A comparative cost analysis of electricity produced by a diesel and a wind power generation system for an energy load located in Chimbote, Ancash-Perú.

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***Abstract*– In this research work, a comparative cost analysis of electricity produced by a non-renewable and a renewable energy system is carried out. A 165.4-kWh daily electric load is established on the basis of a community-type profile, with a 20.5-kW peak load and a load factor of 0.34.**

Using simulation built-in features from HOMER Pro, optimum sizing for both a diesel-based system and a wind power system is carried out. A proposed non-renewable energy supply alternative consists of a 23-kW diesel generator, a 40-kWh storage capacity, and a 5.8-kW DC-AC converter. On the other hand, a proposed renewable energy supply alternative consists of a 135-kW wind power generation, an 821-kWh storage capacity, and a 49.2-kW DC-AC converter.

A levelized cost of electricity (LCOE) approach is used for comparison purposes. Also, net present cost (NPC) is calculated for the proposed energy supply alternatives.

It is concluded that for comparative cost analysis key aspects, such electric load profile and its correlation with wind speed availability on hourly basis, play a significant role. However, the incorporation of environmental benefits could overcome some economic feasibility barriers in the near future.

Keywords—Renewable Resources, Clean Energy, Cost Analysis, Environmental Sustainability.

I. INTRODUCTION

Energy supply based on renewable resources is gaining an increasing attention worldwide. According to different references, Peru is considered to have high wind speed levels compared to other regions in the world. Also, prices for fossil fuels in Peru are considered similar to international levels if not slightly higher. Besides, environmental concerns associated with the use of fossil fuels for electricity supply, in locations not yet connected to main electric grid, are getting more attention in many regions.

In this research work, a reference electric load located in Chimbote-Ancash will be considered for simulation purposes. Ancash region is located on the northern coastal region of Peru.

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II. BACKGROUND

According to Ref. [01], this work analyses the techno-economic feasibility of an autonomous hybrid renewable energy system for providing electricity for an academic township in the East District of Sikkim, India. The resources considered for the system were solar energy, wind energy, biogas, syngas and hydrokinetic energy with batteries as back-up. HOMER Pro Microgrid Tool, developed by the National Renewable Energy Laboratory, United States of America has been used as the simulation and assessment tool for modeling performed with hourly data input. Various constraints were implemented to limit the maximum installation capacities of the components considered. All the technical and financial specifications of the components were availed from the local Indian markets. A total of 31 possible combinations of the different resources were analyzed for net present cost, Levelized cost of energy, battery storage, emissions, area requirements and employment potential. The best combination was identified by applying a very widespread multi-criteria decision-making technique named Analytical Hierarchy Process. The Photovoltaic-Wind-Biogas-Syngas-Hydrokinetic-Battery based Hybrid Renewable Energy System was found to be the best combination with a Levelized Cost of Energy of 0.095 $/kWh. Finally, sensitivity analysis was carried out for various parameters to comprehend the behavior of the system for a broader application in the region.

According to Ref. [02], the perpetual dwindling of fossil fuel and its environmental impacts has become a thing of great concern as most countries in the world depend on it for energy generation. The economic development of most of these countries relies on fossil fuel price. Nigeria is one of the countries in the world that solely depends on fossil fuels for electricity generation, and this has greatly affected the growth of its power sector. Hence, there is a need for harnessing renewable energy sources (RES) for electricity generation due to its high availability in abundant quantity in the country. In this study, the viability of developing a standalone hybrid RES system using solar and wind for Giri village (Nigeria) is assessed. The techno-economic and environmental analysis was examined using hybrid optimization model for electric renewable (HOMER) simulation tool by selecting the optimum configuration based on cost of energy (COE), net present cost (NPC), renewable fraction (RF), and greenhouse gas emission (GHG). From the obtained results and sensitivity analysis, the optimal configuration has an NPC of $1.01 m and COE $0.110/kWh, with an operating cost of $4723. The system is environmentally friendly with a renewable fraction of 98.3% and GHG emission of 2889.36 kg/year.

