Evaluation of Solar and Wind Hybrid Power Potential for Lambayeque Region in Peru

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Renewable Energy has been receiving increasing attention worldwide, and in recent years also in Peru. As from 2010, the so called Renewable Energy Resources (RER) have entered the Peruvian Wholesale Energy Market through a bidding process that includes solar, wind, biomass, and hydroelectric (up to 20 MW of installed capacity) plants. Currently, solar energy contributes with 3,6% of total energy during daytime, while wind energy contributes with 2,3% of total energy during daytime, and 4,8% of total energy during night time.

Reference Data associated with Solar and Wind Resources availability have been elaborated in recent years by local agencies. Field measurements of solar irradiation (W/m^2) and wind power density (W/m^2) have been carried out in order to compare with reference data.

A preliminary evaluation of a hybrid system composed by a 1-kW solar power sub-system and a 1-kW wind power sub-system show an adequate feasibility for rural applications with a LCOE of 0,139 US$/kWh which is lower than the electricity cost associated with the use of a diesel generator.

Renewable Energy, Solar Irradiation, Wind Power Density, Hybrid Systems, Electricity Generation

I. Introduction

A. Renewable Energies Resources in Peru

Renewable Energy Resources (RER) were established as a especial energy category in 2008 as a result of Decret Law 1002. In Peru the term RER includes solar, wind, biomass, and hydropower (up to 20 MW of installed capacity) plants.

In 2010, a 23-MW capacity cogeneration plant that runs on biomass started to sell electricity to the main grid. Also, in 2011, a 4,5-MW capacity thermal plant that runs on biogas (produced at a landfill) started to sell electricity to the main grid. Besides, in 2012, four 20-MWp solar power plants started to run, and one year later, another 13-MW solar power plant also started operations. Furthermore, in 2014, the first wind power park started operations with a 32-MW installed capacity. In the same year, another wind power park, with 30-MW and 80-MW installed capacities also started operations.

Last year, a 145-MWp solar power plant and a 132-MW wind power plant also started operations. The renewable energy projects were implemented through a bidding process that took place in 2010, 2011, 2013 and 2016. Next bidding process is expected for 2019.

B. Electricity Generation in Peru

Electricity generation in Peru is based mainly on hydropower and natural gas plants. Also, coal, fuel oil, and diesel power plants are used. With regard to RER power plants participation, solar, wind, and biomass generation is accounted for. In Table 1, current electricity generation mix is shown.

In Peru, peak time period is considered from 18h00 to 23h00. Sundays and holidays are not including for tariff calculation purposes. In Table 1, it can be seen that the maximum power demand in February 2019 occurred at 19h00. At that time, solar power contribution was certainly zero. Meantime, wind power contribution accounted for around 4,8%. On the other hand, daytime peak power demand was reached at 11h30. At that time, solar power contribution accounted for around 3,6%. Meantime, wind power contribution was 2,3%. Thus, it can be observed some kind of complementation between solar and wind power production.

TABLE I
CURRENT ELECTRICITY GENERATION MIX IN PERU

ENERGY	ENERGY PRODUCED (MW.h)			
RESOURCE	11h30	%	19h00	%
DIESEL	1200	0.0%	1200	0.0%
FUEL OIL	25000	0.4%	24600	0.4%
COAL	0	0.0%	0	0.0%
NATURAL GAS	1770761	28.2%	1506585	25.0%
HYDROPOWER	4111708	65.4%	4198604	69.6%
BIOGAS	8800	0.1%	9450	0.2%
BAGASSE	0	0.0%	0	0.0%
SOLAR	224568	3.6%	0	0.0%
WIND	145430	2.3%	290834	4.8%
TOTAL	6287467	100.0%	6031273	100.0%

Source: COES-SINAC 2019

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II. SOLAR AND WIND RESOURCE ASSESSMENT

A. Solar Irradiation Map

In 2003, as a result of a joint collaboration between the Ministry of Energy and Mines and the Local Weather Agency (SENAMHI), a solar atlas was elaborated for all the 24 regions of Peru.

Solar irradiation data was based on simulation techniques and also on data measured from 1975 to 1990. Average daily solar irradiation levels may vary from 3,0 to 7,5 kW.h/m^2-day in some parts of the country.

For illustration purposes, Table II shows average reference data for each region of Peru. However, different solar irradiation levels can be observed in some areas within the same region. Also solar irradiation values vary among the different months of the year, considering three major regions in the country: coast, highland, and jungle.

Some regions show an important potential for solar power generation, including Arequipa, Moquegua, and Tacna. That is why most of the large scale solar power plants are based in that area. Also, Lambayeque and Piura show good potential for solar power generation.

