A comparative cost analysis of electricity produced by a diesel and a solar-PV 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 solar photovoltaic 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 131-kW solar PV generation, a 427-kWh storage capacity, and a 24.7-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 solar radiation 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 solar radiation 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.

II. BACKGROUND

According to Ref. [01], HOMER stands for Hybrid Optimization Model for Electric Renewables. Midwest Research Institute has the copyrights of this software. It was developed by National Renewable Energy Laboratory (NREL) of United States. It is used to help the designing of various power plant configurations. It has different built-in components in it such as PV panels, Wind turbines, Utility loads of various kinds, Generators, Converters and Battery Backup etc. It is used to simulate various schematics of power plants and then those schematics are simulated to find most optimized power plant configuration with respect to operating cost, net present cost (NPC), gases emission and economic comparison etc. The demand of electricity is increasing throughout the world. Needed to design some innovative new renewables energy systems which can decrease the dependence on conventional energy resources. Analyzing different cases and according to these cases we can evaluate their power generation, pollutant gases emissions, net present cost and average electrical production cost are estimated using HOMER Pro software.

According to Ref. [02], the article contains the average daily electric load pro- file (for 24 h of the day) for the five categories of residential buildings (duplex, single family bungalow, traditional court yard, flat/apartment dwelling and 'face-me-I-face-you') in Nigeria. In each one, 10 buildings per residential building type were surveyed for the collection of data with the aid of a questionnaire. In each surveyed household, a household member completed the energy audit section of the questionnaire with the assistance of the questionnaire administrator while the section of the questionnaire designed as a time-of-use diary was left with the household for completion. For each building surveyed, the data retrieved from the completed time-of-use diary was used in Microsoft Excel for computing the hourly electricity load profile for the seven days of the week. In order to obtain the hourly energy load (in watts) for each building, the power rating of the appliances used during each of the 24 h of the day was summed and the result in watts was converted to kWh by dividing by 1000. Each dwelling's daily load profile was obtained as an average of the load profile for the seven days of the week. The article as well provides data on the solar photovoltaic systems' components designed to supply electricity to the building and the levelized cost of electricity

19th LACCEI International Multi-Conference for Engineering, Education, and Technology: "Prospective and trends in technology and skills for sustainable social development" "Leveraging emerging technologies to construct the future", Virtual Edition, July 19 - 23, 2021.

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(LCOE) of the systems for the base case scenario and different sensitivity cases obtained from simulations using HOMER Pro. The load profile data provided in this article can be reused by other researchers in the design of solar photovoltaic systems for residential buildings.

According to Ref. [03], the study evaluated the outcome differences when adopting five different solar irradiation databases on the sizing of hybrid solar photovoltaic-diesel generators designed to supply electricity to isolated mini-grids. To do this, the two most widely adopted photovoltaic (PV) simulation packages in the market, namely PVsyst® and HOMER Energy® were used. The different origins, data timespan, space and time resolution, of the five most relevant solar irradiation databases available for the region were compared. A case study was presented to illustrate the influences of the solar irradiation database and the solar simulation tool on the resulting PV generator. Furthermore, the hourly behavior of the energy supply to an existing load in a mini-grid in the Brazilian Amazon was evaluated, together with the savings in diesel obtained with the resulting PV generator. Evaluating the five options of solar radiation databases, for the same PV plant configuration, variations of up to 19.7% were found in the expectation of PV generation. When the simulation software package was varied, the combined effect (radiation database X PV system sizing tool) showed differences of up to 20.6%. This demonstrates that despite having different algorithms, computational tools have a small influence (less than 1%) on results. These combined differences, taking into account the load curve behavior and the total diesel generation capacity installed at the site, resulted in over 100% differences in the optimum PV generator size in the case study. The total savings in diesel fuel, over a 15-yr period, ranged from $ 6.5 million to over $ 16 million (> 2.5 times) for the smallest PV system. This demonstrates the importance of the correct choice of database. These evaluations can be extended to mini-grids of any size elsewhere. The novelty and originality of this study is to demonstrate and quantify for the first time the influence of the solar radiation database and the PV simulator package on the sizing of PV-diesel generators. The consequences of this study are not only of scientific and academic importance, but of economic and commercial interest as well.

