A METHODOLOGY TO IDENTIFY MOST PROMISING AREAS FOR THE IMPLEMENTATION OF HYBRID PHOTOVOLTAIC WIND ENERGY SYSTEMS

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Abstract. *The purpose of this paper is to present a technical study on the inclusion of HPS (Hybrid Power Systems) for electricity supply in isolated communities in Argentina. Based on the location of rural areas with higher levels of electrification needs and a better quality for the utilization of solar photovoltaic and wind energy, we evaluate the possibility of using solar and wind power resources to operate independently or in a hybrid system configuration. Four simulations were performed, considering different possible combinations for the HPS: wind-solar-diesel, solar-diesel, wind-diesel and wind-solar. To perform these simulations, the software HOMER®, develop by the NREL was used. The results obtained from the model, showed that the wind-solar-diesel HPS configuration generates the cheapest kWh. And after having performed a comparing study of costs for extending a conventional network of 30 km and the installation and operation of the wind-solar-diesel HPS, it could be determined that the latter option is feasible, reaching economy savings of over 51,000.00 U$D at the end of the project life.*

Keywords*: Electrical system, rural electrification, hybrid power system, computer simulation, HOMER®, Argentina.*

1. INTRODUCTION

Energy is essential to the quality of human life and is considered a fundamental input in productive activities, taking an important role in the development of mankind.

The production and consumption of energy has a strong interaction with the environment. The use of fossil fuels leads to the exhaustion of their reserves and the use of renewable resources acts in detriment of their future availability. The use and consumption of energy implies multiple impacts on soil, water and atmosphere, resulting from their production, conversion and use.

In the case of Argentina, the total installed capacity is approximately 30.8 GW, and the annual generation reached 121.9 GWh/year in 2008 (Secretaría de Energía Argentina, 2009). The country has an electric grid that includes 28,933 km of high voltage overhead lines which cover most of the country (CAMMESA, 2009). The share of renewable energy in Argentina is around 37%, but 35.3% are related to the large-scale Hydropower, and only 1.7% for other sources. The main sources of renewables are the Eolic, which represents 0.1% of total installed power, and the Small Hydro Power (SHP), less than 30 MW, with a contribution of 1.6%. Solar energy has been used on a reduced scale, having no significant participation in the Argentinian energy matrix (Secretaría de Energía Argentina, 2009).

Despite of being Argentina a self-sufficient energy country, it has almost two million people without access to electricity, equaling 5% of its total population, most of which lives in rural areas (INDEC, 2001). Although there are remote areas that have no electricity, the biggest problem faced by the Argentinian government are the regions within the greater economic and industrial development provinces, which also have no access to electricity, gas or water.

The search of new alternatives to supply electricity for those areas represents a challenging task in the National Strategic Energy Plan, especially when considering that, in order to have a better quality of life, rural dwellers should acquire urban consumption habits. As the possibility of distributed generation is almost unexplored in Argentina, we believe that the utilization of autonomous systems that use renewable energy resources would contribute with a new perspective in this field. A proper evaluation of this new concept must then be carried out.

The present work comprehensively analyses the possible areas for the deployment of a wind-solar Hybrid Power System (HPS) for electricity supply. The entire Argentinian territory is taken into account, including areas that lack access to electricity and are far from large centers, as well as areas around the major consumption centers, that do not have access to the grid either. In order to investigate the possibility of using alternative energy sources, the wind and solar power resource in Argentina are detailed. Finally, a study on the implementation of a HPS for power supplying in communities without access to the grid is carried out, in which a wind-solar hybrid system is scaled considering the possibility of using a diesel generator as a back-up.

2. IDENTIFICATION OF THE REGIONS BASED ON ITS NATURAL RESOURCES

In order to qualify for the installation of a wind-solar HPS, a region must meet two basic conditions: high need for electrical supply and great wind or, solar potential, or preferably both.

The aim of this work is to study the implementation of a wind-solar HPS. In this context, we should seek for a region in which both resources are complementary.

