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Economic Analysis of Hybrid Renewable Model for Subtropical Climate

GM Shafiullah*[,a], Amanullah M.T. Oo[a], ABM Shawkat Ali[b], Dennis Jarvis[b], Peter Wolfs[c]

[a] Faculty of Sciences, Engineering & Health, CQ University, Australia, QLD-4702
[b] Faculty of Arts, Business, Informatics & Education, CQ University, Australia, QLD-4702
[c] Faculty of Science and Engineering, Curtin University of Technology, Australia, WA-6845

Abstract

Current power systems create environmental impacts due to utilization of fossil fuels, especially coal, as carbon dioxide is emitted into the atmosphere. In contrast to fossil fuels, renewable energy offers alternative sources of energy which are in general pollution free, technologically effective and environmentally sustainable. There is an increased interest in renewable energy, particularly solar and wind energy, which provides electricity without giving rise to carbon dioxide emissions. This paper presents economic analysis of a renewable hybrid system for a subtropical climate and also investigated the impact of renewable energy sources to the existing and future smart power system. The daily mean global solar irradiance and three hourly mean wind speed have been collected from the Rockhampton Aero Weather Station, Queensland (RAWS), Australia for this study. Hybrid Optimization Model for Electric Renewable (HOMER), a computer model developed by National Renewable Energy Laboratory (NREL) has been used to perform comparative analysis of solar and wind energy with diesel and hybrid systems. Initially total net present cost (NPC), cost of energy (COE) and the renewable fraction (RF) have been measured as performances metrics to compare the performances of different systems. For better optimization, the model has been refined with sensitivity analysis which explores performance variations due to wind speed, solar irradiation and diesel fuel prices. From the simulation, it is shown that there are a number of factors that impact the integration and performance of renewable energy sources to the power systems.

Keywords: *Renewable Energy, Smart Grid, HOMER, Performances Metrics, Sensitivity Analysis.*

1. Introduction

A recent issue of increasing public focus is the need for robust, sustainable and climate friendly power transmission and distribution systems that are intelligent, reliable and green. Current power systems create environmental impacts as well as global warming due to utilization of fossil fuels, especially coal, as carbon dioxide is emitted into the atmosphere. Renewable energy is starting to be used as the panacea for solving the climate change or global warming problems. However, the existing power systems will be unable to integrate renewable energy sources as the systems were not developed for such integration. The lack of smart technology to provide utilities and consumers with better information in real time damages the security and efficiency of the entire electricity system. A modern smart power grid will bring benefits through seamless integration of renewable energy sources to the grid.

There are a number of challenges in integrating renewable energy sources with the existing power systems. Substantial research, planning and development are required for increased integration of renewable energy sources with the current power transmission and distribution network. Therefore at the beginning of the 21st Century, the Governments, the utility companies and the research communities are working together to develop an intelligent grid system, now commonly known as the Smart Grid that reduces overall greenhouse gas emissions with demand management and encourages energy efficiency, improves reliability, and manages power more efficiently and effectively [1-3].

The Center for American Progress provides a concept called a clean-electricity or clean energy "pipeline" which produces large scale renewable electricity; deliver electricity nationwide on a new high capacity grid; manages all power generation and distribution with new sophisticated information technology methods; allows consumers to contribute energy to the grid [2]. In April 2003, the Department of Energy (DOE), USA declared its 'Grid 2030' mission, the vision of which was: *Grid 2030*

* Corresponding author. Tel.: +61749309313
E-mail: g.shafiullah@cqu.edu.au

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energizes a competitive North American Market place for electricity. It connects everyone to abundant, affordable, clean, efficient and reliable electric power anytime, anywhere. It provides the best and most secure electric services available in the world [4]. To fulfill this vision, Electrical Power Research Institute's (EPRI's) has undertaken an Intelligrid^{SM} initiative to develop the technical foundation for a smart power grid that links electricity systems with communication and computer technology to achieve tremendous gains in reliability and customer services [5]. Figure 1 shows a schematic diagram of EPRI's Intelligrid model.

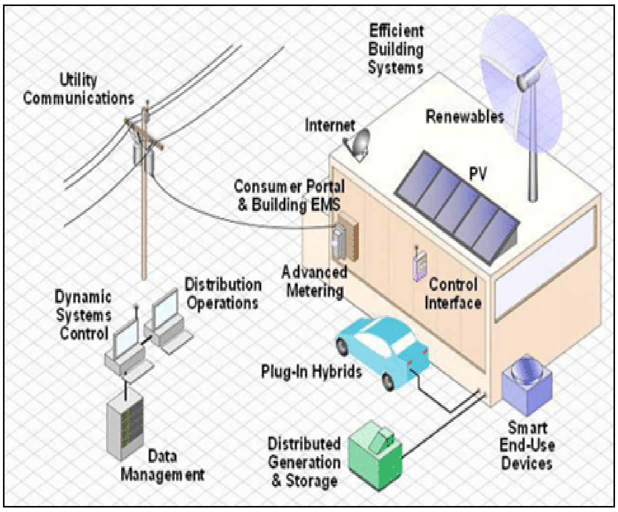


Figure 1: A typical scenario of EPRI's Intelligrid Model [5]

To meet the challenges in their existing power systems, the European Union establishes the SmartGrids European Technology Platform in 2005. The SmartGrids European Technology Platform [6] vision is that Europe's electricity network must be flexible (fulfilling customer needs); accessible (access to all network users, particularly for renewable energy sources and high efficiency local generation with low carbon emission); reliable (assuring security and quality of supply); and economic (cost and energy efficient management).