According to Ref. [03], the primary goal of this study is to determine the minimum cost of energy (COE) for five different global locations – Squamish, Canada; Los Angeles and Golden, USA; and Brisbane and Adelaide, Australia – based on renewable energy systems. We do this by investigating power generation and hydrogen production via renewable energy resources (mainly solar and wind) to produce synthetic fuels by capturing CO_2 from the atmosphere. Nine different renewable energy systems are considered based on photovoltaic (PV), wind turbines (WT) and combinations thereof, including battery banks and hydrogen technologies. We used the Hybrid Optimization. Model for Multiple Energy Resources (HOMER Pro) microgrid software to simulate the optimum size of system components and to identify the cost-effective configurations based on particular locations. When considering minimum COE, the results show that integration of PV, WT, a battery bank, an electrolyzer and a hydrogen tank are at 0.50 $/kWh at Golden, Colorado, USA. We also found that without a battery bank, the minimum COE is 0.78 $/kWh at the same location. In this case, the cost increase is due to the capital cost of system components, mainly the hydrogen technologies. The results of this study suggest that hydrogen has economic benefits over batteries for long-term energy storage in off-grid energy systems.

According to Ref. [04], this paper focuses on the techno-economic feasibility of a grid-tied hybrid microgrid system for local inhabitants of Kallar Kahar near Chakwal city of Punjab province in Pakistan and investigates the potential for electricity generation through hybrid wind, photovoltaic and biomass system. The comprehensive resource assessment of wind, biomass and solar energy is carried out for grid integration. Homer Pro software is used to model a hybrid microgrid system. Optimization results and sensitivity analysis is carried out to ensure the robustness and cost-effectiveness of the proposed hybrid microgrid system. The total load has been optimally shared among generated power through wind, photovoltaic and biomass resources and surplus power is supplied to the national grid in case of low local demand of the load. The results of techno- economic feasibility study show that hybrid power system can generate more than 50 MW. The cost of energy based on peak load demand profiles are considered for both residential and commercial sectors. The cost of hybrid system for peak load of 73.6 MW is 180.2 million USD and levelized cost of energy is 0.05744 $/kWh.

According to Ref. [05], hybrid optimization model for electric renewable (HOMER) Pro is a renewable energy-based system optimization tool developed by National Renewable Energy Laboratory (NREL), USA is used to model HS. It is freely downloadable software. HOMER perform optimization, simulation and sensitivity analysis. This is a general-purpose system design tool that enables power system design either for off-grid or grid-connected application. HOMER sizes up the system specifications such as the load profile, wind resources, solar resources, diesel price, system control parameter, constraint parameter as well as components technical and economics details. HOMER performs numbers of hourly simulation for best possible matching between the load and the supply in order to design an optimal system. Thereafter, it creates feasible system configurations categorized according to cost effectiveness and presents the optimal configuration based on the lowest NPC. HOMER also performs the sensitivity analysis to explore the effect of changes of different factors on the different system configurations. Climatic data [wind speed (WS) and solar irradiation], site load profile, HS component's technical details and costs, system control as well as system constraints serve as input to the software.

According to Ref. [06], Standalone Hybrid Photovoltaic/Wind Energy (PV/WE) systems shall be sized for minimal cost, considering initial capital, continuous operational, and occasional maintenance costs, beside replacement costs over the life of the system. Two of the most utilized sizing techniques are critical month and algorithmic optimization. Critical month technique ensures energy supply without supply and demand (S & D) issues but at the expense of higher cost while algorithmic optimization requires complex mathematical formulations followed by synthesis of appropriate algorithm. This paper proposes a simple mathematical approach to size cost-effective near-optimal hybrid PV/WE system with battery energy storage (BES) and fossil fuel generator (FFG) without complex formulation and algorithm synthesis. Standalone Hybrid PV/WE system with BES and FFG is sized using proposed method and bench marked against a system in Homer Pro Microgrid Analysis Tool. Three systems are sized ranging from few kilo-watts (kW) to mega-watts (MW) in North America, Europe and Southeast Asia to validate proposed method universality.