The initial phase is the identification and preliminary assessment of potential areas where the system could be installed. This stage can be performed for both solar and wind energy through the use of solar and wind resource maps, and general meteorological data based on nature (PRADO, 2009). However, it is worth noting that these procedures represent only an indicative of the potential available at a given site and should not be the only assessment methods. On site measurements are essential to ensure that there is potential to justify the investment.

Below there is a description of the procedures to characterize the two resources that will be used in this work: solar and wind.

2.1. Solar Resource

Generally, two kinds of measurements of the solar resource for energy production application are used. One of them only records the component of global radiation and the other one records the direct and diffuse components of radiation so as to obtain the incoming global radiation based on those values (MACEDO, 2005).

The most common way of presenting the solarimetric measured data is in terms of energy per unit area, or irradiation on the horizontal plane. Data can also be obtained in the form of density of radiation incident on a given surface (irradiance). From accurate analysis over a long period of time, an average value corresponding to a specific period, for example, an average day for the period of a month is usually calculated.

The resource was characterized in the areas studied based on the "Atlas of Solar Energy of Argentina" (GROSSI, 2007), which presents a set of monthly distribution of mean global radiation and hours of sunlight (effective insolation) maps for the different months of the year.

For the northern region of the country, the Atlas presents mean daily global irradiation values on the horizontal plane ranging from a minimum of 3.0 (kWh/m^2/day) for the month of June (winter) to 7.5 (kWh/m^2/day) in January (summer), showing values over 4.0 (kWh/m^2/day) during most of the year. The reference (GROSSI et al., 2009) considers that the minimum theoretical value to justify the use of a photovoltaic system is 4.5 (kWh/m^2/day).

In the southern region of the country, values have a greater range of variation throughout the year, ranging from 1.0 (kWh/m^2/day) in June (winter) to 6.5 (kWh/m^2/day) in January (summer). Mean values are much lower than those measured in the northern region, a fact that practically rules out the use of this technology in this region.

In the central region values range from 2.0 (kWh/m^2/day) to 6.5 (kWh/m^2/day) which represents a good opportunity for the installation of a photovoltaic system for energy production.

2.2. Eolic Resource

To characterize the wind resource, we used the "GIS, Wind Potential National Map" (CREE, 2007), performed by the IT Department of the Secretariat for Coordination and Control, Ministry of Federal Planning, Public Investment and Services and the Regional Centre for Wind Energy (CREE), located in the Province of Chubut.

The wind data was obtained from the analysis of the last five years in various weather stations, most of which belong to the National Weather Service.

From the Atlas analysis, it was found that there are two standout areas, showing the highest values of average wind speed. Firstly, there is the Patagonia region, which has the best registry not only nationwide, but also worldwide (6 m/s to 13 m/s). Secondly, there is the province of Buenos Aires, more specifically the areas along the Atlantic coast, where the average wind speed reaches 6-8 m/s.

It is important to say that this work only analyses the average wind speed as a parameter to compare the different sites. Other features such as weather, constancy, directionality, or turbulence should be considered in a wind project (ROBERTS, 2008). However, as a first grade of the wind resource quality, the average speed is the most significant parameter.

2.3. Geographical sitting

From the information exposed above, it could be concluded that the Argentinian Atlantic coast, specifically the region of General Pueyrredón, part of the Province of Buenos Aires, is the area with good levels of solar radiation throughout the year and excellent records of average wind speed. Referring to CAMESSA in its annual report for 2009, it was found that this region has isolated areas that are not provided with electricity supply. Because of these characteristics, the area of General Pueyrredón was chosen to carry out the technical study for the installation of HPS.

The district of General Pueyrredón has a surface of 1,460 km^2 and a population of 564,056 inhabitants. An important fact is that 96% of the total district population (541,733 inhabitants) resides in the city of Mar del Plata, which represents only 5.47% of the total district territory (80 km^2) (INDEC, 2001). The district is bordered by the Argentinian Sea (Atlantic Ocean) to the East, which represents a large exhibition area of 40 km coastline.