However, country like Australia, due to its availability of coal to produce cheap energy, is lack behind compared to USA and Europe in attempts to integrate renewable energy sources and building smart grid infrastructure. Australia's reliance on coal-fired power gives it one of the world's highest per-capita greenhouse gas emission rates [1-3, 7]. Therefore, it is necessary to reinvigorate the Australian economy by building new generation, transmission and distribution systems for efficient use of low-carbon electricity. In Australia, the Intelligent Grid Program [8] was launched on 19 August 2008 being established under the CSIRO's Energy Transformed Flagship, and focuses on the national need to reduce greenhouse gas emissions [1]. The Townsville Solar City Project administrated by the Australian Government and Ergon Energy (A local Queensland based distribution utility organization) has conducted 742 residential and commercial assessments, and installed 1445 smart meters, 160kW of solar panels and eight advanced energy storage systems. Ergon Energy is also working on analyzing the impacts of high photovoltaic's (PV) penetration on the grid. Western Power's (a local Western Australia based transmission and distribution utility organization) Solar City program includes a PV saturation trial to test the impact of distributed generation on the network. The Solar cities program has helped many distributors to understand the impact of inverter connected renewable distributed generation (DG). This analysis included smart meters that collect bi-directional data to capture how much power the distributed generator is feeding back to the grid [1, 9].

Wind generation is one of the fastest growing and cost effective resources among different renewable energy sources. Solar energy is the most promising renewable energy source which is free from green house gas emission that encourages interest worldwide. Small scale photovoltaic technology is cost-effective in providing electricity in rural or remote areas, in particular country like Australia [10].

In addition to solar and wind, bio-gas and geothermal are also useful renewable energy sources that can play a key role in reducing carbon emissions [9]. As the penetration [11] of renewable energy continues to increase, it is time to rethink to develop a sustainable, green power system which is capable to integrate the various renewable energy sources. Fortunately an operational smart grid has the potential to mitigate some of the difficulties encountered by renewable energy generation. Renewable energy sources such as wind or solar are weather-driven, and therefore non-scheduled as these sources depend on wind flow or solar activity respectively. The use of smarter grid operations allows for greater penetration of variable energy sources through more flexible management of the system. Integration studies are continuing to improve performance, though there are still a few existing challenges [12-13].

Zoulias and Lymberopoulos [14] investigated a techno-economic analysis of the integration of hydrogen energy technologies in renewable energy-based stand-alone power systems using HOMER simulation tool. The experimental result shows that the replacement of fossil fuel based gensets with hydrogen technologies is technically feasible and economically favorable compared to the PV-diesel system as long as a 50% reduction on the cost of electrolysers and a 40% reduction on the cost of hydrogen tanks are made.

Kaiser and Aditya [15] developed a model using HOMER simulation tool to find out the best technically viable renewable based energy system for the consumers located in Saint Martin Island, Bangladesh. Experimental results showed that it will be better to create PV-wind minigrid combination system for 50 homes instead of single home system.

Setiawan et al. [16] presented a design scenario for supplying electricity and fulfill clean water demand in remote areas by utilizing renewable energy sources and a diesel generator with a reverse osmosis desalination plant as a deferrable load. HOMER has been used to find the optimum configuration for a hybrid power system. It has shown that this hybrid power system is more efficient compared to stand-alone system both economically and environmentally.

This paper investigates the impacts and integration of renewable energy sources with power system, analyzing the benefits and outcomes for a typical Australian power network. In particular a hybrid renewable energy model has been developed to investigate the necessity of solar and wind power considering pollution, production cost and cost of energy. This paper is organized as follows: Section II discusses the evaluation of the model. Section III presents experimental setup to build a hybrid renewable energy system. Results and discussions are described in Section IV. Section V concludes the article with future directions.

2. Model Evaluation

A renewable energy hybrid model has been developed using HOMER to explore the impacts of renewable energy sources on the modern power grid. This section presented necessary data collection procedure and the simulation software used in this study to develop the hybrid model with the measured performance metrics.

2.1. Data Collection

Data have been collected from the Australia Bureau of Meteorology [17] for the location of Rockhampton and position of the RAWS (-23.3753^0, 150.4775^0, 10.4m). Daily mean solar radiation data and three hourly mean wind speed data have been collected from the year of 2007 as shown in Tables 1 and 2 respectively as a sample data. Data have been collected using a real time automatic system which performs quality checking.