According to Ref. [04], this research proposes, through HOMER, to evaluate the technical and economic feasibility of a hybrid energy system, taking advantage of solar and wind resources in a remote community in Haiti. Several configurations were analyzed, the most viable has a net present cost (NPC) of US$ 389,647 and US$ 0.497/kWh of energy cost (COE). It could produce 82,124 kW h/yr and 0% of unmet annual load. This configuration still has 9.6% excess electricity, which is important for a possible increase in load. A sensitivity analysis was performed, which shows the performance and technical feasibility of the system for future load increase.

According to Ref. [05], stand-alone solar photovoltaic (SA-SPV) systems are attractive option for rural electrification

programs in many countries. These systems are invariably provided with battery energy storage (BES) for using stored electricity during nighttime. Availability of bi-directional power electronic converter promises to enhance application of these SA-SPV systems for generating, storing and feeding electricity to local micro-grids. Further, the advantages of such systems can be maximized by minimizing energy losses at different sub-system levels in the system. In the present work, we demonstrate use of HOMER Pro simulation software for simulation of energy performance of SA-SPV (6.75 kWp) system installed in Renewable Energy Systems Laboratory in our Institute, aiming at quantitative estimation of energy losses due to stand-alone mode of operation. The system is provided with battery energy storage (800 Ah) that is used for supplying electricity for night time street lighting on campus up to eleven hours per day. The results of simulation show that when the existing SA-SPV system is upgraded to grid-tied SPV system, by incorporating bi-directional converter, the system will produce total 11086 kWh annually at the site, out of which 4536 kWh will be fed to the local single-phase micro-grid, which accounts for energy lost if the system continues to operate as SA-SPV system.

According to Ref. [06], the interest of power is expanding step by step all through the world. Because of constrained measure of fossil fuel, it is vital to outline some new non-renewable energy frameworks that can diminish the reliance on ordinary energy asset. A hybrid off-grid renewable energy framework might be utilized to reduction reliance on the traditional energy assets. Advancement of crossover framework is a procedure to choose the best mix of part and their cost that can give shabby, solid and successful option energy resource. In this framework, the essential wellspring of power is sun based solar photovoltaic system and biomass gasifier generator set while fuel cell and batteries are utilized as reinforcement supply. HOMER simulator has been utilized to recreate off the grid and it checks the specialized and financial criteria of this hybrid energy system. The execution of every segment of this framework is dissected lastly delicate examination has been performing to enhance the mixture framework at various conditions. In view of the recreation result, it is found that the cost of energy (COE) of a biomass gasifier generator set, solar PV and fuel cell crossover energy system has been found to be 15.064 Rs/kWh and complete net present cost Rs.51,890. The abundance power in the proposed framework is observed to be 36 kWh/yr with zero rates unmet electrical burden.

According to Ref. [07], it shows the approach to the design aspects of a hybrid energy system that will target educational institutes. The purpose of this work is the computation, simulation & optimization of hybrid energy system. The hybrid energy system comes from the biomass gasifier generator set, solar and fuel cell with battery storage system to fulfill partially load requirement of Energy Centre, MANIT Bhopal. The computation software used for this work is HOMER Pro 3.2.3. HOMER Pro is a design simulation model that analyzed the sizing, costing optimization and

control strategy of the hybrid energy system. The analysis of such hybrid energy systems feeding AC primary load of 101 kWh/day energy consumption with a 5-kW maximum load demand. The simulation results show that optimized size of components, biomass gasifier (5 kW) – solar (5 kW) – fuel cell (5 kW) and optimized cost of energy about 15.064 Rs/kWh.

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 solar PV 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:

$$E = P \times t \tag{1}$$

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:

$$LF = DEE / (MED \times 24 \text{ hours}) \tag{2}$$

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:

$$LCOE = (CAPEX-A + OPEX) / E \tag{3}$$

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:

$$CAPEX\text{-}A = CAPEX \times [i \times (1+i)^n/(1+i)^n-1] \tag{4}$$

where:

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

With regard to discount rates, the following relationship applies:

$$NDR = DRD + EIR + DRD \times EIR \tag{5}$$

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. Solar Photovoltaic Generation System

Electricity produced by solar photovoltaic (PV) systems is directly correlated to local solar radiation availability. It is anticipated that solar radiation 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 solar radiation (W/m^2) 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, solar energy most likely would only be available at most from 06h00 to 18h00.