The first large scale solar power plants in Peru started to be built in 2010 an entered into operation in 2012.

TABLE II
SOLAR IRRADIATION REFERENCE DATA

Region	W/m2-day	Region	W/m2-day
Amazonas	5.5	Lambayeque	6.5
Ancash	6.0	Lima	5.0
Apurimac	6.5	Loreto	4.5
Arequipa	7.0	Madre de Dios	5.0
Ayacucho	6.5	Moquegua	7.0
Cajamarca	6.0	Pasco	5.5
Cuzco	5.5	Piura	6.5
Huancavelica	6.0	Puno	5.5
Huanuco	5.0	San Martin	5.5
Ica	6.5	Tacna	7.0
Junin	5.5	Tumbes	6.5
La Libertad	6.5	Ucayali	5.0

Source: Solar Atlas Peru 2003.

B. Wind Speed Map

In 2008, as a result of a joint collaboration between the Ministry of Energy and Mines and an international consulting firm, a wind atlas was elaborated for all the 24 regions of Peru.

Wind speed data was based on simulation techniques and also on data measured using instrumentation specific for this purpose. Average wind speed at 100 m height may vary from 3,0 to 11,0 m/s in some parts of the country.

For illustration purposes, Table III shows average reference data for each region of Peru. However, different wind speed levels can be observed in some areas within the same region. Also wind speed values vary among the different months of the year, considering three major regions in the country: coast, highland, and jungle.

Some regions show an important potential for wind power generation, including Nazca and Marcona (within the Ica region). That is why a couple of large scale wind power plants are based in that area. Also, Piura shows good potential for solar power generation, and that is why a couple of large scale wind power plants are also based in that area. Besides, other regions such Lambayeque and La Libertad show good potential for wind power generation.

The first large scale wind power plants in Peru started to be built in 2010 an entered into operation in 2014.

TABLE III
WIND SPEED REFERENCE DATA

Region	m/s	Region	m/s
Amazonas	5.0	Lambayeque	6.5
Ancash	5.0	Lima	5.5
Apurimac	4.0	Loreto	4.0
Arequipa	6.5	Madre de Dios	4.0
Ayacucho	5.0	Moquegua	6.0
Cajamarca	9.0	Pasco	4.0
Cuzco	4.0	Piura	9.0
Huancavelica	5.0	Puno	5.0
Huanuco	4.0	San Martin	4.0
Ica	10.0	Tacna	6.0
Junin	4.0	Tumbes	5.0
La Libertad	7.0	Ucayali	4.0

Source: Wind Atlas Peru 2008.

Also, from Table II and Table III, it can be inferred that there are some regions wherein both solar and wind power generation show good potential, such Lambayeque for instance.

III. SOLAR IRRADIATION AND WIND SPEED MEASUREMENTS

A. Solar Irradiation Measurement

As part of the present study, solar irradiation in Lambayeque was measured. For illustration purposes, Figure 1 shows data registered for a typical day, starting at around 06h00 and ending at around 18h00. Highest solar irradiation is observed at around noon reaching 1250 W/m^2.

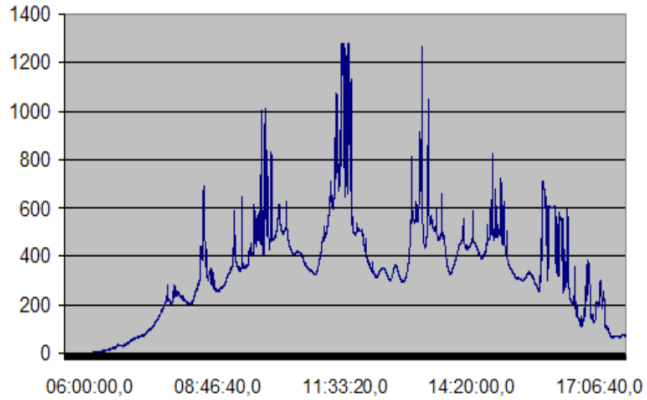

Fig. 1. Solar irradiation (W/m^2) measured in Lambayeque.

B. Wind Speed Measurement

As part of the present study, wind speed in Lambayeque was measured. For illustration purposes, Figure 2 shows data registered for a typical day, starting at around 17h00 and ending at around 01h00 next day. Highest wind speed is observed at 17h00 reaching 9 m/s.