Table 1: Weekly Solar Radiation

Day	Radiation (kWh/m^2/day)
Day 1	6.400000
Day 2	5.838889
Day 3	7.377778
Day 4	6.872222
Day 5	8.366667
Day 6	6.036111
Day 7	8.372222

Table2: Daily Wind Speed

Hour/Time	Speed(m/s)
00:00	2.758133
03:00	6.639949
06:00	5.720571
09:00	10.47069
12:00	8.478704
15:00	9.398081
18:00	5.720571
21:00	6.639949

2.2. Simulation Software

HOMER version 2.68 [18] has been used in this study to investigate the feasibility and cost analysis comparisons of various renewable energy sources. HOMER models a power system's physical behaviour and its life-cycle cost which allows the modeller to compare many design options based on their technical and economical merits. It can evaluate design options both for off-grid and grid-connected power systems for remote, stand-alone and distributed generation applications. Inputs to HOMER contain load data, renewable source data such as photovoltaic, wind turbines, system component specifications and costs, and various information regarding optimisation. It simulates thousands of system configurations, optimises for lifecycle cost and generates results of sensitivity analyses on most of the inputs. It repeats the optimisation process for each value of the input, so it is possible to examine the effects of changes in the value on the results [18-20].

In this paper NPC, RF and COE have been considered as performance metrics to evaluate and compare the performances of different systems. The total NPC of a system is the present value of all the costs that it incurs over its lifetime, minus the present value of all the revenue that it earns over its lifetime. Costs include capital costs, replacement costs, Operation and Maintenance (O&M) costs, fuel costs, emissions penalties, and the costs of buying power from the grid. Revenues include salvage value and grid sales revenue [17-19].

On the other hand COE is the average cost per KWh of electricity. To calculate the COE, HOMER divides the annualised cost of producing electricity (the total annualised cost minus the cost of serving the thermal load) by the total useful electric energy production. The NPC is a more trustworthy number than the COE therefore in this analysis NPC has counted as the primary metrics [17-18].

The RF is the portion of the system's total energy production originating from renewable power sources. HOMER calculates the RF by dividing the total annual renewable power production (the energy produced by the PV array, wind turbines, hydro turbine, and biogas-fuelled generators) by the total energy production [17 – 18].

3. Hybrid Renewable Energy System

To investigate the strategic impacts of renewable energy in the smart power system in this paper, a model has been developed and simulate with HOMER to identify the operational characteristics of different renewable energy sources with the existing power grid. This paper also calculates the cost of different hybrid systems and compares their performances based on performance metrics such as NPC, RF and COE. Simulation, optimisation and cost analysis of the models have been performed and final recommendation has been made. In this study solar and wind energy have been integrated with a grid-connected system and designed a PV/wind/grid-connected hybrid system. This hybrid system consists of an electric load, renewable energy sources (solar and wind) and other system components such as, PV, wind turbines, converter, grid.

3.1. Electric Load

A typical load profile was considered for this analysis based on Australian average monthly load demands. Daily load demand is illustrated in Figure 2 in which the 13:00 to 16:00 time period has been observed as peak demand. The electric load has a seasonal variation in December, January and February as peak months during summer while March to June requires fewer loads during winter which is shown in Figure 3. The annual average of the electric load is 200 kWh/day and the annual peak load is 27 kW of the data collected for this study.

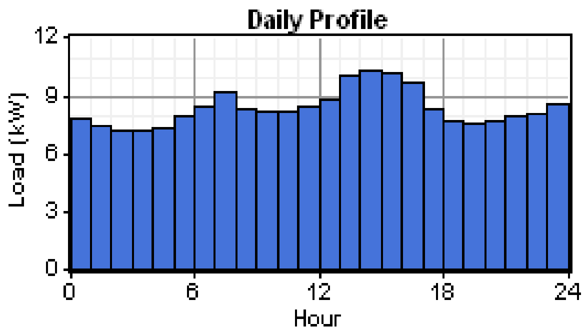
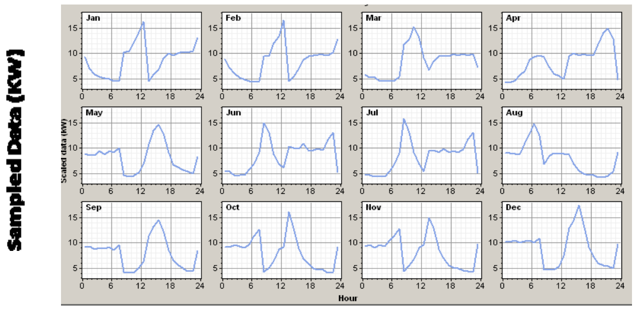


Figure 2: Daily load profile



Hour

Figure 3: Monthly load variations

3.2. Renewable Energy Sources

3.2.1. Solar Energy

Daily solar radiation data were imported into HOMER to calculate daily radiation and monthly average values of clearness index. Figure 4 illustrates that solar radiation is high between October to December. The average annual clearness index is 0.568 and the average daily radiation is 5.68. Figure 4 demonstrates the daily radiation in kWh/m^2 per day and the clearness index curve over the whole year. Considering the radiation variation, the sensitivity analysis is done with four values around the mean radiation.

