# Performance Analysis of Solar-Wind-Diesel-Battery Hybrid Energy System for KLIA Sepang Station of Malaysia

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**ABSTRACT:** A large number of populations of the world live in rural or remote areas those are geographically isolated. Power supply and uninterrupted fuel transportation to produce electrical power for these remote areas poses a great challenge. Using renewable energy in hybrid energy system might be a pathway to solve this problem. Malaysia is a large hilly land with the gift of renewable energy resources. There is a good chance to utilize these renewable resources to produce electrical power and to limit the dependency on the fossil fuel as well as reduce the carbon emissions. In this perspective, a research is carried out to analyze the performance of a solar-wind-diesel-battery hybrid energy system for a remote area named "KLIA Sepang station" in the state of Selangor, Malaysia. In this study, a 56 kW hybrid energy system has been proposed that is capable to support more than 50 households and 6 shops in that area. Real time field data of solar radiation and wind speed is used for the simulation and optimization of operations using "Homer" renewable energy software. The proposed system can reduce $CO_2$ emission by about 16 tons per year compared to diesel generator only. In the same time the Cost of energy (COE) of the optimized system is USD 5.126 /kWh.The proposed hybrid energy system might be applicable for other parts of the world where the climate conditions are similar.

## 1. Introduction

Usage of renewable energy for electricity generation is a priority research topic now a day. Remarkable efforts to expand the energy sources and to intensify the deployment of renewable energy options have been increasing around the world. The first priority in intensifying renewable energy deployment in the 21st century is the combined effects of the depletion of fossil fuels and the awareness of environmental degradation[1]. Therefore, policy makers and researchers are paying more attention to research in this field. For an instance, European Union countries aim to get 20% of its energy from renewable sources by 2020[2]. Renewables include wind, solar, hydro-electric and tidal power as well as geothermal energy and biomass. More renewable energy will enable the EU to cut

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greenhouse emissions and make it less dependent on imported energy. Malaysia is blessed with abundant energy resources. It has the world's largest wind sources and the larger Global Solar radiation for its geographical position[3]. During the last two decades, electrical energy consumption in Malaysia increased significantly due to rapid economic development and the absence of energy conservation measures. It is expected that peak loads will reach 60 GW in 2023 which causes total investment may exceed $90 billion. Therefore, there is an urgent need to develop energy conservation policies for sustainable development[4]. Almost all its electricity is produced from the combustion of fossil fuels [5]neglecting the use of its renewable energy resources such as wind and solar to generate electricity. Apart from local conservation efforts, with increasing load demand and global warming, policy makers are looking at environment-friendly type of energy solutions to preserve the earth for the future generations. Wind and photovoltaic energy holds the most potential to meet our energy demands. As a result such power generation systems have been attracted greatly all over the world. However, increasing number of renewable energy sources requires new strategies for their operations in order to maintain or improve the power-supply stability, quality and reliability[6]. Malaysia is a country hilly area. Grid extension to populations living in such areas is costly and unfeasible. In such situations decentralized renewable energy based power generating options can provide feasible alternatives options. These alternatives may include hybrid power systems like wind-pv-diesel, wind-diesel, pv-diesel and others with or without battery backup option. In this research, a complete performance analysis of a solar-wind-diesel-battery hybrid energy system for the remote area of "KLIA Sepang station" in the state "Selangor" of Malaysia is proposed. Focus is given to system engineering, energy production, system stability and reliability using Homer renewable energy software and real time data. Therefore HOMER (Hybrid optimization Model for Electric Renewable), a software developed by National Renewable Energy Laboratory (NREL), USA for micro-power optimization model, has been used to find out the best energy efficient renewable based hybrid system options for the island. It contains a number of energy component models and evaluates suitable technology options based on cost and availability of resources [7]. To design the optimum system HOMER performs thousands of hourly simulations. HOMER also performs sensitivity analysis to see the impact of solar isolation, PV investment cost, and wind speed and diesel fuel price on the COE [8].