According to Ref. [07], a method for designing hybrid electricity generation systems is presented. It is based on the Modified Electric System Cascade Analysis method. The Power Pinch analysis is used as a guideline for development of an isolated power supply system, which consists of photovoltaic panels, wind turbines and energy storage units. The design procedure uses a simulation model, developed using MATLAB/SIMULINK and applies the developed algorithms for obtaining an optimal design. A validation of the Modified Electric System Cascade Analysis method is performed by comparing the obtained results with those from the Homer Pro software. The procedure takes as inputs hourly wind speed, solar radiation, demands, as well as cost data, for the generation and storage facilities. It is also applied to minimize the loss of power supply probability and to minimize the number of storage units. The algorithm has been demonstrated with a case study on a site in Oujda city, with daily electrical energy demand of 18.7 kWh, resulting in a combination of photovoltaic panels, wind turbine and batteries at minimal cost. The results from the Modified Electric System Cascade Analysis and HOMER Pro show that both tools successfully identified the optimal solution with difference of 0.04% in produced energy, 5.4% in potential excess of electricity and 0.07% in the cost of the energy.

III. Methodology

A proposed methodology for this study is based on determination of local electric demand, considerations for project lifetime and economics, sizing of a diesel system, and sizing of a wind power system, followed by a comparison of electricity generation cost.

A. Electric Power and Energy Demand

It is rather important to distinguish between Power and Energy requirements. Therefore, with regard to electricity demand, it must be established in terms of "instantaneous" electrical power (kW) required over time (hours) on a daily basis. A load profile for electric power demand would normally include seasonal and scale variations over a year, and the upcoming years.

For a particular time-period of the day, "cumulative" electric energy demand may be calculated as:

E = P x t (1)

where:

E = electric energy (kWh)
P = electric power (kW)
t = time-period (hours)

Therefore, required electric energy can be calculated on a daily basis and expressed in terms of kWh/day.

For a particular daily electric energy demand, a load factor can be calculated as:

LF = DEE / (MED x 24 hours) (2)

where:

LF = load factor (no units)
DEE = daily electric energy demand (kWh/day)
MED = maximum electric power demand (kW)

In classic electric systems, main criteria for sizing usually include the maximum electric power demand (kW), even if it may only take place once in a while or even if it is expected to take place only several years ahead. However, when dealing with off-grid systems and required storage capacity, energy demand (kWh) plays a critical role for properly sizing a system. Also, load profile plays a critical role considering its potential correlation, or not, in time with a locally available renewable energy source.

B. Project lifetime and economics

Project lifetime must be established in order to assess economic feasibility and for comparison purposes among alternative proposals. Usually, project lifetime is considered around 15-25 years.

A key indicator that is used for comparison purposes is the Levelized Cost of Electricity (LCOE) and it can be calculated as follows:

LCOE = (CAPEX-A + OPEX) / E (3)

where:

LCOE = levelized cost of electricity (US$/kWh)
CAPEX-A = capital expenditure (US$/yr)
OPEX = operational expenditures (US$/yr)
E = electricity produced (kWh/yr)

It should be noted that replacement cost of certain components could be incorporated as additional CAPEX that is expected to take place, at a later time, during the project lifetime.

Normally, CAPEX figures are not expressed on a yearly basis but rather on a total cost at the beginning of project lifetime. However, a CAPEX value could be expressed on a yearly basis by:

CAPEX-A =CAPEX x [i x $(1+i)^n/(1+i)^n$-1] (4)

where:

CAPEX = capital expenditure (US$)
i = discount rate (no units)
n = project lifetime (years)

With regard to discount rates, the following relationship applies:

NDR = DRD + EIR + DRD x EIR (5)

NDR = nominal discount rate (no units)
EIR = expected inflation rate (no units)
RDR = real discount rate (no units)

C. Diesel-based Generation System

Diesel-based generation systems are usually capable of supply an entire electric demand managing several variations of power demand over time. However, manufacturers normally specify a minimum load for operation, therefore a storage system should be incorporated for off-grid applications. Also, a DC-AC converter would be needed in order to handle the stored energy.