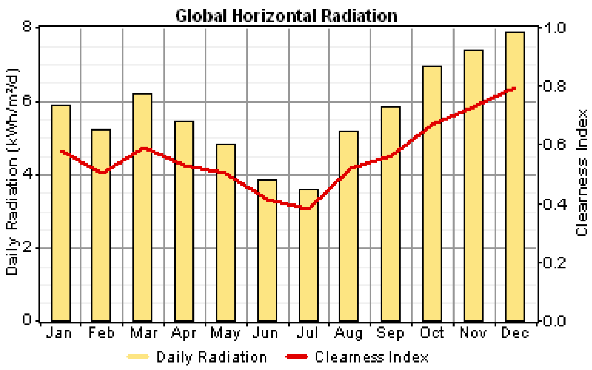


Figure 4: Daily solar radiation with clearness index

3.2.2. Wind Energy

Three hourly wind speed data (m/s) were imported into HOMER to synthesised based on weibull factor *k=1.74,* auto correlation factor=*0.901,* diurnal pattern strength=*0.0271,* and hour of peak wind speed=*22.* Figure 5 shows the monthly wind speed between 4.557 and 7.427 m/s. Wind speed also varies with seasonal condition similar to solar radiation. From Figure 5 it has seen that there is a deficiency of wind speeds from June to August, and higher speeds from October to March.

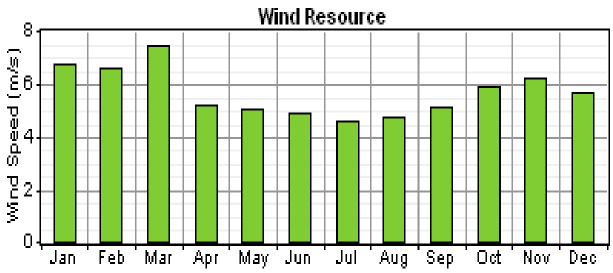


Figure 5: Monthly wind speed variations

3.3. Hybrid System Components

The major components of the grid-connected hybrid system are PV panels, wind turbines, and a power converter. For economic analysis, the number of units to be used, capital costs, replacement and O&M costs, and operating hours have to be defined in HOMER in order to simulate the system.

3.3.1. Photovoltaic

The initial installation cost of photovoltaic arrays may vary from $4.00 to $5.00 per watt [21]. For an optimum solution, the installation cost for a 1.0 kW stand-alone PV array is assumed $4500 and O&M cost is considered to be practically zero. Sizes of the photovoltaic arrays are varied 1 to 4 kW.

3.3.2. Wind Turbine

For this study BWC Excel-R 7.5 kW DC wind turbine has been used which is manufactured by Bergey Windpower [22]. The installation, capital and O&M cost of this turbine is respectively $17500, $15000 and zero.

3.3.3. Power Converter

A converter is required to convert AC-DC or DC-AC. The installation costs for a 1.0kW converter is $800, replacement cost is $700 and O&M cost is considered practically zero.

3.3.4. Grid

This proposed system is a grid-connected system in which the Grid acts as a backup power component. The grid is activated and supplies electricity when there is not enough renewable energy power to meet the load [23].

4. Results and Discussions

To evaluate the performances of different hybrid systems in this study, optimal systems' performance and the sensitivity analysis have been measured using HOMER simulation tools. To identify an optimal hybrid system, the PV/wind/grid-connected system may be varied assuming the electricity fixed at 0.3$/kWh. Figure 6 shows the proposed hybrid system developed with HOMER.

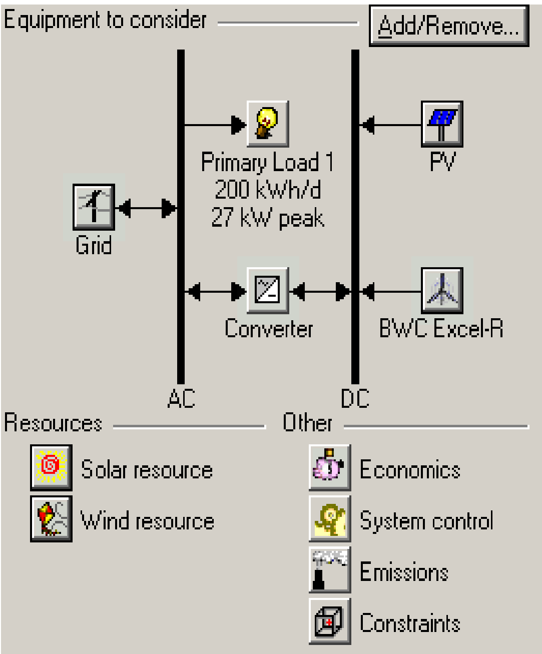


Figure 6: Hybrid renewable energy system with HOMER

4.1. Optimization Results

Simulations have been conducted considering different values for solar radiation, wind speed and power providing more flexibility in the experiments. The optimisation results for specific wind speed (5.67m/s), solar irradiation (5.68 kWh/m^2 per day), and grid electricity price (0.3$/kWh) are illustrated in Figure 7. It is seen that, a wind based power system is economically more feasible with a minimum total NPC of $ 212456 and a minimum COE of $0.228/kWh than the PV-wind system; however the economic performance of a PV-wind system is almost similar to the wind only system. This difference is due to the abundance of the wind energy resource and the cost of a wind turbine generator being less than the solar array modules. This wind and PV-wind system represents greater RF (0.64) which means that a bigger proportion of renewable energy is generated.