3. ACQUISITION PROCEDURE OF WEATHER INFORMATION

In this stage more accurate weather information was used: from time series of solar radiation and wind speed, it is possible to calculate the hourly energy produced by HPS.

In order to determine the optimal configuration of HPS that could guarantee the load needs at all times, the software HOMER® - Hybrid Optimization Model for Electric Renewables (HOMER, 2011) was used. HOMER® is a computer model developed by NREL (National Renewable Energy Laboratory), which performs a technical and economic analysis comparing various possible configurations of a hybrid system, looking for the optimum operating point. As a first step, the software simulates the operation of the energy system for each hour of the year based on input information such as component costs and natural resources (wind, solar, biomass). Other information set into the software are the system costs throughout its life cycle. After modeling the system, the software displays a list of results with all the possible combinations that meet the conditions for properly delivering energy to the load. The results are sorted by the kilowatt hour (kWh) cost for electricity generated.

In the next stage the available solar and wind resources are estimated for the region under analysis.

3.1. Solar resource availability

The solar radiation values were obtained from a meteorological station located in the city of Balcarce, which is located west of the General Pueyrredón district. Unlike the data on wind speed, solar radiation data is not highly influenced by the distance between the measurement site and the location of the solar system. So, working with radiation data measured at a point located 70 kilometers from the site under consideration does not cause a significant error. The values used for the study are presented in Tab. 1.

Table 1. Solar radiation data, meteorological station of INTA, Balcarce

BALCARCE	**LATITUDE:** 35º75' S				**LONGITUDE:** 58º17' W				**HIGH:** 130 m			
	JAN	**FEV**	**MAR**	**ABR**	**MAY**	**JUN**	**JUL**	**AUG**	**SET**	**OCT**	**NOV**	**DEC**	**Avg**
(kWh/m^2/day)	6.6	6.2	4.7	3.3	2.2	1.7	1.8	2.7	3.6	5.2	6.2	6.7	**4.2**

From this information, HOMER® software creates synthetic solar data corresponding to a series of 8,760 values of irradiation, one for each hour of the year. The software uses a mathematical algorithm to create hourly data, using additional data such as latitude and longitude of the place. Although the system is not working with real hourly data, the simulations performed by the software reproduce results closer to reality. Figure 1 shows the empirical range of values synthetized for the months of December, March, June and September.

From these series of empirical solar radiation, the power of the photovoltaic generator system and the number of panels are estimated.

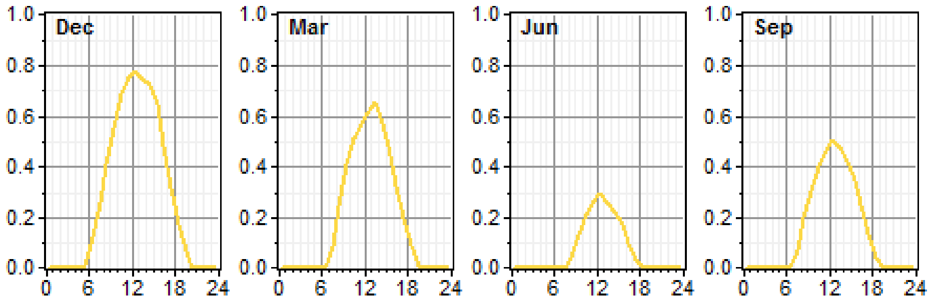


Figure 1. Solar radiation of a typical day considering seasonality (kW/m^2)

3.2. Eolic resource availability

To obtain the power generated by wind turbine, we must first know the average wind speed at the site, which is usually measured by anemometers located ten meters off the ground.

In this case, the data used is supplied by the meteorological station located at Mar del Plata airport, which lies east of the General Pueyrredón district having latitude: 37º56' S and longitude: 57°35' W. Measurements were made at ten meter tall, with an acquisition interval of one hour, recording the average wind speed and direction. The measurement period used in this work were the years 2005 and 2006. Table 2 shows the results of statistical analysis from the series.