Basically, solar PV electricity production will vary during the day as a function of solar radiation. Nominal PV capacity is expressed in terms of kWp which refers to electric power to be produced by the PV modules only if they receive a solar radiation of 1 kW/m^2. An energy storage system is required in order to supply electricity during night time and other intervals of solar resource unavailability. Also, a DC-AC converter would be needed in order to handle the stored energy.

For solar PV systems, CAPEX values are referred to solar PV modules, storage system, and DC-AC converter purchase, including installation costs. OPEX values include only operation and maintenance cost, and it is usually regarded as a low cost, particularly for solar PV modules. 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 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, 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

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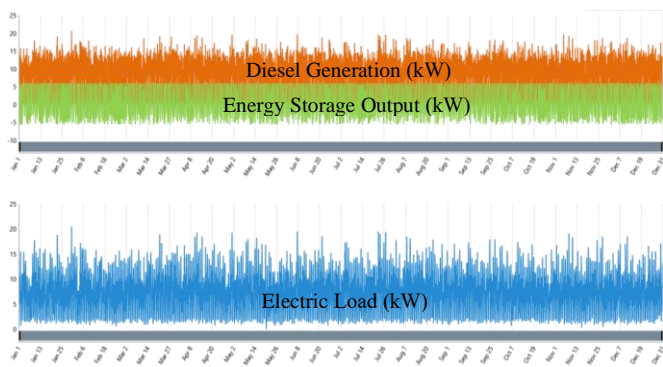suitable combination of diesel generation and energy storage throughout the entire year.

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/hr. 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/yr 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/yr while energy output is 7,281 kWh/yr. In Fig. 2, a basic configuration for the proposed system is shown.
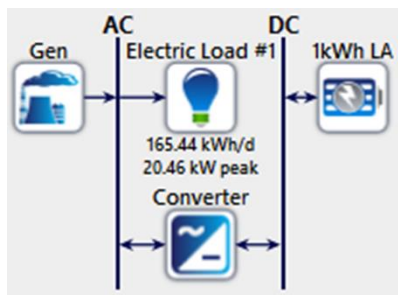

Fig. 2. Basic configuration of a diesel-based generation system

D. Solar Photovoltaic System

In general terms, Peru is considered to have high solar radiation 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 solar radiation is estimated on the basis of NASA Prediction of Worldwide Energy Resource (POWER) database, using monthly averages for global horizontal radiation over 22-yr period (Jul 1983 – Jun 2005). Table II shows local solar radiation for the present study.

TABLE II
LOCAL SOLAR RADIATION

Month	Clearness Index	Daily Radiation (kWh/m2-day)
Jan	0.473	5.03
Feb	0.536	5.75
Mar	0.557	5.86
Apr	0.542	5.35
May	0.537	4.87
Jun	0.519	4.47
Jul	0.487	4.28
Aug	0.5	4.74
Sep	0.483	4.93
Oct	0.477	5.06
Nov	0.478	5.07
Dec	0.506	5.34

Source: NASA data built-in HOMER Pro

Local solar radiation in Chimbote has an average value of 5.06 kWh/m^2-day, with a range from 4.28 kWh/m^2-day (in July) to 5.86 kWh/m^2-day (in March).

A generic PV flat plate is selected using HOMER Pro Library. For a 1-kWp size, CAPEX is estimated as 1500 US$/kWp while OPEX is considered as 30 US$/yr. Also, a derating factor of 80% for a 20-yr period will be used.

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: a 131-kW solar PV system, a 427-kWh storage system, and a 24.7-kW DC-AC converter. Fig. 3 shows solar PV 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.
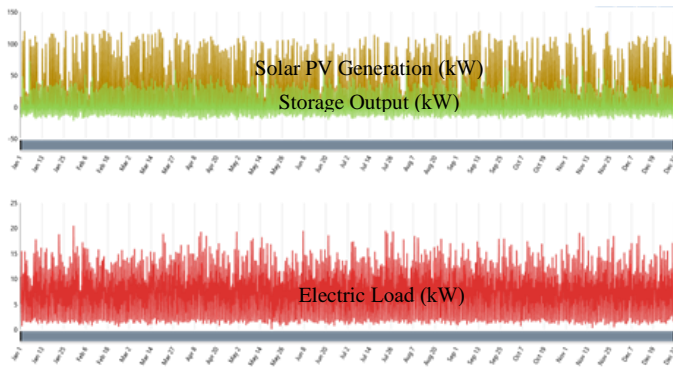
Fig. 3. Solar-PV generation output, energy storage output and electric load.