## 2. Data resource and location analysis:

We have got daily solar radiation data for each month of the year 2009 from the Malaysian meteorological department. An estimation of solar insulation on horizontal surface has been done by using well known Angstrom Correlation and the sunshine hour data of Klia Sepang Station, Malaysian Meteorological Department, the nearest meteorological station from Selangor, Malaysia [9]. Also a method has been developed by DLR, Germany which is a combination of DLR / SUNY –model output for Global Horizontal Insulation (GHI) is sampled for 16.3 km spatial resolution, and the calculated data has been collected from the Malaysian Meteorological Department for Malaysia [10]. Figure 1 shows the schematic diagram of hybrid energy system. Seven tidal gauge stations were set up by Malaysian Meteorological department and Malaysian Renewable Energy Committee for the feasibility study of tidal energy [9]. But the result was not in favour. So, only the solar, wind source and average temperature data have been considered to find out the best hybrid options of renewable based efficient system. Figure 1 shows the schematic diagram of hybrid energy system.

**Table 1.** Yearly wind Power density and wind energy density:

| Station | Year | Meteorological | | Weibull | | $V_{mp}$ | $V_{max,E}$ |
|---|---|---|---|---|---|---|---|
| | | P/A | E/A | P/A | E/A | | |
| Klia | 2008 | 20.36 | 175.91 | 20.63 | 178.24 | 1.43 | 4.40 |
| Sepang | 2009 | 17.73 | 153.19 | 18.16 | 156.90 | 0.72 | 4.55 |

In the table 1 the parameters have been used as follows P/A as wind Power density, E/A as wind Energy density, $V_{mp}$ as most probable wind speed and $V_{max,E}$ as maximum energy carrying by the wind speed.

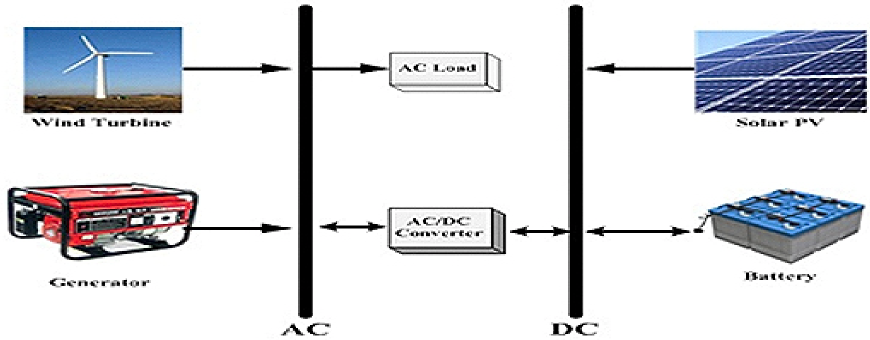



**Figure 1.** Schematic diagram of hybrid energy system.

Table 1 show the meteorological data of klia sepang station in the year 2008 and 2009 and also defined the Weibull values with power density and energy density.

## 3. Hybrid Energy System Components

### *3.1. Solar Energy (Photovoltaic)*

As hourly data is available as monthly averaged global radiation data has been taken from Malaysian Meteorological Department [11]. HOMER introduces clearness index from the latitude and longitude information of the selected site. HOMER creates the synthesized 8760 hourly values for a year using the Graham algorithm. Figure 5 illustrates that the solar radiation is high in February, March, April, august, September and October. The cost of PV module including installation has been considered as USD 250 /W for Malaysia. Life time of the modules has been taken as 20 years.5 kW, 18 kW and 30 kW PV modules are considered. The parameters considered for the simulation solar PV are furnished in table 2. Figure 2 shows global horizontal radiation data for KLIA Sepang station of Malaysia.

**Table 2.** Solar PV array-technical Parameters and Cost assumption

| Parameter | Value |
|---|---|
| **Capital Cost** | 250 $/W |
| **Replacement Cost** | 200 $/W |
| **Operation and Maintenance Cost** | 20 $/W |
| **Lifetime** | 20 Years |
| **Derating factor** | 80 % |
| **Tracking System** | No Tracking System |