Table 2. Statistical analysis results

Average Velocity (Vm)	3.80
Standard deviation	2.38
Minimum (higher 1.5 m/s)	1.67
Maximum	15.56
Number of data	17,411
Calms (lower 1.5 m/s)	13.31%

From the time series, the frequency distribution of wind speed, which is a graphical representation to visualize how the wind intensity is distributed and which range of speed occurs most frequently within the data series, can be obtained. To simplify the work with time series, a probability density function is used, so called Weibull distribution, which is used for long-term prognosis in estimating the potential for electricity generation. The Weibull distribution is very useful because it simplifies the process of calculations and avoids working with the entire set of data obtained in measurements. This function depends on two parameters, a shape factor (k) and a scale factor (c) (CAMERLYNCK, 2004). Figure 2 shows the frequency distribution obtained from the time series, with a rank of speed of 1 m/s. The same figure also shows the Weibull function that best fits this frequency distribution, which has the parameters k = 1.75 and c = 4.24.

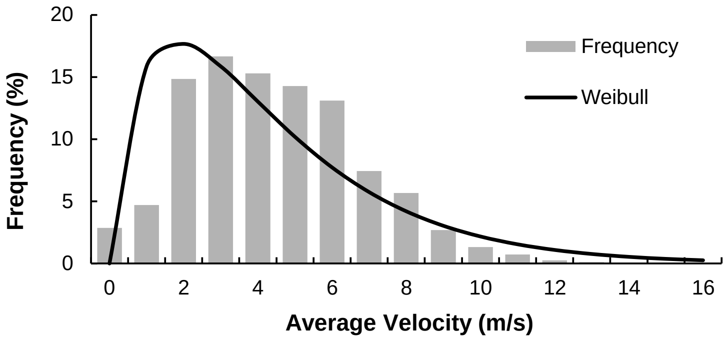


Figure 2. Wind speed frequency distribution and probability density function of Weibull

With the data obtained from the meteorological station of Mar del Plata airport, curves of hourly average wind speed throughout the day were graphed. Figure 3 shows these results for the month representing a season, i.e. December (summer), March (autumn), June (winter) and September (spring).

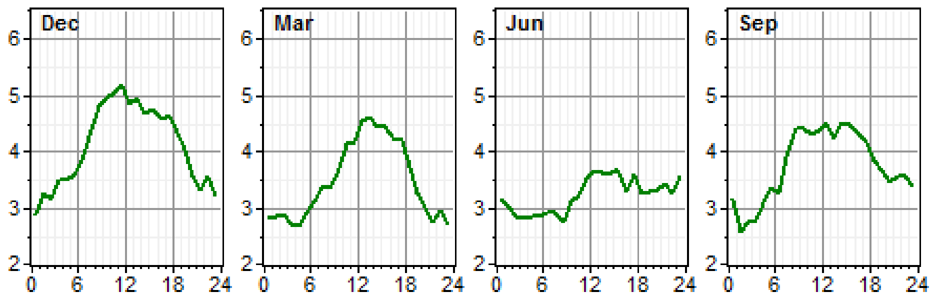


Figure 3. Wind speed distribution of a typical day considering seasonality (m/s)

3.3. Wind and solar energy availability at the site

From the information of wind and solar resource presented earlier the specific energy available, or the available energy content, expressed in kWh/m^2, can be estimated. The amount of energy the HPS will effectively generate depends mainly on the energy conversion efficiency of the solar panels and on the wind turbine chosen to construct the system. For the local studied, it was estimated an available specific energy of 0.21 kWh/m^2/day.

4. LOAD

For a correct sizing of the HPS, the load characteristics need to be understood, especially the peak load, so that the designed system is able to fully meet the needs of its users.

The model of energy consumption in rural communities, and generally in remote loads, fed by HPS should be carefully analyzed in order to reproduce the corresponding load curve with the greatest accuracy. For this project we used a load curve that represents the consumption pattern of a typical rural community in the study area (GUTIÉRREZ, 2001).

To estimate the load curves, the specification of electrical equipment found in a residence was used. Items considered to build the load curve of a typical dwelling are shown in Tab. 3, which provides the energy consumed by each piece of equipment and the average time of use over a day. Finally, one load curve for summer and one for winter are presented. The main difference between one and the other is the time of light bulb use and the use of fans instead of electric heater in the summer.