The best optimum NPC ($174,340), COE (0.187) and RF (0.93) have achieved from the wind speed (8.0 m/s), solar irradiation (3.68 kWh/m^2 per day), and grid electricity price (0.4$/kWh) shown in Figure 8. However, in this case electricity price is more than usual. Therefore, it is required to conduct further studies with more and useful data. From Figure 7 and 8 it has been observed that a PV-wind system or wind only system is more economical compared to the standard grid system.

Sensitivity variables

Global Solar (kWh/m²/d) 5.68 Wind Speed (m/s) 5.67 Rate 1 Power Price ($/kWh) 0.3

Double clic[Solar Data Scaled Average]ation results.

PV (kW)	XLR	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
	3	16	1000	$ 65,300	11,519	$ 212,546	0.228	0.64
1	3	16	1000	$ 69,300	11,399	$ 215,022	0.230	0.64
			1000	$ 0	21,900	$ 279,956	0.300	0.00
1		1	1000	$ 4,800	21,742	$ 282,731	0.303	0.01

Figure 7: Optimization results with wind speed (5.67m/s), solar irradiation (5.68 kWh/m^2 per day), and grid electricity price (0.3$/kWh)

Sensitivity variables

Global Solar (kWh/m²/d) 3.68 Wind Speed (m/s) 8 Rate 1 Power Price ($/kWh) 0.4

Double click on a system below for simulation results.

PV (kW)	XLR	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
	6	40	1000	$ 137,000	2,644	$ 170,800	0.183	0.93
1	6	40	1000	$ 141,000	2,608	$ 174,340	0.187	0.93
			1000	$ 0	29,200	$ 373,275	0.400	0.00
1		1	1000	$ 4,800	29,061	$ 376,299	0.403	0.01

Figure 8: Best optimum results with wind speed (3.68m/s), solar irradiation (8.0 kWh/m^2 per day), and grid electricity price (0.4$/kWh)

The cash flow summary in Figure 9 shows that in the optimised PV-wind system most of the cost is required for the grid component while the least cost is for the PV. Therefore it can be stated that most of the cost is due to grid component and converters while renewable energy sources requires less expenditure which is one of their most useful features.

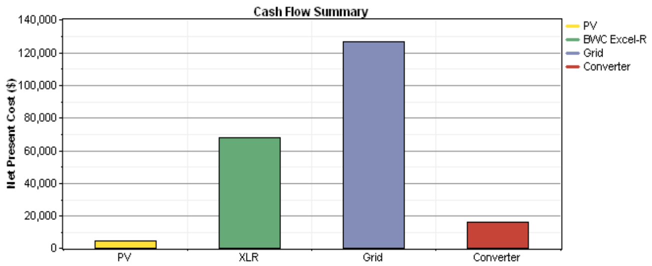


Figure 9: Cash flow summary

Figure 10 shows that in the optimised wind-PV-grid system most of the capital cost is required for the wind turbine and PV module. However, most of the operating cost is due to grid component and converters while renewable energy sources require less expenditure.

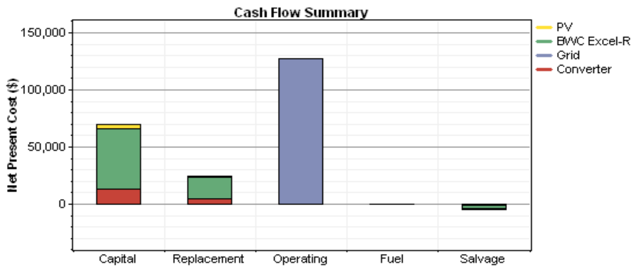


Figure 10: Net present cost of the hybrid renewable system

The monthly average electric energy production is represented in Figure 11. The wind turbine produces 63,795 kWh/year and the grid produces 35,850 kWh/year. In this system the wind turbine contributed 64% and the PV array contributed only 1% of the total energy production. Further analysis need to be undertaken to increase the contribution of PV array modules.

4.2. Sensitivity Results

Sensitivity analysis is a measure that checks the sensitivity of a model when changing the value of the parameters of the model and also changing the structure of the model. This analysis is useful in support decision making or the development of recommendations from the model. In this paper sensitivity analysis has been undertaken to study the effects of variation in the solar radiation and wind speed, and to make appropriate recommendations in developing a hybrid renewable energy system. The simulation software simulates the long-term implementation of the hybrid system based on respective search sizes for the predefined sensitivity values of the components. The model has been simulated based on the three sensitivity variables: wind speed, solar irradiation and grid electricity price and different NPC, COE and RF values have been observed as model outputs.

HOMER simulates all the systems in their respective predefined search spaces. Simulation is undertaken for every possible system combination and configuration for a period of one year. The sensitivity variable has been set for solar irradiation (G=3.68, 5.68, 7.68, 9.58, 10.68), wind speed (v=3.0, 4.0, 5.0, 5.67, 6.0. 7.0, 8.0), and the grid electricity price (p=0.05, 0.1, 0.2, 0.3, 0.4). A total of 175 sensitivity cases were run for each system configuration. The simulation was carried out with an Intel Core 2 Duo CPU, 3.2 GB of RAM with Windows XP Operating System.