Basically, overall system cost should include CAPEX and OPEX figures. CAPEX values are referred to diesel generator, storage system, and DC-AC converter purchase, including installation costs. OPEX values include not only operation and maintenance cost but also fuel cost which in a few cases tend to be a key aspect. Equipment lifetime must be considered in order to properly determine required replacement costs over project lifetime.

D. Wind Power Generation System

Electricity produced by wind power systems is directly correlated to local wind speed availability. It is anticipated that wind speed will certainly have different values for each month of the year, and it will even be different from day to day. Therefore, it is required to establish a daily wind speed (m/s) availability over time (hour). It should be noted that renewable energy resource availability may or may not necessarily correlate with electric energy demand not even in average values and certainly nor in occurrence over a 24-hr period. Actually, wind energy most likely will be available for the 24-hr period but in an intermittent pattern.

Basically, wind electricity production will vary throughout a day as a cubic function of wind speed. Nominal wind power capacity is expressed in terms of kW which refers to electric power to be produced by the wind energy converters only if they receive the nominal wind speed at the rotor center as specified by the manufacturer. An energy storage system is required in order to supply electricity during intervals of low resource availability. Also, a DC-AC converter would be needed in order to handle the stored energy.

For wind energy systems, CAPEX values are referred to wind energy converters, storage system, and DC-AC converter purchase, including installation costs. OPEX values include only operation and maintenance cost. Equipment lifetime must be carefully considered in order to properly determine required replacement costs, particularly for the storage system, over project duration.

IV. RESULTS

A simulation process has been conducted, using HOMER Pro, considering a reference community-type electric load located in Chimbote, Ancash, Peru.

A. Electric Power and Energy Demand

A reference electric load profile for the year 2021 is considered as follows.

TABLE I
REFERENCE ELECTRIC LOAD

Hour	kW	Hour	kW	Hour	kW
0	2	8	8	16	9
1	2	9	8	17	10
2	2	10	8	18	12
3	2	11	8	19	12
4	2	12	8	20	12
5	3	13	8	21	12
6	5	14	8	22	9
7	7	15	8	23	5

On the basis of above initial data, a daily load of 170 kWh/day would be obtained, along with a peak load of 12 kW, and a load factor of 0.59. However, in order to capture anticipated and more realistic patterns, HOMER Pro introduces Random Variability features such as 10% of day-to-day (size varies but profile shape remains constant) and 20% of timestep (size remains the same but profile shape varies). After considering those Random Variability factors, updated load profile indicates a daily load of 165.44 kWh/day, a peak load of 20.46 kW and a load factor of 0.34, which will be used in this study for simulation purposes.

B. Project lifetime and economics

Considering local financial context, for this particular case, a nominal discount rate of 12% and an expected inflation rate of 2% are considered. Therefore, a real discount rate of 9.8% would apply.

Project lifetime will be considered as 20 years which is considered as an average reference compared to renewable energy projects in the country.

C. Diesel-based Generation System

A generic diesel generator is selected using HOMER Pro Library. Also, HOMER Pro auto-size feature will be used in order to determine optimum capacity. CAPEX is estimated as 500 US$/kW while OPEX is estimated as 0.050 US$/hr. Local fuel price is considered as 1 US$/liter. Diesel generator lifetime is estimated as 15000 hours with a minimum load ratio of 20%.

A generic 1-kWh storage unit is considered. CAPEX is estimated as 300 US$/kWh while OPEX is estimated as 10 US$/yr per unit. A generic 1-kWh storage unit has 12V, and 83.4 Ah of maximum capacity. Lifetime is considered as 10 years on the basis of 800 kWh throughput, and minimum state of charge is 40%.

Also, a generic DC-AC converter unit is considered. CAPEX is estimated as 300 US$/kW while OPEX is considered to have a very low value. Lifetime is considered as 15 years with 95% of efficiency.

