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Microgrid simulation and modeling for a utility in southern Negros Oriental, Philippines

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ABSTRACT

An increasingly distributed energy future means localized generation at the distribution level. This means higher efficiency and helps decarbonize our energy system. The challenge for utilities is to adapt to emerging technologies and evolve but connecting renewable energy into existing systems is not without costs. With optimization tools like HOMER, the task of determining the most cost-effective system becomes simpler and faster. This paper aims to determine the optimal renewable energy source for a utility coverage area. Negros Oriental in the Philippines has abundant solar radiation most times of the year. Based on National Renewable Energy Laboratory data, it has considerable potential for wind energy. The area also has the potential for small hydro. The study obtains the costs and the possible configurations for the distribution system. It uses actual load profiles recorded by the utility. The study has also looked at publications that used HOMER as a tool, ascertaining its influence in the simulation of microgrids. The optimal system combination for the area is Grid and 40 Vestas 82 Wind Turbines. The effect of reduced wind speeds and a higher power price is noted. While many similar studies stop at obtaining the most cost-effective system, this paper has a section on post-HOMER discussion that inspects the implications of the results.

1. Introduction

The global call to achieve energy sustainability and mitigate climate change has become louder in recent years. Now it is more than just electrification of remote places. The need for more renewable energy (RE) resources is so clear and these resources have to work harmoniously with existing systems, while 100% renewable is still not achievable.

Microgrids which are generally collections of consumers, generators, with or without energy storage entities, can be operated as small grids capable of connecting to the main grid and being self-sufficient (Loix, 2009). Microgrids may be classified as utility microgrids, industrial or commercial microgrids, and remote microgrids. Utility microgrids are microgrids that are owned and operated by utilities. They can facilitate the introduction of distributed resources and can help handle local load growths to reduce congestion. Industrial or commercial microgrids are those that have critical or sensitive loads requiring high power quality and reliability such as data centers, university campuses, shopping centers and the like. These microgrids can switch over to islanding in the event of faults from the main grid, during maintenance and other events. Remote microgrids, on the other hand, are microgrids located away from the electricity grid and are aimed at providing locally available power to consumers. These autonomous microgrids may connect to the main network in the future.

The challenge for utilities at present is the need to adapt to emerging technologies and evolve or change its market model to remain significant and competitive (Patel, 2013). With the emergence of Smart Grids and Distributed Generation (DG), employing small-scale technologies consisting of modular generators typically RE sources closer to consumers, utilities have to face both the opportunities and the difficulties. The adoption of DG and renewables comes with costs (John, 2014).

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This study centers on a utility microgrid for Southern Negros Oriental. Negros Oriental and the Philippine Islands have abundant solar radiation most times of the year. Based on National Renewable Energy Laboratory (NREL) data, Negros Oriental has a potential for wind energy (Elliott et al., 2001). Fig. 1 shows Negros Oriental in purple, denoting a potential of 2000-3000 MW. The area also has the potential for hydro. In fact, a 0.8 MW run-of-river hydroelectric plant in Amlan, Negros Oriental has been operational for many years now. In this study, the flow rates for hydro are assumed and these are micro sources that may connect at the distribution level.

Mainly, this paper aims to find out the different costs and the possible RE combinations for the distribution system based on actual load profile. A basic hybrid RE model is developed for eventual integration of the optimal renewable for the microgrid or minigrid. This model, developed using HOMER, is explored using different scenarios. Connecting RE into existing systems is costly and needs adequate planning to minimize wasteful expenditure. With tools and software like HOMER, the task of determining the most cost-effective renewable becomes simpler and faster.

As to the structure of this paper, it starts with a brief look at the publications or studies that have used HOMER as a tool. This will find out how extensive its influence is in the simulation and analysis of systems. This will partly be the paper's contribution. It will then go into describing the site used and the step-by-step methodology utilized in the case. It goes on to describe the modeling data collection, followed by a discussion of the simulation and the proposed system, with its resources, components, parameters, economics, constraints and costs. It proceeds into the optimization results and sensitivities and an elaboration of the indications for the utility. Following that is a section that attempts to inspect the implications of the results and discusses the limitations.

2. HOMER as a tool

HOMER is popular software developed by NREL to assist in the design of micropower systems and facilitate the comparison of different power generation technologies. HOMER can model a power system's physical behavior and the related costs. It can also help quantify the effects of uncertainty since it can do sensitivity analysis aside from simulation (Lambert et al., 2006). Of the 19 software tools evaluated in a study, it was found to be the most widely used tool for hybrid renewable energy systems (Sinha and Chandel, 2014). It has been used in many studies ranging from techno-economic analysis in remote areas (Chauhan and Saini, 2016a; Corrand et al., 2013; Amutha and Rajini, 2015; Rahman et al., 2016; El Khashab and Al Ghamedi, 2015), hybrids with different storage systems (Chua et al., 2015; Ramli et al., 2015b; Silva et al., 2013), economic evaluation of biomass gasification plant (Montuori et al., 2014), to RE viability analysis for universities and schools (Glaisa et al., 2014; Park and Kwon, 2016; Sahoo et al., 2015; Singh et al., 2015), and also along with other software and simulators (Marneni et al., 2015). A study has identified that HOMER has been used in developing countries more than other regions and has been used for loads less than a kW to 2,213,000 kW (Bahramara et al., 2016). Fig. 2 shows on the global map the locations of some studies that have used HOMER software, the green one is the site for the case study in this paper while Table 1 presents some published studies using HOMER as a tool either solely for simulations or techno-economic analysis or with additional purposes. The absence of entry in the Existing System column means there was none specified.