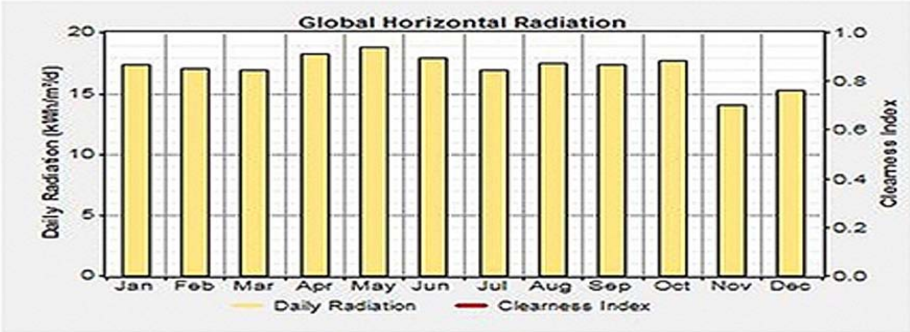



**Figure 2.** Global Horizontal Radiation for KLIA Sepang Station (2009), Malaysia.

*3.2. Wind Energy (Wind Turbines)*

When hourly data is not available, hourly data can be generated synthetically from the monthly averages. HOMER's synthetic wind speed data generator is a little more different to use than the solar data because it requires four parameters [12]. Technical and economic parameters for selected wind turbine are furnished in table 3. Figure 3 shows average Wind speed of every month in 2009 of Klia Sepang station of Malaysia. The Weibull value: k value is a measure of distribution of wind speed over the year of 2009 for KLIA Sepang Station. It is important for the average wind speed in a year span. In this study the value of k is taken as 2.

**Table 3.** Technical and economic parameters of wind turbine.

| Parameter | Value |
|---|---|
| **Rated Power** | 10 kW |
| **Starting Wind Speed** | 2.860 m/s |
| **Rated Wind Speed** | 2.04 m/s |
| **Cut-off Wind Speed** | 2.010 m/s |
| **Capital Cost** | 150 $/kW |
| **Replacement Cost** | 120 $/kW |
| **Operation and Maintenance Cost** | 1 $/kW |
| **Lifetime** | 15 years |

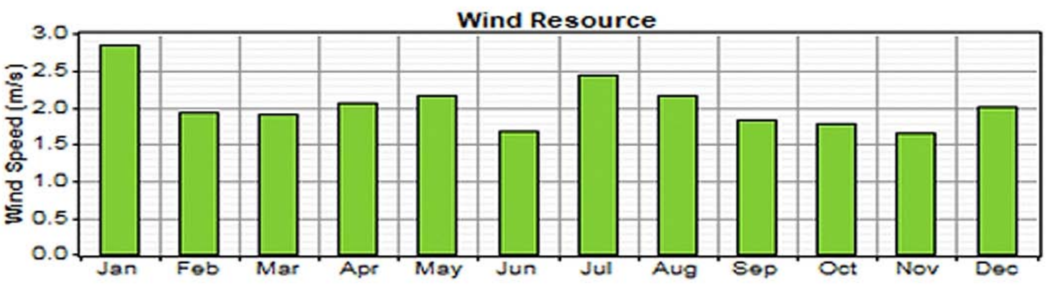



**Figure 3.** Average Wind speed of every month in 2009 of KLIA Sepang station of Malaysia.

## 4. Simulation, Optimization results and discussion

Figure 4 shows the energy yield for the feasible hybrid PV-diesel-wind-battery system. Figure 6 shows the details calculation and cost analysis related to energy generated by PV, wind turbine and diesel generator system. Figure 5 shows the optimization and simulation results for PV-diesel-wind turbine-battery system for a solar radiation of 6.09 kWh/m2/d, diesel price of 1$/L, maximum capacity shortage of 0 %.( All the currency values were in terms of USD). The optimization results for specific wind speed 2.04 m/s, solar irradiation parameters 6.09 kWh/m2/d and diesel price 1 USD are illustrated in Figure 6. It is seen that a PV, wind turbine, diesel generator and battery hybrid system is economically more feasible with a minimum COE of USD 5.126/kWh and a minimum NPC of 786,822 USD. The hybrid system comprised of 18 kW PV array, two wind turbines (10 kW each), a diesel generator with a rated power of 15 kW (using 3kW) and 25 storage batteries in addition to 3 kW converters is found to be the most feasible system.