According to HOMER Pro algorithm, the following optimum solution is proposed: a 23-kW diesel generator, a 40-kWh storage system, and a 5.81-kW DC-AC converter. Fig. 1 shows diesel generation output, energy storage output, and expected electric load for the period Jan-Dec. 2021. In general, it is noticed that electric load can be served by a suitable combination of diesel generation and energy storage throughout the entire year.

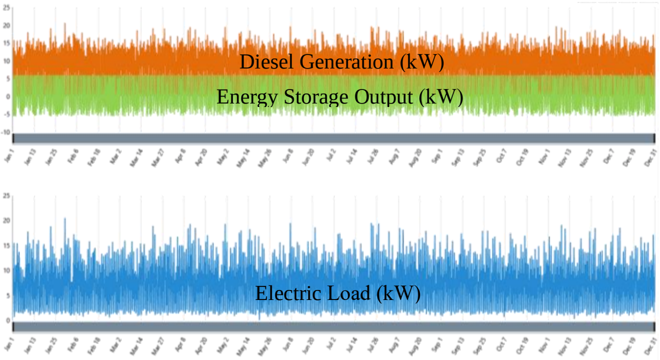

Fig. 1. Diesel generation output, energy storage output and electric load.

Total Net Present Cost for the above system is 340,916 US$ and Levelized Cost of Electricity is 0.6543 US$/kWh. Total cost for the system includes capital, replacement, operating and maintenance, fuel, and salvage for each component: diesel generator, storage system, and DC-AC converter. For the above system CAPEX is 84,460 US$ and OPEX is 29,484 US$/yr.

In the proposed system, 63,195 kWh/yr would be produced with almost no excess electricity compared to required electric load.

Total fuel consumption is 22,604 liters/yr while average fuel consumption is 2.58 liter/hour. The system will operate 5,983 hrs/yr, with a capacity factor of 31.4%, an average electric output of 10.6 kW, and an average electric efficiency of 28.4%. Diesel generator is expected to operate with a minimum electric output of 5.75 kW and a maximum electric output of 20.5 kW.

The storage system is composed by 40 units of 1-kWh capacity with a total usable capacity of 24 kWh. Autonomy is considered as 3.48 hours while expected life is 3.73 years. Energy input is 9,573 kWh/year while energy output is 7,664 kWh/yr. Annual throughput for the energy storage system is 8,568 kWh/yr.

The proposed system includes a 5.81-kW DC-AC converter with an average output of 2.28 kW. Capacity factor is 14.3%, energy input is 7,664 kWh/year while energy output is 7,281 kWh/year. In Fig. 2, a basic configuration for the proposed system is shown.

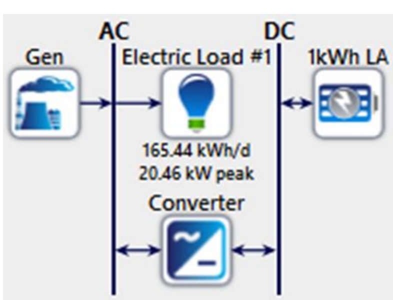

Fig. 2. Basic configuration of a diesel-based generation system

D. *Wind Power Generation System*

In general terms, Peru is considered to have high wind speed levels but not in all the regions of the country, as indicated in Ref. [08]. As a reference, Chimbote is located on the northern coastal area of Peru, with a latitude of 9°3.8' South, and a longitude of 78°35.3' West. Local wind speed is estimated on the basis of NASA Prediction of Worldwide Energy Resource (POWER) database, using monthly averages for wind speed over a 30-yr period (Jan 1984 – Dec 2013). Table II shows local wind speed for this study.

TABLE II
LOCAL WIND SPEED

Month	Wind Speed (m/s)
Jan	5.24
Feb	5.28
Mar	4.77
Apr	4.36
May	5.39
Jun	6.27
Jul	6.45
Aug	7.39
Sep	7.42
Oct	6.69
Nov	5.42
Dec	5.02

Source: NASA data built-in HOMER Pro

Local wind speed, measured at 10 m, in Chimbote has an average value of 5.81 m/s, with a range from 4.36 m/s (in April) to 7.42 m/s (in September).