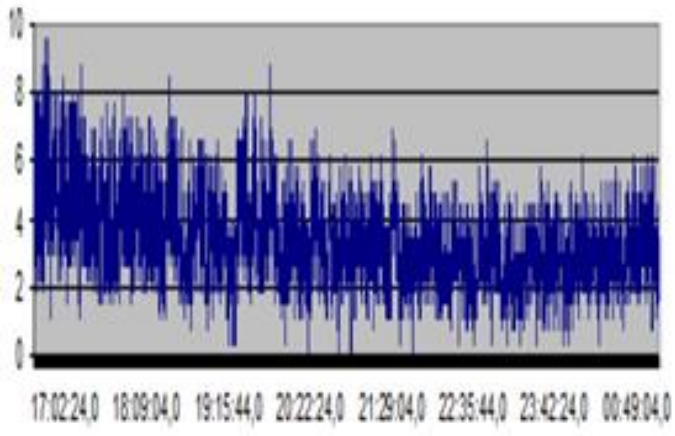

Fig. 2 Wind speed (m/s) measured at 15 m. in Lambayeque.

From Figure 1 and Figure 2, it can be noticed that solar irradiation and wind speed levels depicted in the solar and wind maps can be considered as a valid reference.

III. FEASIBILITY OF HYBRID ENERGY SYSTEMS

For illustration purposes, a hybrid energy system composed of a 1-kW solar power sub-system and a 1-kW wind power sub-system is considered for feasibility evaluation under local conditions in Lambayeque.

Average energy delivered by the solar power sub-system operating under solar irradiation conditions in Lambayeque would account for 6.5 kWh/day. Considering an accumulation system using 12 VDC, storage capacity would be 542 Ah. Thus, considering one day as autonomy or reserve period and 0,6 depth of discharge would result in 6 batteries of 150-Ah capacity each.

Also, average energy delivered by the wind power sub-system operating under wind speed conditions in Lambayeque would account for 10,8 kWh/day considering a plant factor of 0,4. Considering an accumulation system using 12 VDC, storage capacity would be 900 Ah. Thus, considering a 0,6 depth of discharge would result in 10 batteries of 150-Ah capacity each.

CAPEX for solar power sub-system is estimated as 3000 US/kW while OPEX is estimated as 0.02 US$/kWh. Considering a life cycle of 20 years and a 12% discount rate, a CAPEX of 401,64 US$/yr and an OPEX of 47.45 US$/yr are obtained. Also, CAPEX for wind power sub-system is estimated as 2000 US$/kW while OPEX is estimated as 0,035 US$/kWh.

Considering a life cycle of 15 years and a 12% discount rate, a CAPEX of 293,65 US$/yr and an OPEX of 137,97 US$/yr are obtained. Overall costs for a solar-wind hybrid system result as a CAPEX of 695,28US$/yr and an OPEX of 185,42 US$/yr.

Thus, levelized cost of energy (LCOE) for the energy hybrid system becomes 0.139 US$/kWh which is lower than the LCOE for a typical diesel generator. Therefore, a solar-wind power hybrid systems turns to be a better option for rural areas under renewable energy resource availability in the Lambayeque region, considering that diesel generators require spare parts and significant maintenance which tend to be difficult to comply in rural areas. Besides, the utilization of fossil fuels tends to increase carbon dioxide emissions among others.

IV. CONCLUSIONS

The role of Renewable Energy Resources (RER) for electricity generation in Peru has started to increase in Peru. Nowadays, solar energy contributes with 3,6% of total energy during daytime, while wind energy contributes with 2,3% of total energy during daytime, and 4,8% of total energy during night time.

According to reference data, solar irradiation may vary from 3,0 to 7,5 kW.h/m^2 in Peru, while wind speed (measured at 100 m.) may vary from 3,0 to 11,0 m/s in Peru. There are some regions, such Lambayeque that show good potential for both, solar and wind power applications. Solar irradiation and wind speed measurements carried out in Lambayeque are consistent with average data from the solar and wind maps elaborated in previous years by local agencies.

A preliminary evaluation of a hybrid system composed by a 1-kW solar power sub-system and a 1-kW wind power sub-system show an adequate feasibility for rural applications. Under local conditions in Lambayeque, such hybrid system would produce 6,5 kWh/day (solar power) and 10,8 kWh/day (wind power).

Considering a CAPEX of 2000 US$/kW and an OPEX of 0,02 US$/kWh for the solar power sub-system with 20 years of life cycle, a CAPEX of 3000 US$/kW and an OPEX of 0,035 US$/kWh for the wind power sub-system with 15 years of life cycle, and a discount rate of 12%, an LCOE of 0,139 is obtained. Thus, it is concluded that a solar-wind hybrid system may be feasible for rural applications in Lambayeque.

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