Total Net Present Cost for the above system is 453,294 US$ and Levelized Cost of Electricity is 0.8706 US$/kWh. Total cost for the system includes capital, replacement, operating and maintenance, and salvage for each component: solar PV system, storage system, and DC-AC converter. For the above system CAPEX is 383,414 US$ and OPEX is 14,136 US$/yr.

In the proposed system, 193,362 kWh/yr would be produced, that is 63.3% of excess electricity compared to required electric load.

The solar PV system has a rated capacity of 131 kWp, an average output of 22.1 kW and 530 kWh/day. Capacity factor is 16.9% and total production accounts for 193,362 kWh/yr.

The storage system is composed by 427 units of 1-kWh capacity with a total usable capacity of 256 kWh. Autonomy is considered as 37.2 hours while expected life is 10 years. Energy input is 37,648 kWh/yr while energy output is 30,199 kWh/yr. Annual throughput for the energy storage system is 33,764 kWh/yr.

The proposed system includes a 24.7-kW DC-AC converter with an average output of 6.89 kW. Capacity factor is 27.93%, energy input is 63,515 kWh/yr while energy output is 60,339 kWh/yr.

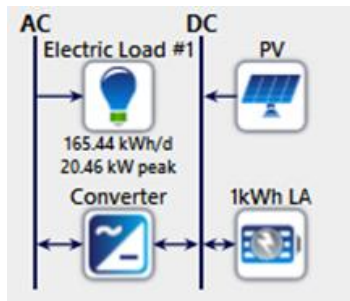In Fig. 4, a basic configuration for the proposed system is shown.

Fig. 4. Basic configuration of a solar-PV generation system

The highest available solar radiation in Chimbote occurs during March. Fig 5. shows average daily values for solar radiation (kW/m^2) and electric load (kW). It can be noticed

that, after 15h00, electric load increases while solar irradiation decreases.
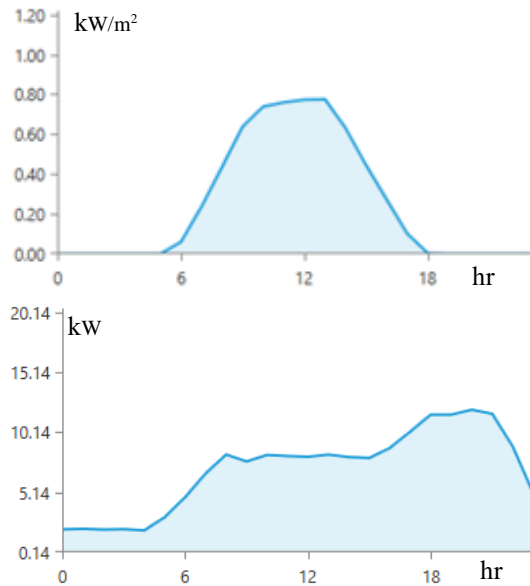

Fig. 5. Daily Solar Radiation (kW/m^2) and Electric Load (kW) in March.

On the other hand, the lowest available solar radiation in Chimbote occurs during September. Fig 6. shows average daily values for solar radiation (kW/m^2) and electric load (kW). It can also be noticed that, after 15h00, electric load increases while solar radiation decreases.
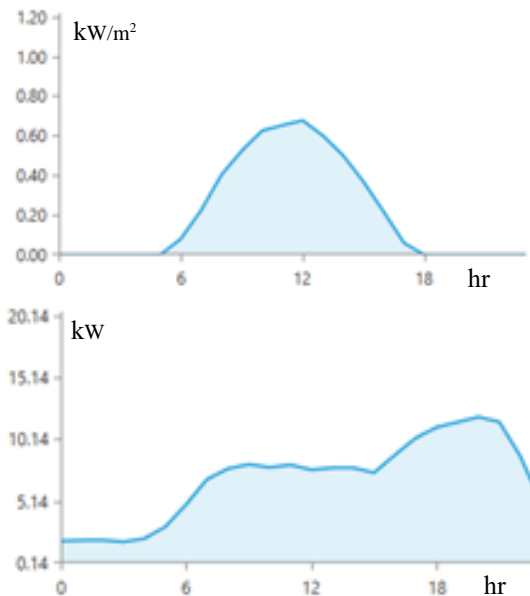

Fig. 6. Daily Solar Radiation (kW/m^2) and Electric Load (kW) in September.