A generic 3-kW wind turbine is selected using HOMER Pro Library. For a 3-kW size, CAPEX is estimated as 15000 US$ while OPEX is considered as 120 US$/yr. Hub height is 17 m and a 20-yr lifetime is considered.

As before, a generic 1-kWh storage unit and a DC-AC converter unit are select from HOMER Pro Library.

According to HOMER Pro algorithm, the following optimum solution is proposed: 45 wind energy converters of 3-kW capacity each, an 821-kWh storage system, and a 49.2-kW DC-AC converter. Fig. 3 shows wind power generation output, energy storage output, and expected electric load for the upcoming period Jan-Dec. 2021. In general, it is noticed that nominal capacity for major components is larger compared to those associated with a diesel generation system.

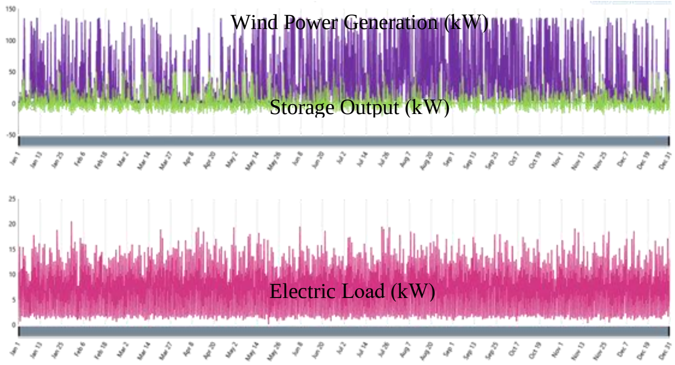

Fig. 3. Wind power generation output, energy storage output and electric load.

Total Net Present Cost for the above system is 1,152,263 US$ and Levelized Cost of Electricity is 2.21 US$/kWh. Total cost for the system includes capital, replacement, operating and maintenance, and salvage for each component: wind energy converters, storage system, and DC-AC converter. For the above system CAPEX is 1,036,309 US$ and OPEX is 25,058 US$/yr.

In the proposed system, 282,579 kWh/yr would be produced, that is 76.2% of excess electricity compared to required electric load.

The wind power system has a rated capacity of 135 kW, an average output of 32.3 kW and 774 kWh/day. Capacity factor is 23.9% and total production accounts for 282,579 kWh/yr.

The storage system is composed by 821 units of 1-kWh capacity with a total usable capacity of 493 kWh. Autonomy is considered as 71.5 hours while expected life is 10 years. Energy input is 23,359 kWh/yr while energy output is 18,708 kWh/yr. Annual throughput for the energy storage system is 20,916 kWh/yr.

The proposed system includes a 49.2-kW DC-AC converter with an average output of 2.03 kW. Capacity factor is 4.13%, energy input is 18,708 kWh/yr while energy output is 17,772 kWh/yr.

In Fig. 4, a basic configuration for the proposed system is shown.

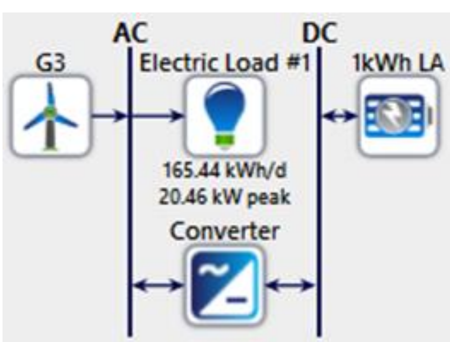

Fig. 4. Basic configuration of a wind power generation system

The highest available wind speed in Chimbote occurs during September. Fig 5. shows average daily values for wind speed (m/s) and electric load (kW). It can be noticed that, after 18h00, electric load increases while wind speed decreases.