From the sensitivity analysis output optimal system type (OST) and surface plot were highlighted to explore the model characteristics considering solar radiation, wind speed and grid electricity price. Figure 12 shows that the PV-wind system is feasible when the grid electricity price is more than \$0.3/kWh and wind speed is more than 3.0 m/s while solar radiation is fixed at 9.68 kWh/m^2/day. However, grid-wind system is more suitable than the grid only system if the electricity price increase to \$0.1/kWh. This happened due to the availability of a large amount of wind energy.

Figure 13 shows a surface plot in which NPC and COE has measured in which wind speed and electricity price are variables with a fixed solar radiation of 7.68 kWh/m^2/day. From these graphical representations, it has concluded that a particular system would be optimal at a certain sensitivity variables or conditions.

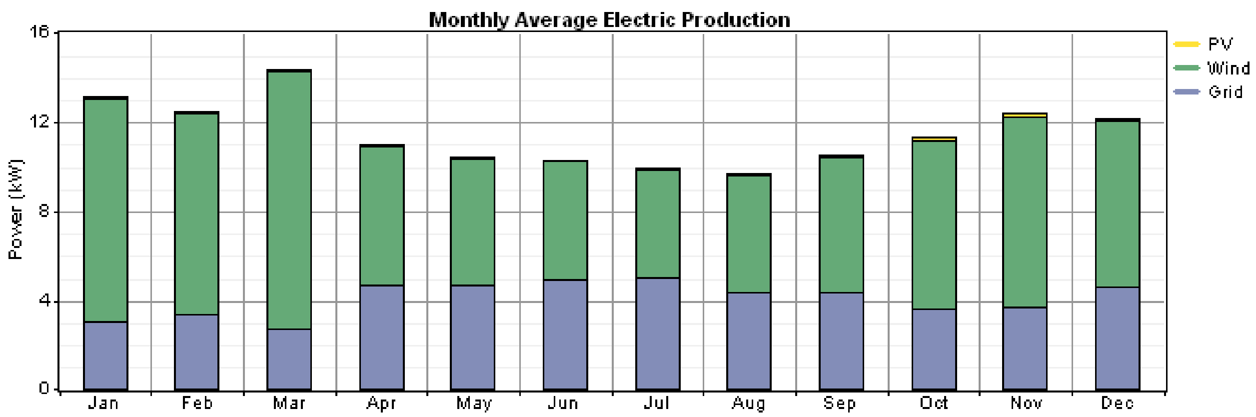


Figure 11: Monthly average electric energy production

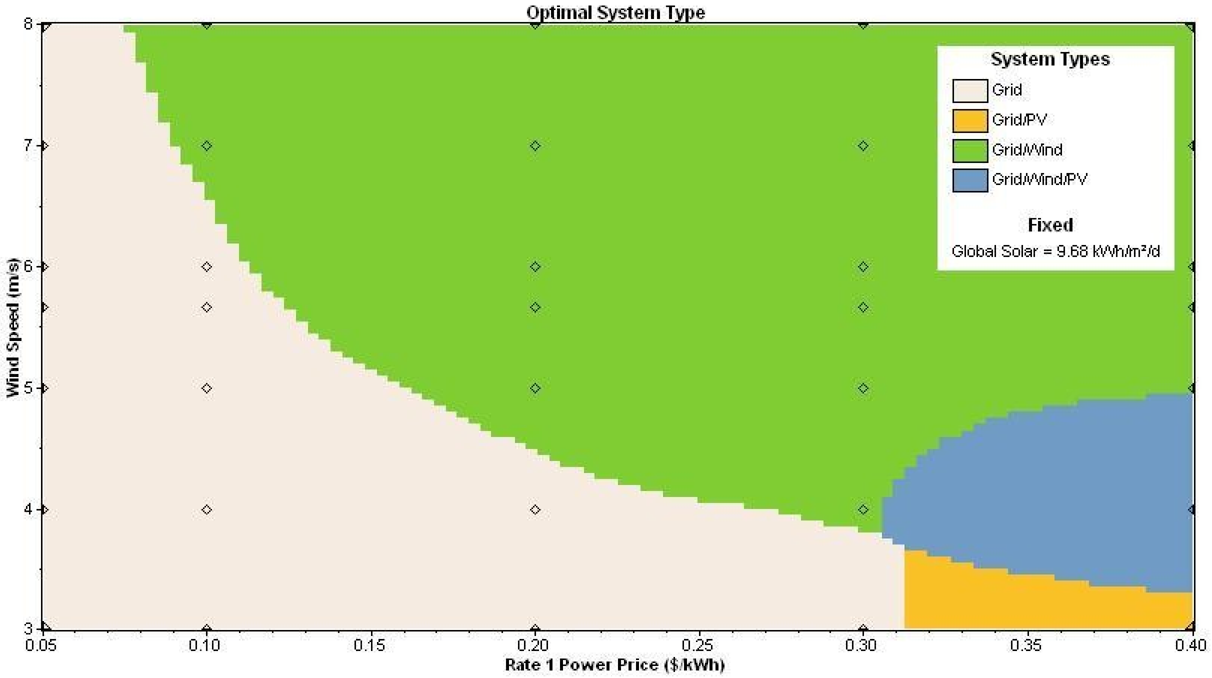


Figure 12: Sensitivity results with fixed solar radiation 9.68 kWh/m^2/day

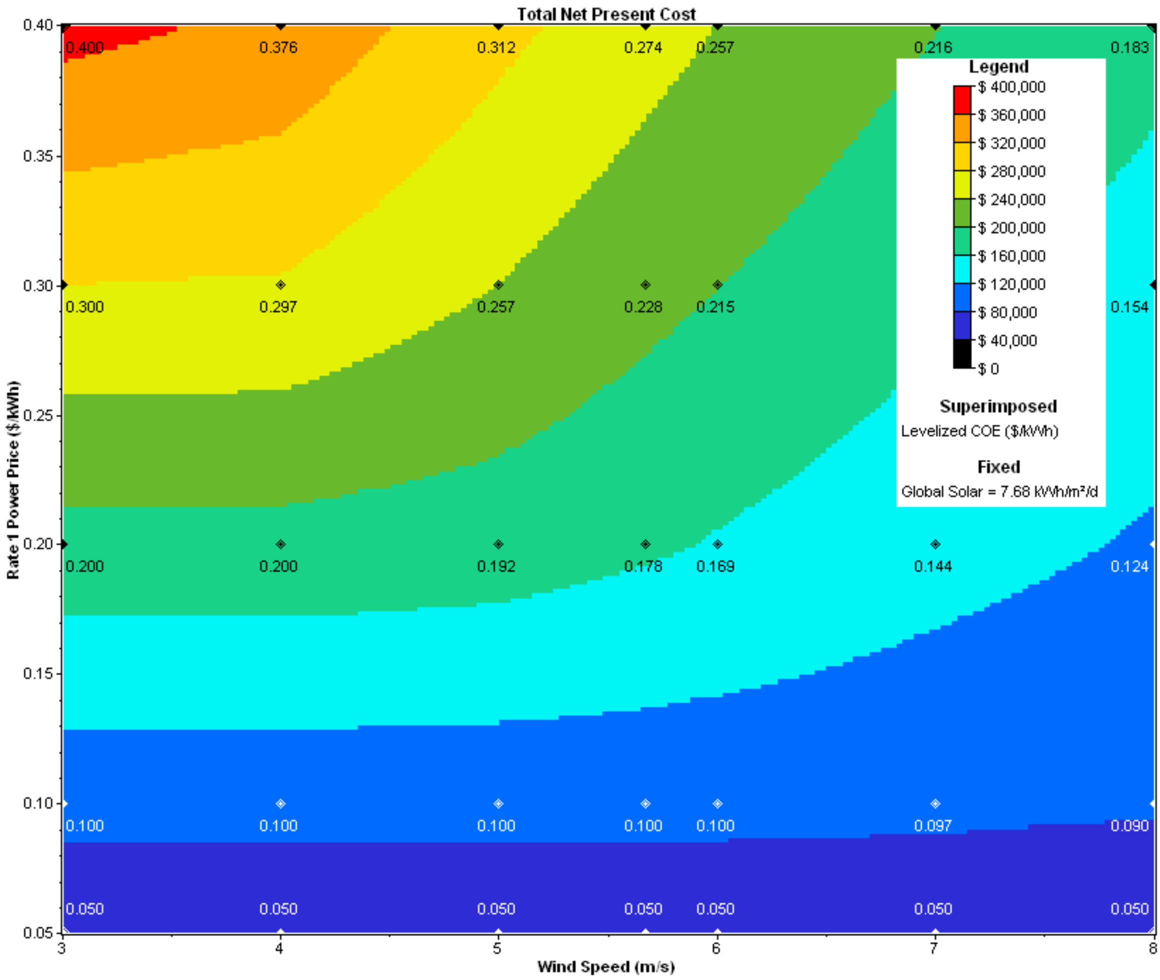


Figure 13: Sensitivity analysis with surface plot

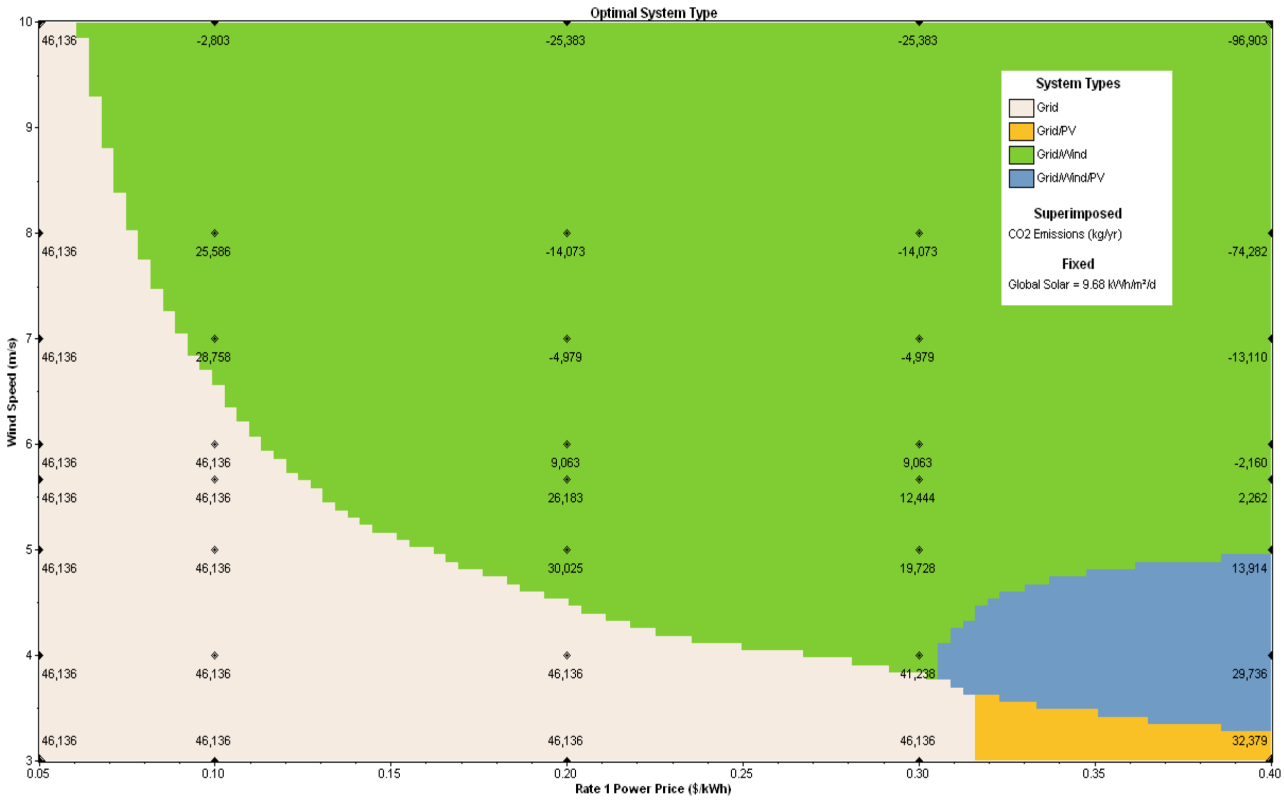


Figure 14: Annual emissions (kg/year) of carbon dioxide

4.2. Emission Analysis

Use of renewable energy sources in the generation of energy reduces the emission of CO_2, SO_2, and NOx in the atmosphere that saves the environment from global warming. Comparative analysis in between emission and COE are simulated based on the three sensitivity variables (wind speed, solar irradiation, and grid electricity price). This study estimates the total yearly emission from standard grid-connected-, wind/grid-connected-, PV/grid-connected- and