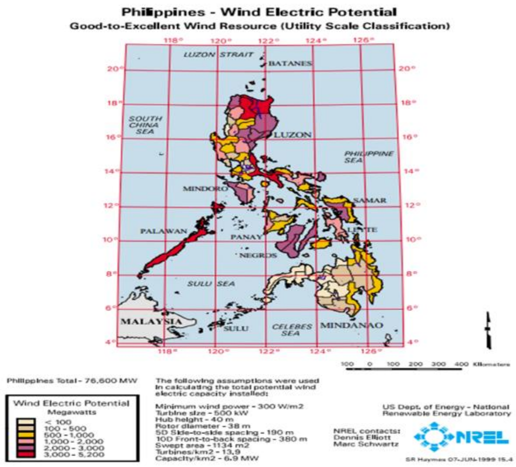


Fig. 1: Wind potential in Philippines

Fig. 2: HOMER usage representative case studies map

2.1. Site description

Negros Oriental occupies the southeastern half of the island of Negros, shown in Fig. 3 It is subdivided into 19 municipalities and six cities, with Dumaguete City as capital. It is grouped into three districts, with the capital in the 2nd district along with two other cities and five towns. The 3rd district is composed of the southern municipalities of Bacong, Valencia, Dauin, Zamboanguita, Siaton, Santa Catalina, Bayawan City, and Basay. The area for the study is from Dumaguete City down to the southernmost town of Basay but extends to the northern City of Tanjay and the municipalities of Amlan, San Jose, and Sibulan as they belong to the coverage area of a single distribution utility. Fig. 4 shows the local utility coverage.

Table 1: Selected sites with HOMER simulations

Country	Coverage/Scale	Existing System	Configuration Findings
South Korea (Yoo et al., 2014)	Ulleungdo Island	Diesel Gen + Hydro	Diesel Gen + Hydro + PV + Wind + Batteries + Converters
South Korea (Baek et al., 2016)	City of Busan	Grid (98% Nuclear)	PV + Wind + Converter + Battery
South Korea (Kim et al., 2014)	Island of Jeju	Grid	Grid + PV + Wind + Converter + Battery
India (Sen and Bhattacharyya, 2014)	Palari Village		Biodiesel Gen + Hydro + PV + Batteries + Converters
India (Kumar and Manoharan, 2014)	State of Tamil Nadu		Diesel + PV + Battery + Converter
India (Chauhan and Saini, 2016b)	Off-Grid Village Hamlets of State of Uttarakhand		PV + Wind + Hydro + Biomass + Battery + Converter
India (Amutha and Rajini, 2016)	Small Village in Kadayam, Tamilnadu		PV + Hydro + Wind + Battery
Bangladesh (Nandi and Ghosh, 2009)	Coastal Administrative Unit of Sikatunda		PV + Wind + Battery
Bangladesh (Das et al., 2016)	Village of Dhankhali		Diesel Gen + Hydro + PV + Battery
Malaysia (Basir Khan et al., 2015)	Tioman Resort Island in South China Sea	Grid of Diesel Gen + Hydro	Diesel + PV + Hydro + Battery
Malaysia (Lau et al., 2015)	Malaysian Islands	Diesel Gen	Diesel + PV + Battery
Algeria (Nacer et al., 2016)	Dairy Farms in Mitidja	Conventional Grid	Grid + PV (Northern Coastal Regions); Grid + Wind (Highland Farms); Grid + PV + Wind (Ghardaia Region)
Algeria (Bentouba and Bourouis, 2016)	Remote Rural Area of Timiaouine in Adrar Province	Diesel Gen	Diesel + PV + Wind
Canada (Rahman et al., 2016)	Sandy Lake First Nation Community in Ontario	Diesel Gen	Diesel + Battery (0% RE) Diesel + PV + Wind (different RE scenarios)
Canada (Bhattarai and Thompson, 2016)	Remote Community of Brochet in Manitoba	Diesel Gen	Diesel + Wind + Battery + Converter
Egypt (Diab et al., 2016)	Factory in New Borg El Arab City		Diesel + PV + Wind + Battery
Indonesia (Prasetyaningsari et al., 2013)	Aeration System, Sleman Regency, Yogyakarta		PV + Battery + Converter
Brazil (Silveira et al., 2015)	Fernando de Noronha Archipelago	Conventional Grid	Diesel + PV + Wind + Battery + Converter
Australia (Nazir et al., 2014)	Different Islands		Generalized: Wind and Solar
Ethiopia (Bekele and Tadesse, 2012)	Remote Area of Dejen district		Diesel + PV + Wind + Battery + Converter
Iran (Asrari et al., 2012)	Remote Area in Sheikh Abolhassan	Diesel Gen	Diesel + Wind (if with RE)
Turkey (Demiroren and Yilmaz, 2010)	Island of Gökceada	Conventional Grid	Wind + Battery + Converter
United Arab Emirates (Rohani and Nour, 2014)	Remote Area in Ras Musherib, Abu Dhabi		Diesel + PV + Wind + Battery + Converter
USA (Shah et al., 2015)	Regions of Prescott, Sacramento and Houghton		PV + Combined Heat and Power (CHP) + Battery
Iraq (Al-Karaghouli and Kazmerski, 2010)	Health Clinic System in Southern Iraq		PV + Battery + Converter
Sri Lanka (Givler and Lilienthal, 2005)	Home Solar Power Systems		PV + Battery for loads ranging from 3 kWh/d to 13 kWh/d; Higher loads best served by Gen/PV/Batt Hybrid
Somaliland (Abdilahi et al., 2014)	Urban Centers of Somaliland	Diesel Gen	Diesel + PV + Wind + + Battery + Converter
Nigeria (Olatomiwa et al., 2016)	Rural Health Clinics in six geo-political zones		Diesel + PV + Wind + Battery
Tunisia (Maatallah et al., 2016)	City of Biserte		Diesel + PV + Wind
Saudi Arabia (Ramli et al., 2015a)	City of Makkah, Saudi Arabia	Diesel Gen (diesel price, one of the cheapest in the world)	Diesel + PV + Converter