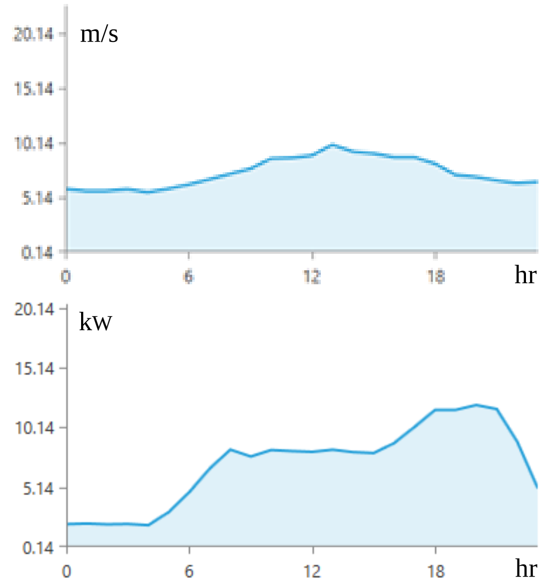

Fig. 5. Daily Wind Speed (m/s) and Electric Load (kW) in September.

On the other hand, the lowest available wind speed in Chimbote occurs during April. Fig 6. shows average daily values for wind speed (m/s) and electric load (kW). It can also be noticed that, after 18h00, electric load increases while wind speed decreases.

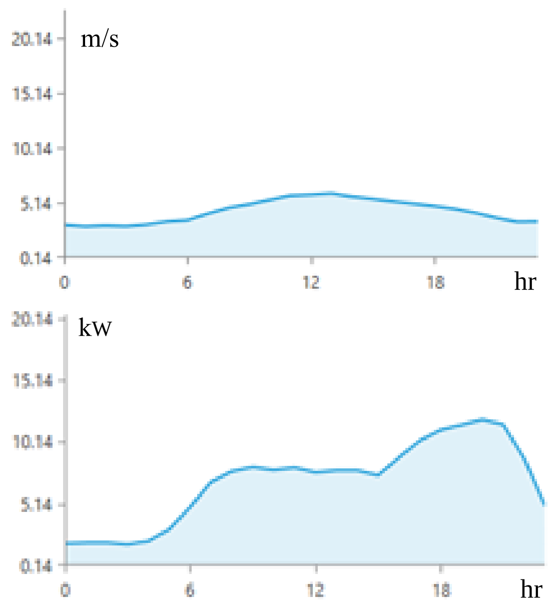

Fig. 6. Daily Wind Speed (m/s) and Electric Load (kW) in April.

With regard to the proposed system, Fig. 7 shows a maximum expected electricity excess to be produced on June

8, 2021 at 01h00. At that time, electric load would only be 1.97 kW but wind power production would be as high as 135 kW since wind speed would also be as high as 13.1 m/s.

Wind Power generation would be 135 kW, from which 1.97 kW would be used to supply the required load and 133.02 kW would be excess electricity. Storage capacity would be as high as 821 kWh which is already 100% state of charge.

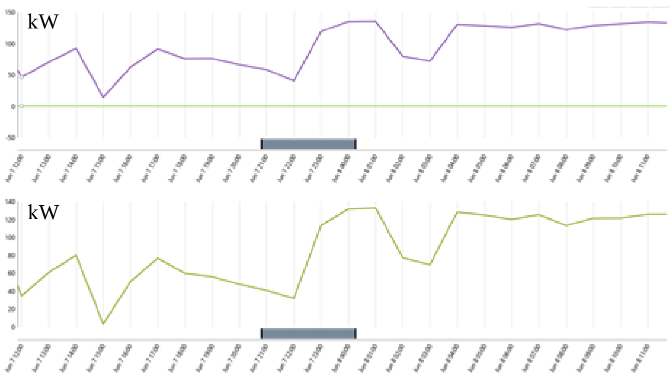

Fig. 7. Expected electricity excess for June 8, 2021.

On the other hand, Fig. 8 shows a maximum unmet electricity expected to occur on March 10, 2021 at 21h00. At that time, electric load would be 10.95 kW but wind power production would be zero since wind speed would be as low as 1.15 m/s. Storage capacity would be as low as 328.7 kWh which is 40% of total capacity, and therefore it would not be available for output as stated by the manufacturer specifications.