For a community of 20 houses of the type shown in Tab. 3, the load curves for summer and winter were mounted, which are displayed in Fig. 5 and 6, respectively.

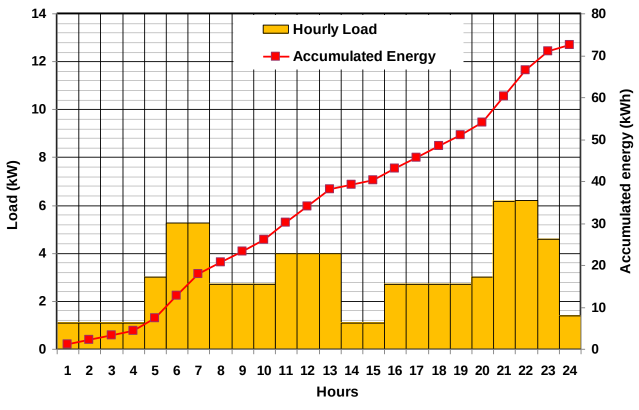
As the graphic shows, there is a peak of energy consumed at night, from 8:00 pm until 11:00 pm, due to the simultaneous use of equipment such as lamps, televisions, fans and refrigerators. In addition to the nocturnal peak, it can be observed that in both load curves (summer and winter) there is another peak of consumption, in the morning from 5:00 am to 8:00 am.

In rural communities, firewood is usually used for home-heating. However, early in the morning (5:00 am), while the wood-burning heating system has not begun yet, the electric heating system is turned on, due to the severe cold weather. For this reason, the morning peak period in the winter is more significant, as Fig. 6 shows.

The load curves values were entered in the HOMER® software, which simulated the operation of the system by performing an energy balance for each of the 8,760 hours of the year. Since the load profile for the whole year is not available, HOMER® has a statistical model based on the average value of a given hour of a typical day; from which random values are generated corresponding to the same hour for the other days of the year.

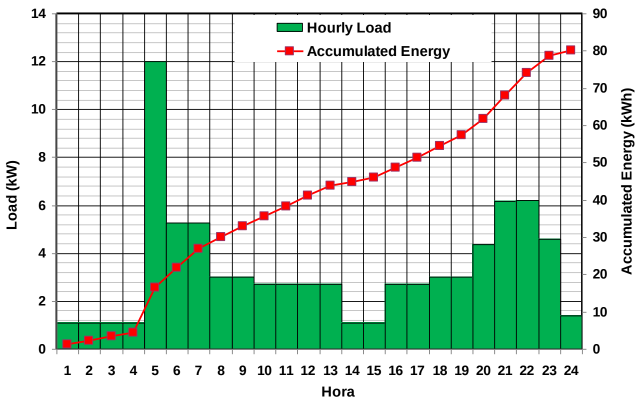
Table 3. Electric equipment used in a typical rural home

		Number of operating hours during day	
Equipment	**Power (W)**	**Winter**	**Summer**
Radio	80	16	16
Fridge	130	10	10
Fluorescent lamp 1	1x15	12	8
Fluorescent lamp 2	3x23	4	3
TV 20"	90	5	5
Fan	65	0	3
Electric heater	450	1	0
Cell phone charger	2.25	1	1



Total demand: 71.8 kWh/day, Peak Load: 11.0 kW, Average Load: 2.99 kW

Figure 5. Typical load curve for summer



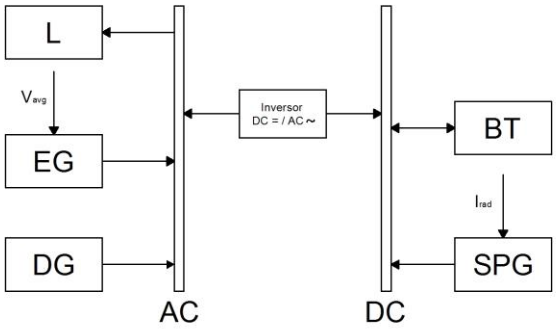
Total demand: 80.1 kWh/day, Peak Load: 19.8 kW, Average Load: 3.31 kW