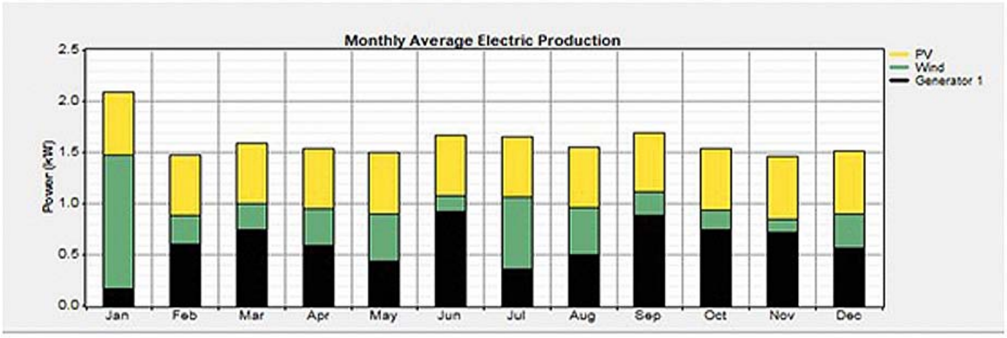
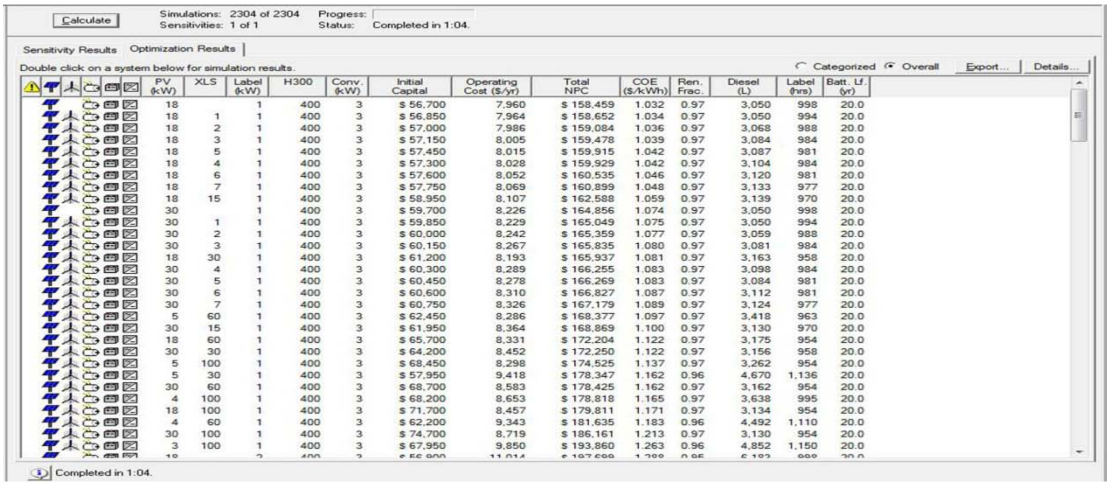
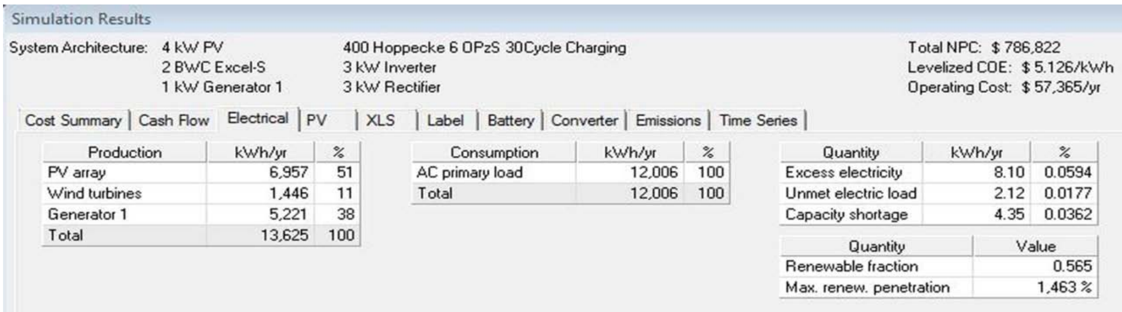



