013), Ipieca. Available at: https://www.ipieca.org/resources/saving-energy-in-the-oil-and-gas-industry-2013

Khan, M. J., & Iqbal, M. T. (2005). Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland. Renewable Energy, 30(6), 835-854. https://doi.org/10.1016/j.renene.2004.09.001

Macinnes, E. (2021) Geothermal energy, GeoExpro. Available at: https://geoexpro.com/geothermal-energy/

Nugroho, E. A., Suhanan, S., & Cahyono, R. B. (2022). Study on The Design of Solar-Wind Energy System to Reduce The Use of Gas Fuel in The Southeast Sumatra Block, 3(4), 730-743. https://doi.org/10.46799/jss.v3i4.371

Oliveira-Pinto, S., Rosa-Santos, P., & Taveira-Pinto, F. (2019). Electricity supply to offshore oil and gas platforms from Renewable Ocean Wave Energy: Overview and Case Study Analysis. Energy Conversion and Management, 186, 556-569. https://doi.org/10.1016/j.enconman.2019.02.050

Rahmat, M. B., Arfianto, A. Z., Santoso, T. B., Santoso, T., and Gunantara, N. (2020). Development of autopilot unmanned Smartboat vehicle (AUSV) based on fishing zone prediction map. Journal of Physics: Conference Series, 1595. https://doi.org/10.1088/1742-6596/1595/1/012036

Ritchie, H., Roser, M. & Rosado, P. (2020) CO_2 and greenhouse gas emissions, Our World in Data. Available at: https://ourworldindata.org/co2-and-greenhouse-gas-emissions

Rongsopa, R. (2011). Hybrid power generation for offshore wellhead platform: A starting point for offshore Green Energy. International Petroleum Technology Conference Paper Number: IPTC-14563-MS. https://doi.org/10.2523/iptc-14563-ms

Seedath, R. (2021). Sustainable Energy Development in SIDS: International Journal of Renewable Energy Research, 11(4). https://doi.org/10.20508/ijrer.v11i4

Seong, C. K., & Hong, T. Y. (1995). A review of offshore oil fields development in Malaysia. A Review Of Offshore Oil Fields Development In Malaysia. https://doi.org/10.2118/29307-ms

Swarnkar, N. M., Gidwani, L., & Sharma, R. (2016). An application of Homer Pro in optimization of hybrid energy system for electrification of Technical Institute. 2016 International Conference on Energy Efficient Technologies for Sustainability (ICEETS), p. 56-61. https://doi.org/10.1109/iceets.2016.7582899

Trinidad and Tobago Oil and Gas Upstream Market - Growth, Trends, COVID-19 Impact,and Forecasts (2022). (n.d.). http://surl.li/ijyls

Tiong, Y. K., Zahari, M. A., Wong, S. F., & Dol, S. S. (2015). The feasibility of wind and solar energy application for oil and gas offshore platform. IOP Conference Series: Materials Science and Engineering, 78. https://doi.org/10.1088/1757-899x/78/1/012042

Tawiah, S., Marfo, S. A., & Benah, D. (2016). Solar Power for Sustainable Offshore Petroleum Exploration and production in Africa. Research Gate. https://doi.org/10.2118/afrc-2588537-ms

UNDP (2011). Human Development Report 2011. http://surl.li/ijymk

World Resource Institute. (2023). http://surl.li/ijymp