PV/wind/grid-connected system. From experimental results it was shown that grid-connected system emitted 68,036 kg CO_2 per year, while a PV-wind grid-connected emitted only 17,785 kg/yr. A PV/grid-connected system emitted 67,394 kg CO_2 per year and wind grid-connected system emitted only 18,351 kg/yr. Therefore it can be concluded with the use of renewable it is possible to reduce an enormous amount of CO_2 emission in the atmosphere. However, in this study contribution of solar energy is less compare to wind energy as solar energy is available only for a few hours in a day and initial establishment cost if high.

From experimental results it was shown that hybrid system requires more NPC than the grid-connected system. For the benefit of emissions reduction, it may be needed to sacrifice with high upfront capital costs. Figure 14 shows the annual emission from CO_2 in different scenarios. Therefore this hybrid model reduces enormous amount of CO_2 emission per year in the atmosphere as well save the environment for a sustainable future.

Based on the optimisation results, it was observed that wind energy plays a key role in this hybrid energy system as more than 50% of energy was produced from wind turbines while less than 5% energy was produced from solar radiation. A major reason for these results is renewable energy sources are weather-driven and it is possible to get wind energy 24 hours a day, 7 days a week and 365 days a year, while solar energy mostly depends on the availability of sunshine, which may be only 6 to 8 hours a day. Therefore from the analysis, the wind energy resource has more impact on the implementation of hybrid renewable energy systems for the future smart power network.

5. Conclusion