**Figure 4.** Energy yield for the feasible hybrid PV-diesel-wind-battery system.




| PV (kW) | XLS | Label (kW) | H300 | Conv. (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Diesel (L) | Label (hrs) | Batt. Lf. (yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | | 1 | 400 | 3 | $ 56,700 | 7,960 | $ 158,459 | 1.032 | 0.97 | 3,050 | 998 | 20.0 |
| 18 | 1 | 1 | 400 | 3 | $ 56,850 | 7,964 | $ 158,652 | 1.034 | 0.97 | 3,050 | 994 | 20.0 |
| 18 | 2 | 1 | 400 | 3 | $ 57,000 | 7,986 | $ 159,084 | 1.036 | 0.97 | 3,068 | 988 | 20.0 |
| 18 | 3 | 1 | 400 | 3 | $ 57,150 | 8,005 | $ 159,478 | 1.039 | 0.97 | 3,084 | 984 | 20.0 |
| 18 | 5 | 1 | 400 | 3 | $ 57,450 | 8,015 | $ 159,915 | 1.042 | 0.97 | 3,087 | 981 | 20.0 |
| 18 | 4 | 1 | 400 | 3 | $ 57,300 | 8,028 | $ 159,929 | 1.042 | 0.97 | 3,104 | 984 | 20.0 |
| 18 | 6 | 1 | 400 | 3 | $ 57,600 | 8,052 | $ 160,535 | 1.046 | 0.97 | 3,120 | 981 | 20.0 |
| 18 | 7 | 1 | 400 | 3 | $ 57,750 | 8,069 | $ 160,899 | 1.048 | 0.97 | 3,133 | 977 | 20.0 |
| 18 | 15 | 1 | 400 | 3 | $ 58,950 | 8,107 | $ 162,588 | 1.059 | 0.97 | 3,139 | 970 | 20.0 |
| 30 | | 1 | 400 | 3 | $ 59,700 | 8,226 | $ 164,856 | 1.074 | 0.97 | 3,050 | 998 | 20.0 |
| 30 | 1 | 1 | 400 | 3 | $ 59,850 | 8,229 | $ 165,049 | 1.075 | 0.97 | 3,050 | 994 | 20.0 |
| 30 | 2 | 1 | 400 | 3 | $ 60,000 | 8,242 | $ 165,359 | 1.077 | 0.97 | 3,059 | 988 | 20.0 |
| 30 | 3 | 1 | 400 | 3 | $ 60,150 | 8,267 | $ 165,835 | 1.080 | 0.97 | 3,081 | 984 | 20.0 |
| 18 | 30 | 1 | 400 | 3 | $ 61,200 | 8,193 | $ 165,937 | 1.081 | 0.97 | 3,163 | 958 | 20.0 |
| 30 | 4 | 1 | 400 | 3 | $ 60,300 | 8,289 | $ 166,255 | 1.083 | 0.97 | 3,098 | 984 | 20.0 |
| 30 | 5 | 1 | 400 | 3 | $ 60,450 | 8,278 | $ 166,269 | 1.083 | 0.97 | 3,084 | 981 | 20.0 |
| 30 | 6 | 1 | 400 | 3 | $ 60,600 | 8,310 | $ 166,827 | 1.087 | 0.97 | 3,112 | 981 | 20.0 |
| 30 | 7 | 1 | 400 | 3 | $ 60,750 | 8,326 | $ 167,179 | 1.089 | 0.97 | 3,124 | 977 | 20.0 |
| 5 | 60 | 1 | 400 | 3 | $ 62,450 | 8,286 | $ 168,377 | 1.097 | 0.97 | 3,418 | 963 | 20.0 |
| 30 | 15 | 1 | 400 | 3 | $ 61,950 | 8,364 | $ 168,869 | 1.100 | 0.97 | 3,130 | 970 | 20.0 |
| 18 | 60 | 1 | 400 | 3 | $ 65,700 | 8,331 | $ 172,204 | 1.122 | 0.97 | 3,175 | 954 | 20.0 |
| 30 | 30 | 1 | 400 | 3 | $ 64,200 | 8,452 | $ 172,250 | 1.122 | 0.97 | 3,156 | 958 | 20.0 |
| 5 | 100 | 1 | 400 | 3 | $ 68,450 | 8,298 | $ 174,525 | 1.137 | 0.97 | 3,262 | 954 | 20.0 |
| 5 | 30 | 1 | 400 | 3 | $ 57,950 | 9,418 | $ 178,347 | 1.162 | 0.96 | 4,670 | 1,136 | 20.0 |
| 30 | 60 | 1 | 400 | 3 | $ 68,700 | 8,583 | $ 178,425 | 1.162 | 0.97 | 3,162 | 954 | 20.0 |
| 4 | 100 | 1 | 400 | 3 | $ 68,200 | 8,653 | $ 178,818 | 1.165 | 0.97 | 3,638 | 995 | 20.0 |
| 18 | 100 | 1 | 400 | 3 | $ 71,700 | 8,457 | $ 179,811 | 1.171 | 0.97 | 3,134 | 954 | 20.0 |
| 4 | 60 | 1 | 400 | 3 | $ 62,200 | 9,343 | $ 181,635 | 1.183 | 0.96 | 4,492 | 1,110 | 20.0 |
| 30 | 100 | 1 | 400 | 3 | $ 74,700 | 8,719 | $ 186,161 | 1.213 | 0.97 | 3,130 | 954 | 20.0 |
| 3 | 100 | 1 | 400 | 3 | $ 67,950 | 9,850 | $ 193,860 | 1.263 | 0.96 | 4,852 | 1,150 | 20.0 |