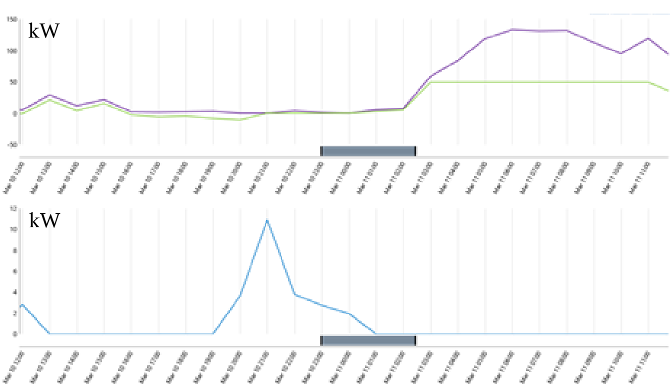

Fig. 8. Expected unmet electricity for March 10, 2021.

For comparison purposes, the outcoming levelized cost of electricity will be utilized. For a diesel-based generation system, LCOE is 0.6543 US$/kWh, and for a wind power system, LCOE is 2.21 US$/kWh. In terms of Net Present Cost, for a diesel-based generation system, NPC is 340,916 US$, and for a wind power generation system, NPC is 1,036,309 US$.

Therefore, a wind power generation system results, in this particular case, 3.4 times more expensive. However, a diesel generation system would produce CO_2 emissions that could be avoided by using a wind power generation system. Considering a factor of 2.8 $kgCO_2$/liter, it is estimated that 63.3 tCO_2/yr could be avoided.

Therefore, it is anticipated that subsequent research work would consider economic benefits associated with positive environmental impacts using, for instance, a Life-Cycle Assessment approach.

V. CONCLUSIONS

On the basis of the findings for this study, the following conclusion are outlined.

1. Electricity load is a function of both electric power (kW) and electric energy (kWh) demand. The load profile plays a significant role when considering the potential use of renewable energy sources. In this case, a 20.46-kW peak load must be served with a 34% load factor which means 6.96 kW as average load.
2. Local wind speed data plays a key role for sizing purposes. Commercial software, like HOMER Pro and others, usually rely on referential databases such NASA and similar ones; however, actual measured data could reveal a different potential for local resource availability. In this case, HOMER Pro built-in database was used for wind speed estimation due to lack of local measured data.
3. In general terms, CAPEX figures play a more significant role for a wind power generation system compared to a diesel-based generation system. In this study, 1,036,309 US$ and 84,460 US$ respectively.
4. In general terms, OPEX figures play a bit more significant role for a diesel-based generation system compared to a wind power generation system. In this study, 29,484 US$/yr and 25,058 US$/yr, respectively.
5. Carbon dioxide emissions would be avoided if a wind power generation system is implemented instead of a diesel-based generation system. In this case, 63.3 tCO_2/yr could be avoided. Future regional carbon credits may contribute to improve the feasibility of renewable energy systems.
6. Discount rates may also play a significant role for cost analysis purposes. Impact of local expected inflation rates would introduce uncertainty with regard to investments in long-term components, usually associated with renewable energy systems. In this study, a conservative estimation of 2% for inflation rate along with a typical nominal discount rate of 12% would lead to a real discount rate of 9.8%.
7. Project lifetime as well as individual component lifetime will also play a significant role in

establishing properly replacement costs, usually for fossil fuel generators and energy storage systems.

8. If cost analysis is carried out for on-grid systems, average annual renewable resource availability could be useful; however, for off-grid systems that need to meet a particular electric demand, renewable resource availability over time becomes crucial.
9. Excess electricity may be high for certain time period over the year depending on resource availability and state-of-charge of storage system, and it contributes to increase overall generation costs.
10. Levelized cost of electricity is a suitable approach for cost analysis since it incorporates not only initial costs but also operational and replacement costs during project lifetime.
11. Last but not least, further considerations of economic benefits associated with positive environmental impacts would certainly contribute to fairly include additional advantages associated with renewable energy systems.

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