2.2. Methodology for the optimization

In summary, this study involves:

- General assessment of existing system
- Plan system with target components
- Obtain load profile (Actual)
- Obtain resource data (Actual or download from internet
- Perform simulation and sensitivity analysis
- Internet results

3. The modeling

3.1. Data collection and load profile

The local utility, a cooperative called Negros Oriental Electric Cooperative II (NORECO II), distributes electricity to the aforementioned areas. Providing its baseload requirement is Kepco Salcon Power Corporation and its intermediate load is provided by Green Core Geothermal Incorporated. The peaking load requirement is satisfied by purchasing from the Wholesale Electricity Spot Market (WESM), a platform where electricity is traded and prices are governed by market and commercial forces. The daily load profile, their latest available, came in an Excel file that was prepared by utility personnel.

Fig. 3: Negros oriental, Philippines location

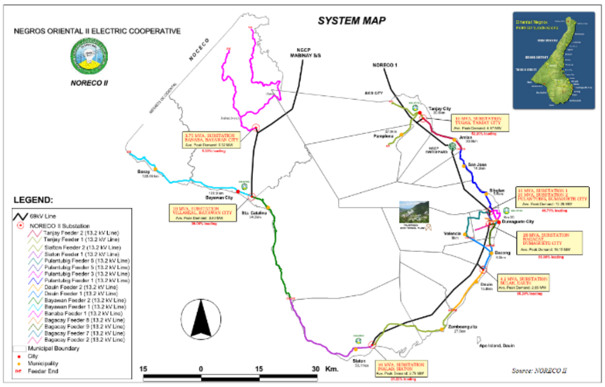


Fig. 4: Local utility coverage area

This study uses the daily average load for each month for the area coverage. Fig. 5 shows as an example, the daily average load profile for the month of December. The site seasonal load profile is shown in Fig. 6. Fig. 7 shows the variation of the daily load profiles across the year.

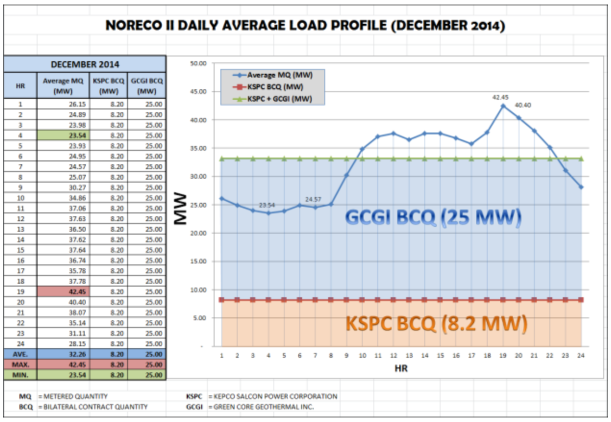


Fig. 5: Daily average load profile for December

3.2. The proposed system

3.2.1. The solar resource

The data for the solar resource is taken from the internet. The specific location for Negros Oriental is at 9° 45' N and 123° E. The "Get Data Via Internet" button retrieves the monthly solar data for the location from the NREL and National Aeronautics and Space Administration (NASA) satellite databases. As shown in Fig. 8, the average solar radiation is 5.202 kWh/m²/d and the average clearness index is 0.528.

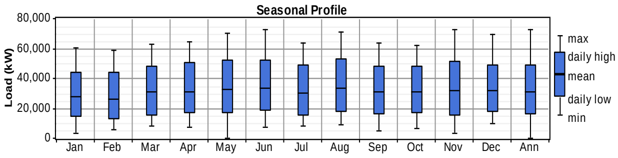


Fig. 6: Site seasonal load profile

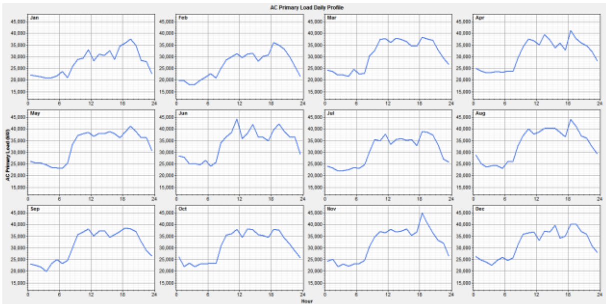
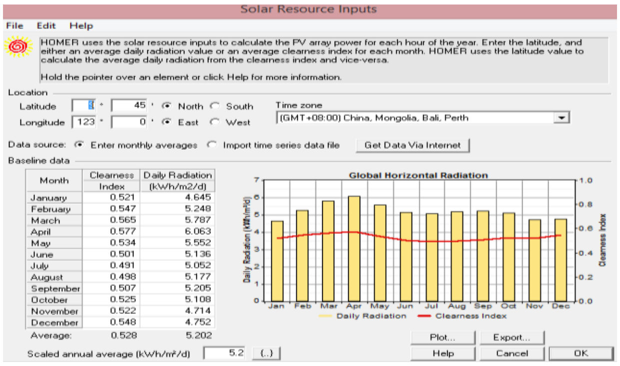