**Figure 5.** Optimization results for PV-diesel-wind turbine-battery system.




| Production | kWh/yr | % |
|---|---|---|
| PV array | 6,957 | 51 |
| Wind turbines | 1,446 | 11 |
| Generator 1 | 5,221 | 38 |
| Total | 13,625 | 100 |

| Consumption | kWh/yr | % |
|---|---|---|
| AC primary load | 12,006 | 100 |
| Total | 12,006 | 100 |

| Quantity | kWh/yr | % |
|---|---|---|
| Excess electricity | 8.10 | 0.0594 |
| Unmet electric load | 2.12 | 0.0177 |
| Capacity shortage | 4.35 | 0.0362 |

| Quantity | Value |
|---|---|
| Renewable fraction | 0.565 |
| Max. renew. penetration | 1,463 % |

**Figure 6.** Energy generated by PV, wind turbine and diesel generator system, excess electricity, un-metload, capacity shortage and renewable fraction.

## 5. Conclusion

The study simulates a PV-wind –diesel-battery hybrid energy system in KLIA Sepang Station of Malaysia. The optimized hybrid energy system was developed considering manufacturing cost and efficiency. The result shows that the COE of the optimized system is USD 5.126 /kWh and the NPC of the optimized system is USD 786,822. The total sensitivity analysis, optimization and simulation process has been conducted through HOMER renewable energy software. This system gives better performance than the other system because if any fault occur in PV panel or in wind turbines then the generator can minimize this problem and also we tried to reduce the cost of power generation from the in general hybrid energy systems. In the near future we will try to introduce some more convenient renewable energy model and proper control system for the hybrid energy system for the different area of the world.

## 6. Acknowledgments

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## 7. References

[1] Chen, H.H., H.-Y. Kang, and A.H. Lee, *Strategic selection of suitable projects for hybrid solar-wind power generation systems.* Renewable and Sustainable Energy Reviews, 2010. **14**(1): p. 413-421.
[2] Ringel, M., *Fostering the use of renewable energies in the European Union: the race between feed-in tariffs and green certificates.* Renewable energy, 2006. **31**(1): p. 1-17.
[3] Solangi, K., et al., *A review on global solar energy policy.* Renewable and Sustainable Energy Reviews, 2011. **15**(4): p. 2149-2163.
[4] Al-Ajlan, S., et al., *Developing sustainable energy policies for electrical energy conservation in Saudi Arabia.* Energy Policy, 2006. **34**(13): p. 1556-1565.
[5] Alyousef, Y. and P. Stevens, *The cost of domestic energy prices to Saudi Arabia.* Energy Policy, 2011. **39**(11): p. 6900-6905.
[6] Marisarla, C. and K.R. Kumar, *A Hybrid Wind and Solar Energy System with Battery Energy Storage for an Isolated System.* IJEIT, 2013. **3**(3): p. 99-104
[7] Rehman, S., et al., *Feasibility study of hybrid retrofits to an isolated off-grid diesel power plant.* Renewable and Sustainable Energy Reviews, 2007. **11**(4): p. 635-653.
[8] Shaahid, S. and I. El-Amin, *Techno-economic evaluation of off-grid hybrid photovoltaic–diesel–battery power systems for rural electrification in Saudi Arabia—a way forward for sustainable development.* Renewable and Sustainable Energy Reviews, 2009. **13**(3): p. 625-633.
[9] Lee, S. and B. Pradhan, *Landslide hazard mapping at Selangor, Malaysia using frequency ratio and logistic regression models.* Landslides, 2007. **4**(1): p. 33-41.
[10] Shen, W., *Optimally sizing of solar array and battery in a standalone photovoltaic system in Malaysia.* Renewable energy, 2009. **34**(1): p. 348-352.
[11] Zulkifli, N., et al. *Probabilistic analysis of solar photovoltaic output based on historical data*. in *Power Engineering and Optimization Conference (PEOCO), 2014 IEEE 8th International*. 2014. IEEE.
[12] Kaygusuz, K. and A. Sarı, *Renewable energy potential and utilization in Turkey.* Energy Conversion and Management, 2003. **44**(3): p. 459-478.