This paper looked at the economic model of hybrid renewable energy sources and explores the impact it has to the grid using HOMER simulation software. The study simulates a PV/wind/ grid-connected hybrid system in central Queensland region. The daily solar radiation and three hourly wind speed data were collected from the Rockhampton Aero Weather Station. In 2007, the mean solar radiation was 5.68 kWh/m^2/day and wind speed was 5.67m/s. The optimized hybrid renewable energy system was developed considering manufacturing cost, and efficiency which includes a BWC excel-R wind turbine, and 1kW PV module. Experimental results show that the COE of energy of the optimized system is 0.23/kWh while the standard electricity is defined as 0.3/kWh. The sensitivity analysis indicates that PV-wind hybrid system is feasible under specific meteorological conditions in Central Queensland region, while wind-grid system is most suitable for most of the conditions. From the developed model it has clearly observed that wind energy has more impact in this hybrid system than the solar energy. From experiments, it has observed that penetration of renewable sources reduces CO_2 emission significantly which reduces global warming as well as plays a key role in developing climate-friendly sustainable power systems for future. However, this study is still in introductory stage and needs to be developed in different areas.

Therefore further investigations are suggested on the following areas:

- Experimental analysis with large volume of data, specially focus on solar radiation
- Analyse the characteristics and availability of renewable energy sources (solar and wind).
- Analyse the prospects of renewable energy in Australia
- Analyse the impact of renewable energy sources with the smart power systems.

Acknowledgments

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