Fig. 7: Site daily load profile



Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.521	4.645
February	0.547	5.248
March	0.565	5.787
April	0.577	6.063
May	0.534	5.552
June	0.501	5.136
July	0.491	5.052
August	0.498	5.177
September	0.507	5.205
October	0.525	5.108
November	0.522	4.714
December	0.548	4.752
Average:	0.528	5.202

Fig. 8: Solar resource inputs

3.2.2. The wind resource

The wind resource inputs are taken from NREL data, taking a random year for the desired region. The Wind Prospector in the NREL website can provide estimates in wind speeds simply by choosing a region, on a point or by a custom query or attribute query. A CSV file may also be downloaded. There is also a HOMER-ready Philippines wind data that is available for download with a HOMER account. Fig. 9 shows the Wind Resource Inputs, the annual average of which is 6.963 m/s.

3.2.3. The hydro resource

The inputs for the hydro resource are assumed and though these are small values, they were compensated with a higher head. Fig. 10 shows the Hydro Resource Inputs.

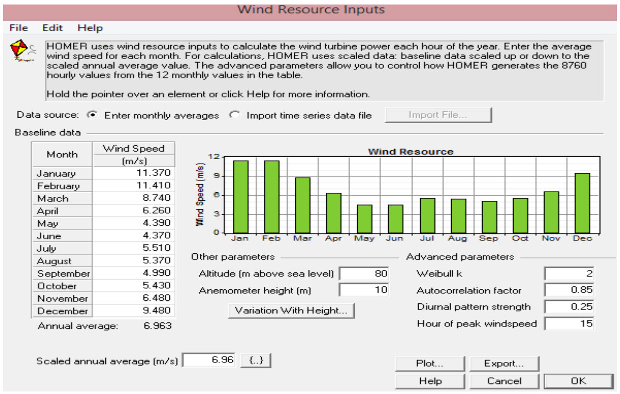


Fig. 9: Solar resource inputs

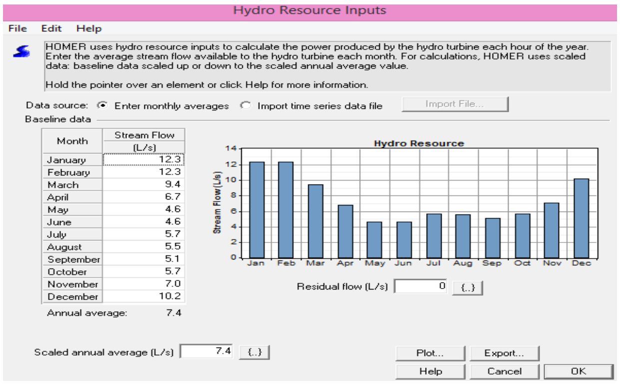


Fig. 10: Hydro resource inputs

3.2.4. The components

SOLAR PVs: The PV module used is generic. The initial costs and operation and maintenance costs are adjusted to include other costs on top. The Solar Model Parameters are shown in Table 2.

Table 2: The solar model parameters

Sizes Considered (kW)	1, 40, 80, 100, 200, 300, 400, 500, 1000, 2000, 4000, 6000, 8000, 1000
Output Current	DC
Lifetime	20 years
PV Derating Factor	80%
Tracking System	No Tracking
Azimuth	0 deg
Ground reflectance	20%

WIND TURBINES: The wind turbines used are Vestas 82 which are rated 1,650 kW AC or 1.65 MW and are optimized for low to medium winds. The Wind Turbine Parameters are found in Table 3.

HYDRO TURBINES: HOMER models run-of-river nstallations. The available head, design flow rate, and efficiency are provided by the user and nominal power is automatically generated by HOMER. The parameters are in Table 4.

Table 3: The wind turbine parameters

Quantities Considered	0, 2, 4, 6, 8,10, 20, 40, 80, 100, 200, 400, 600, 800
Lifetime	20 years
Hub height	59m

Table 4: The hydro turbine parameters

Available Head	50m
Design Flow Rate	7 L/s
Minimum Flow Ratio	50%
Maximum Flow Ratio	150%
Efficiency	85%
Pipe Head Loss	18.2%
Lifetime	25 years

CONVERTERS: Converters are necessary devices whenever a system has DC components serving an AC load and vice versa. Converters can be inverters (DC to AC), rectifiers (AC to DC) or both. Table 5 shows the parameters of the converter model.

Table 5: The converter model parameters

Sizes Considered (kW)	0, 40, 60, 80, 100, 200, 300, 400, 500, 1000, 2000, 3000, 4000, 5000, etc.
Lifetime	15 years
Control Inverter efficiency	90%
Inverter can parallel with AC generator	Yes
Rectifier relative capacity	100%
Rectifier efficiency	90%

BATTERIES: Batteries are integral components in hybrid systems as they permit storage of energy for later use. The variations in the renewable sources' availability make batteries very useful as they are able to provide electricity even when these sources are not actually producing power. The battery chosen is Surrette 4KS25P, with supplier integration into HOMER so the specifications for the battery are also known such as its float life of 12 years. Price used is approximated from online stores. Specifications for the said battery are available online. The Battery Model Parameters are shown in Table 6.