With regard to the proposed system, Fig. 7 shows a maximum expected electricity excess to be produced on November 14, 2021 at noon. At that time, electric load would only be 7.86 kW but solar PV production would be as high as

123.18 kW since solar radiation would also be as high as 1.21 kW/m².

Solar PV generation would be 123.18 kW, from which 4.19 kW would be used to contribute charging the storage system, 8.28 kW would be as input for the DC-AC converter unit, and 110.72 kW would be excess electricity. Considering an efficiency of 95%, DC-AC converter output would be 7.86 kW as required by the electric load at that moment.
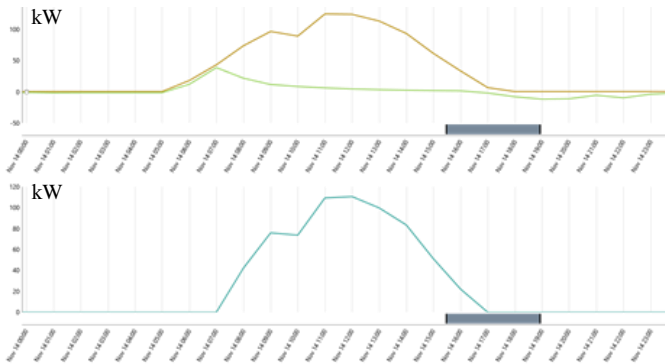

Fig. 7. Expected electricity excess for November 14, 2021.

On the other hand, Fig. 8 shows a maximum unmet electricity expected to occur on August 4, 2021 at 21h00. At that time, electric load would be 12.02 kW but solar PV production would be zero since solar radiation would also be zero. Storage capacity would be as low as 170.94 kWh which is 40% of total capacity, and therefore it would not be available for output as stated by the manufacturer specifications.
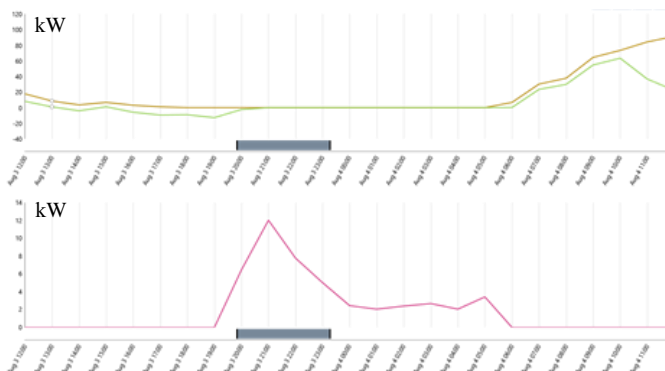

Fig. 8. Expected unmet electricity for August 4, 2021.

For comparison purposes, the outcoming levelized cost of electricity will be utilized. For a diesel-based generation system, LCOE is 0.6543 US$/kWh, and for a solar PV system, LCOE is 0.8706 US$/kWh. In terms of Net Present Cost, for a diesel-based generation system, NPC is 340,916 US$, and for a solar-PV generation system, NPC is 453,294 US$.

Therefore, a solar-PV generation system results, in this particular case, 33% more expensive. However, a diesel generation system would produce CO_2 emissions that could be avoided by using a solar-PV 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 solar radiation 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 solar radiation estimation due to lack of local measured data.
3. In general terms, CAPEX figures play a more significant role for a solar-PV generation system compared to a diesel-based generation system. In this study, 383,414 US$ and 84,460 US$ respectively.
4. In general terms, OPEX figures play a more significant role for a diesel-based generation system compared to a solar-PV generation system. In this study, 29484 US$/yr and 14136 US$/yr, respectively.
5. Carbon dioxide emissions would be avoided if a solar-PV 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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