Table 6: The battery model parameters

Battery type: Surrette 6CS25P Battery	
Quantities Considered (Strings)	1, 10, 20, 40, 80, 120, 240, 300
Lifetime throughout	10,569 kWh
Nominal capacity	1,900 Ah
Voltage	4 V

3.2.5. The control parameters and operating strategies

There are two types of dispatch strategies are available in HOMER: *load following* and *cycle charging*. In *load following*, when the generator runs, it produces just enough power to run the load. On the other hand, in *cycle charging*, when the generator runs, it runs at full power and charges the batteries. An 80% setpoint state of charge is chosen which means that the generator will stop charging the battery when it is 80% charged. The system control inputs used are shown in Table 7.

3.2.6. The economics and constraints

The project lifetime is estimated at 25 years. The annual interest rate is set at 6%. Three sensitivity values are used for the maximum annual capacity shortage and operating reserve is set at 10% of the hourly load. The operating reserve is a capacity that is reserved for a short interval of time in case there is a disruption to the supply. The summary of the constraints inputs used is given in Table 8.

Table 7: The system control inputs

Simulation	
Simulation time step (minutes)	60
Allow systems with multiple generators:	Yes
Allow multiple generators to operate simultaneously:	Yes
Allow systems with generator capacity less than peak load:	Yes
Generator control: Load following	Yes
Generator control: Cycle charging	Yes
Setpoint state of charge:	80%

3.2.7. The costs

A report from the International Renewable Energy Agency (IRENA) showing the total installed cost ranges can provide a guide in choosing the cost assumptions for the different RE generation, the summary is shown in Fig. 11.

Table 8: The constraints inputs

Maximum annual capacity shortage:	0%, 5%, 10%
Minimum renewable fraction:	5%
Operating reserve as percentage of hourly load:	10%
Operating reserve as percentage of annual peak load:	10%
Operating reserve as percentage of solar power output:	25%

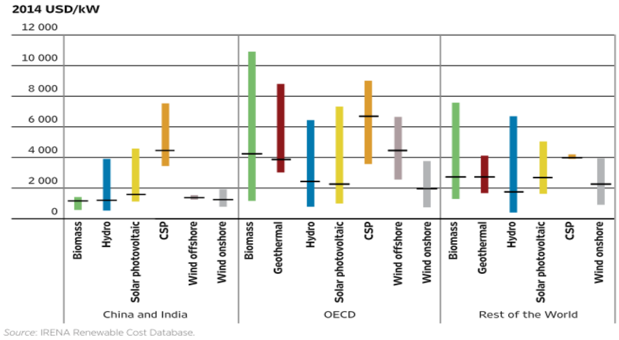


Fig. 11: Typical ranges and weighted averages for total installed costs of renewable power generation technologies by region (Utility-scale) (IRENA, 2015)

Table 9 shows typical solar PV costs, also from the IRENA report.

The NREL, on the other hand, has published the 2013 Cost of Wind Energy Review that provides a good range of the costing for wind projects (Moné et al., 2013). Table 10 shows an important conclusion from that publication.

Table 11 shows cost ranges for different hydropower projects (IRENA, 2012).

The summary of cost inputs is shown in Table 12. These costs are reasonable assumptions. The PV initial costs can also be based on costing by solar electric system suppliers (SES, 2014). Battery initial cost is based on online pricing. Converters usually cost $1000 per kW. No advanced grid inputs and net metering are assumed.

Table 9: Typical installed costs solar PV (IRENA, 2015)

	2010	2013	2014	2010-2014
New Capacity Additions (GW)	16	39	40+	150%+
Cumulative Installed Capacity	39	139	179+	360%+
Regional Weighted Average Installed Cost Utility-scale (2014 USD/kWh)	3700-7060	1690-4250	1570-4340	-39% to -58%
Regional Weighted Average Utility-scale LCOE (2014 USD/kWh)	0.23-0.5	0.12-0.24	0.11-0.28	-44% to -52%

Table 10: Ranges of LCOE and elements for U.S. land-based and offshore wind in 2013 (Moné et al., 2013)

	Land-Based Wind Projects	Offshore Wind Projects
Capital expenditures	$1,447–$3,000/kW	$3,200–$6,000/kW
Operational expenditures	$4–$30/MWh	$20–$59/MWh
Capacity factor	25%–50%	30%–50%
Discount rate	6%–11%	8%–15%
Operational life	20–30 years	20–30 years
Range of LCOE	$103/MWh	$282/MWh

Table 11: Typical installed costs and LCOE of hydropower projects (IRENA, 2012)

	Installed Costs (USD/kW)	Operations and Maintenance Costs (%/year of installed costs)	Capacity Factor (%)
Large Hydro	1050-7650	2-2.5	25-90
Small Hydro	1300-8000	1-4	20-95
Refurbishment/ upgrade	500-1000	1-6	

3.3. Homer simulation

The simulation starts with the assumption that the current energy supplier(s) for the utility can deliver 75MW of power, modeled here as the grid. Wind resource inputs are based on National Renewable Energy Laboratory (NREL) wind speeds at a certain area near Santa Catalina and Siaton. Stream flows for the hydro are assumed. Using a conversion of 1$ = 46 PHP, the utility buys power at $0.16 or $0.18. Other assumptions are: grid purchase capacity of 75000 kW, lifetime of 25 years, annual interest rate to account for inflation is 6%, no monthly fee charged by the utility on the monthly peak demand, no limit on emissions, maximum annual capacity shortage of 10%, grid emissions are 632 g/kWh carbon dioxide, 2.74 g/kWh for sulfur dioxide and 1.34 g/kWh for nitrogen oxides.

The electrical details in Fig. 12 show no unmet electricity and a capacity shortage of 19,205 kWh/yr., which is just around 0.01%. It is assumed that the grid can supply as much as 75,000 kW or more than the current peak demand of 73,000 kW. The total annual grid purchase is 101,718,488 kWh/yr. and with almost no excess electricity.

Table 12: Summary of costs inputs

Item	Initial Costs	Replacement Costs	OandM Costs
PV:			
1kW	$3500	$0	$21/yr.
100kW	$22000	$0	$1900/yr.
1000kW	$1800000	$0	$16000/yr.
Wind 1650kW	$3300000 (@2000/kW)	$0	$54450/yr. (@ $33/kW/yr.)
Hydro 3kW	$18000 (@6000/kW)	$0	$540/yr. (@ 3% of installed costs)
Surrete 6CS25P	$1600	$1600	$2/yr.
Converter	$1000/kW	$1000/kW	$2/kW/yr.

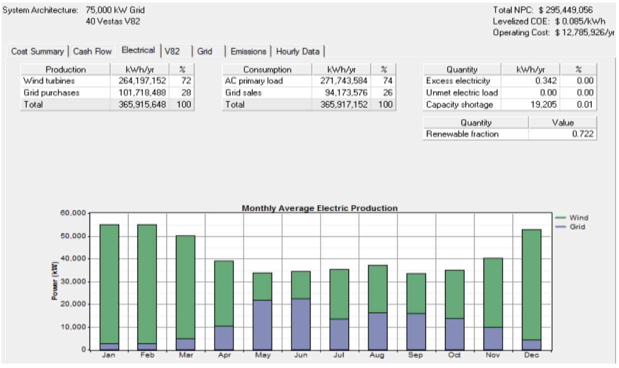


Fig. 12: HOMER optimization results_ electrical

Fig. 13 shows the grid energy charges and the energy purchases. Net purchases that are positive are achieved when energy sold by the grid is less than the energy it purchased.

4. Results and discussion

4.1. General results

The proposed system involves Solar PV, Hydro, Wind, Grid (in this case the power supplier for the utility), converters and batteries. The architecture as simulated in HOMER is shown in Fig. 14.

Fig. 15 is the simulation result where the optimal system is the grid and 40 Vestas V82 wind turbines, without batteries. This is for all cases of maximum annual capacity shortages.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)	Peak Demand (kW)	Energy Charge ($)	Demand Charge ($)
Jan	1,984,130	20,390,264	-18,406,134	45,287	0	0
Feb	1,891,695	19,227,846	-17,336,152	50,236	0	0
Mar	3,550,764	14,309,488	-10,758,724	53,116	0	0
Apr	7,450,170	5,596,077	1,854,093	57,491	296,655	0
May	16,170,863	653,090	15,517,773	59,173	2,482,844	0
Jun	16,253,124	652,606	15,600,518	72,173	2,496,083	0
Jul	9,961,988	3,689,572	6,272,416	57,115	1,003,587	0
Aug	12,220,071	2,767,566	9,452,506	56,109	1,512,401	0
Sep	11,590,771	1,799,495	9,791,276	52,437	1,566,604	0
Oct	10,263,097	3,276,583	6,986,514	53,134	1,117,842	0
Nov	7,104,459	6,280,019	824,440	52,145	131,910	0
Dec	3,277,372	15,530,979	-12,253,607	55,443	0	0
Annual	101,718,488	94,173,576	7,544,915	72,173	10,607,925	0

Fig. 13: HOMER optimization results_ grid

Table 13 shows a comparison of the costs obtained from the simulation with the optimal grid-wind combination. The operating costs for the grid-only condition compared to the hybrid combination are larger in both purchase prices. The operating cost when utility pays 0.16 $/kWh is larger by around $30,693,102 and this increases to $34,803,602 at the higher cost of 0.18 $/kWh. Other cost differences are seen as well.

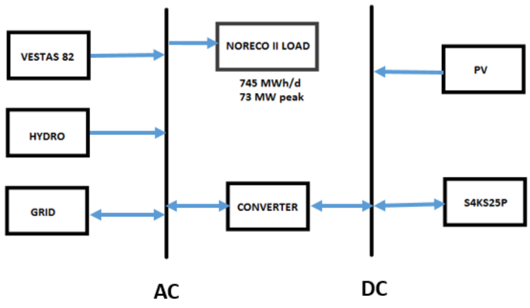


Fig. 14: HOMER optimization results_ Grid

PV (kW)	V82	Hydro (kW)	S4KS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Batt. Lf. (yr)
	40				CC	75000	$ 132,000,000	12,785,926	$ 295,447,040	0.085	0.72	0.00	
	40	2.92			CC	75000	$ 132,018,000	12,784,556	$ 295,447,520	0.085	0.72	0.00	
1	40			40	CC	75000	$ 132,043,504	12,786,943	$ 295,503,552	0.085	0.72	0.00	
1	40	2.92		40	CC	75000	$ 132,061,504	12,785,571	$ 295,504,000	0.085	0.72	0.00	
	40		2	40	CC	75000	$ 132,043,200	12,787,205	$ 295,506,592	0.085	0.72	0.00	12.0
	40	2.92	2	40	CC	75000	$ 132,061,200	12,785,835	$ 295,507,072	0.085	0.72	0.00	12.0
1	40		2	40	CC	75000	$ 132,046,704	12,787,081	$ 295,508,512	0.085	0.72	0.00	12.0
1	40	2.92	2	40	CC	75000	$ 132,064,704	12,785,709	$ 295,508,960	0.085	0.72	0.00	12.0
		2.92			CC	75000	$ 18,000	43,475,940	$ 555,786,432	0.160	0.00	0.00	
					CC	75000	$ 0	43,479,028	$ 555,807,936	0.160	0.00	0.00	
40		2.92		40	CC	75000	$ 146,788	43,469,008	$ 555,826,624	0.160	0.00	0.00	
40		2.92	2	40	CC	75000	$ 149,988	43,469,144	$ 555,831,552	0.160	0.00	0.00	12.0
		2.92	2	40	CC	75000	$ 61,200	43,477,220	$ 555,846,016	0.160	0.00	0.00	12.0
40				40	CC	75000	$ 128,788	43,472,092	$ 555,848,064	0.160	0.00	0.00	
40			2	40	CC	75000	$ 131,988	43,472,228	$ 555,852,992	0.160	0.00	0.00	12.0
			2	40	CC	75000	$ 43,200	43,480,308	$ 555,867,520	0.160	0.00	0.00	12.0

Fig. 15: HOMER optimization result

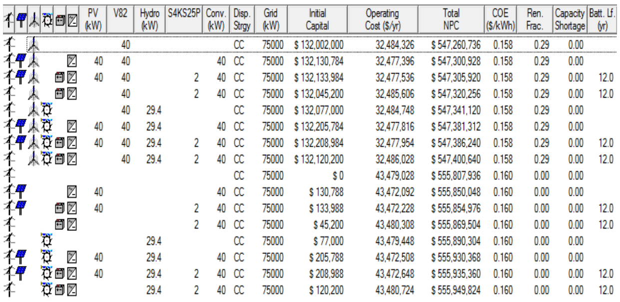
Table 14 shows the various emissions for the configurations considered. Grid only emissions are about 97% higher compared to the two simulated optimal configurations with RE. At both the 0.16$/kWh and 0.18$/kWh, the RE fraction in the result is 0.72, the reason behind the big difference in the emissions. In reality, the power suppliers for the utility deliver a lot of clean energy already with its intermediate load being satisfied with Geothermal Energy. This aspect of the study needs to be dealt with in detail, separately.

4.2. Effect of lower wind speeds

Just very near the chosen area where the wind speeds in the previous simulation were taken from, gives the lower wind speeds that are tried in another simulation. The simulation results are shown in Fig. 16. The cost comparison with the change in wind speeds is shown in Table 15. Although the most cost-effective system at the 0.16 $/kWh rate is still the grid and 40 Vestas 82, the cost of energy is 0.158 $/kWh and there is a noticeable increase in the operating cost and NPC. With the wind speeds change, the wind production of 72% goes to 29% and total energy sold to the grid decreases from 26% to 4%.

4.3. Post-HOMER discussion

HOMER is a popular microgrid simulation and optimization tool used in many parts of the world for systems ranging from homes to entire cities and islands. This paper has provided a short review of how it is being used and where. The tool is reliable and many systems have been implemented using it as a guide. However, users and designers need to consider other essential factors. For one, costing varies depending on location and developer or supplier. Results can be rough estimates and flexibility is key. The true cost of wind energy in a distribution system can only be seen with other costs and factors all properly identified such as transmission, environmental effects, and other areas of consideration or constraints like public policy, consumer costs, public acceptance and government incentives, which are beyond the scope of this study.



PV (kW)	V82	Hydro (kW)	S4KS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Batt. Lf. (yr)
	40				CC	75000	$ 132,002,000	32,484,326	$ 547,260,736	0.158	0.29	0.00	
40	40			40	CC	75000	$ 132,130,784	32,477,396	$ 547,300,928	0.158	0.29	0.00	
40	40		2	40	CC	75000	$ 132,133,984	32,477,536	$ 547,305,920	0.158	0.29	0.00	12.0
	40		2	40	CC	75000	$ 132,045,200	32,485,606	$ 547,320,256	0.158	0.29	0.00	12.0
	40	29.4			CC	75000	$ 132,077,000	32,484,748	$ 547,341,120	0.158	0.29	0.00	
40	40	29.4		40	CC	75000	$ 132,205,784	32,477,816	$ 547,381,312	0.158	0.29	0.00	
40	40	29.4	2	40	CC	75000	$ 132,208,984	32,477,954	$ 547,386,240	0.158	0.29	0.00	12.0
	40	29.4	2	40	CC	75000	$ 132,120,200	32,486,028	$ 547,400,640	0.158	0.29	0.00	12.0
					CC	75000	$ 0	43,479,028	$ 555,807,936	0.160	0.00	0.00	
40				40	CC	75000	$ 130,788	43,472,092	$ 555,850,048	0.160	0.00	0.00	
40			2	40	CC	75000	$ 133,988	43,472,228	$ 555,854,976	0.160	0.00	0.00	12.0
			2	40	CC	75000	$ 45,200	43,480,308	$ 555,869,504	0.160	0.00	0.00	12.0
		29.4			CC	75000	$ 77,000	43,479,448	$ 555,890,304	0.160	0.00	0.00	
40		29.4		40	CC	75000	$ 205,788	43,472,508	$ 555,930,368	0.160	0.00	0.00	
40		29.4	2	40	CC	75000	$ 208,988	43,472,648	$ 555,935,360	0.160	0.00	0.00	12.0
		29.4	2	40	CC	75000	$ 120,200	43,480,724	$ 555,949,824	0.160	0.00	0.00	12.0

Fig. 16: HOMER optimization result (lower wind speeds)

Secondly, siting and other issues relating to it have to be considered. For land use or area that will be required, Table 16 shows some information. In this work, the optimal system is a grid and 40 Vestas 82, which is equivalent to 66 MW of wind power. This installation will require approximately 12 km^2 (3000 acres) of area, assuming a megawatt of wind power needs 0.18 km^2 (44.7 acres).

It is significant to note that on this table from NREL, the standard deviation is very high. A 66 MW project in Mountaineer, West Virginia is located on 4,400 acres. This is roughly 17 square kilometres, which is almost half the entire area of Dumaguete City, Philippines, the capital of the province of Negros Oriental. This consideration is not covered in this study but is very important in the development of a project. An actual site survey should be included in the initial stages of planning.

Sometimes, the simulation results would give negligible and very small differences that may call for common sense or a simple informed decision making. For example, in the simulation result at 0.18 $/kWh where the optimal system is the Grid, 40 Vestas 82 and the 2.92-kW Hydro, the hydro turbine produces 22,644 kW/yr.

Table 13: Comparison of simulation results for different rates*

Sensitivity	System	Initial Cost ($)	Operating Cost ($/yr.)	Total NPC ($)	COE ($/kWh)
@0.16 $/kWh, 5% Max Annual Cap Shortage, 5% Min Ren Fraction	Grid + 40 Vestas 82	132,000,000	12,785,926	295,447,040	0.085
@0.18 $/kWh, 5% Max Annual Cap Shortage, 5% Min Ren Fraction	Grid + 40 Vestas 82 + 2.92 kW Hydro	132,018,000	14,110,310	312,395,104	0.090
@0.16 $/kWh, GRID Only	0	0	43,479,028	555,807,936	0.16
@0.18 $/kWh, GRID Only	0	0	48,913,912	625,283,968	0.18

*The utility usually buys power at either of these rates

Table 14: Comparison of simulation results, emissions

Sensitivity	CO_2	CO	UHC	PM	SO_2	NOx
@0.16$/kWh, 5% Max Annual Cap Shortage, 5% Min Ren Fraction	4,768,385	0	0	0	20,673	10,110
@0.18$/kWh, 5% Max Annual Cap Shortage, 5% Min Ren Fraction	4,754,086	0	0	0	20,611	10,080
GRID Only	171,742,160	0	0	0	744,578	364,137

Table 15: Comparison of simulation results (with wind speeds change)

Sensitivity	System	Initial Cost ($)	Operating Cost ($/yr.)	Total NPC ($)	COE ($/kWh)	Production and Energy Sold
@6.963 m/s annual average, 5% Max Annual Cap Shortage, 5% Min Ren Fraction (previous)	Grid + 40 Vestas 82	132,000,000	12,785,926	295,447,040	0.085	Wind – 72% Grid – 28% Energy Sold – 26%
@3.733 m/s annual average, 5% Max Annual Cap Shortage, 5% Min Ren Fraction	Grid + 40 Vestas 82	132,002,000	32,484,326	547,260,736	0.158	Wind – 29% Grid – 71% Energy Sold – 4%
	GRID Only	0	43,479,028	555,807,936	0.16	

But that is a tiny 0.0083% relative to the wind and grid generation. In some instances, the most practical system might not be the most cost-effective. It can come in as second, or third in the ranking, or even lower. Looking at the other combinations in the optimization results is good practice.

Further, the additional burden that RE can bring into the distribution or transmission system is a limiting factor (Jeffries and White, 2012) that needs additional research and power system analysis.

Table 16: Technology type and system size (NREL, 2016)

Technology	Size (m^2/MW)	Size Std. Dev.
PV <10 kW	12949.9	2.2
PV 10 – 100 kW	22257.7	0.7
PV 100 – 1,000 kW	22257.7	0.7
PV 1 – 10 MW	24685.8	1.7
Wind <10 kW	121406	n/a
Wind 10 – 100 kW	121406	n/a
Wind 100-1000 kW	121406	n/a
Wind 1 – 10 MW	180894.5	25

5. Conclusion

The use of HOMER as a tool in the simulation of microgrids and optimization of various RE installations has been quite extensive as represented by the publications selected and examined.

The simulation and sensitivity runs at the grid purchase price of 0.16 $/kWh, show that with the minimum of five percent RE fraction, the most cost-effective system is composed of 40 Vestas 82 wind turbines, working with the grid, with no converters, and no batteries. The next most desirable in terms of costs at 0.16 $/kWh would include a 2.92 kW hydro turbine. At 0.18 $/kWh, the order is reversed. The two rates, 0.16 $/kWh and at 0.18 $/kWh are used because those are the rates at which the utility buys its power from generation.

When the grid purchase price is at 0.16 $/kWh, the results obtained from the optimization gives the initial capital cost of the optimal system as $132,000,000 and operating cost as $12,785,926 a year. Its total net present cost (NPC) is $295,447,040 and the cost of energy (COE) is $0.085/kWh. That is nearly half the regular power purchase price. When the grid purchase price is at 0.18 $/kWh, the initial capital cost is $132,018,000 and the operating cost increases to $14,110,310. NPC becomes $312,395,104 and the cost of energy is $0.090/kWh, exactly half the cost of buying power from the grid. While there is a hydro turbine in the optimal system for this sensitivity, it is negligible relative to the grid and the wind system; it offers 0.0083% in the electrical production.

While there are tools that make optimization studies relatively easy, users and designers need appropriate data and logical assumptions in order to come up with sensible results. If actual costs can be obtained from the manufacturers and suppliers, the cost results can greatly improve. Resource assessments that are based on real field measurements would help obtain realistic results but demands time and considerable equipment expenditure. Other essential factors have to be considered in project planning and development, such as proper siting and costs that reflect transmission, environmental effects, and incentives, among other things. Moreover, distribution and transmission line impacts of RE and DG can limit their integration and demand additional investigation. These things are not within the scope of this paper.

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