Figure 6. Typical load curve for winter

5. TECHNICAL ANALISIS FOR THE HPS INSTALLATION

The HPS can be defined as the combination of two or more sources of energy with the basic objective of providing electricity to a load. The main advantage of a hybrid system is the possibility of using the available local resources in a jointly and optimized way, thus ensuring high levels of reliability and quality in the service, reducing investment and operational costs. When the HPS provides electricity directly to a load or a mini-network where there is no supply through the grid, we define the system as isolated (MACEDO, 2005).

This paper aims to do a technical evaluation of the installation of a HPS as a stand-alone system configuration to serve rural communities, using renewable energy resources such as Photovoltaic Solar and Wind, as shown in Fig.6.



BT: Battery
DG: Diesel Generator
EG: Eolic Generator
I_{rad}: Radiation intensity
L: Load
SPG: Solar Photovoltaic Generator
V_{avg}: Average Velocity

Figure 6. HPS with Solar Photovoltaic and Eolic generation

5.1. Dimensioning and simulating the HPS

From the information previously obtained, the system was modeled in the HOMER® software. For the analysis, four configurations were simulated. The first one considers a system composed of photovoltaic generation, wind generation and also a diesel generator as a back-up (*wind-solar-diesel*). In the second configuration, the diesel generator is left aside, using only the renewable energies: wind and solar (*wind-solar*). And finally two more configurations are done, considering the unique combination of a renewable source with the diesel generator (*wind-diesel* and *solar-diesel*).

To perform the system simulation, data related to specific components should be included in the software. Firstly, from a range of options, a model for each element of the system must be chosen along with associated costs.

With regards to the general parameters of the system, a *maximum annual capacity shortage* of 0% was considered, which means that the system can never interrupt the supply power to the load (most conservative). An *operating reserve capacity as a percentage of the load* of 10% means that the system is capable to satisfactorily provide a sudden increase in demand of up to 10% at any time. An *operating reserve capacity as a percentage of wind power* means that the system is able to continue providing power satisfactorily before a sudden fall in wind generation; in this work we adopted a value of 50%. And the *operating reserve capacity as a percentage of solar energy* means that the system has the ability to continue providing power satisfactorily before a sudden fall in solar photovoltaic generation of up to 25%.

Regarding economic parameters, the initial investment was considered to be the total installed cost of the component at the beginning of the project. The replacement cost is the cost of replacing a component at the end of its lifetime (25 years), as the case may differ from the initial investment, because not all components of a subsystem need to be replaced (e.g. a wind turbine tower). This cost is only considered if the life of the project exceeds the system components. Operation and maintenance (O&M) is the sum of the annual maintenance costs, including manpower and transportation costs for the technicians to the site, also considering a project life of 25 years. The software uses this information to calculate the cash flow over the life of the system.

The values of parameters chosen to model the system are shown in Tab. 5.

5.2. Results and discussions from the simulations

The results obtained for the four configurations are shown in Tab. 6. These results correspond to the optimal configuration where the system satisfactorily meets the load demand, complying with the operating conditions previously set forth.

It should be emphasized that all the configurations that have share of renewable sources resulted in high levels of efficiency, with the wind turbines capacity factor of 19.7% and the overall photovoltaic efficiency of 15.1% .These factors depend on the good choice of components and on the quality conditions of the resources present on site.

This high efficiency is also reflected in the high penetration of renewable sources in all cases, always lying above 48%, highlighting the *wind-solar-diesel* and *wind-diesel* cases, which reached a penetration rate of more than 80%.

Table 5. Parameters used to model the HPS

General system parameters			
Project life time	25	years	-
Maximum annual capacity shortage	0	%	-
Operating reserve capacity as a percentage of the load	10	%	-
Operating reserve capacity as a percentage of wind power	50	%	-
Operating reserve capacity as a percentage of solar power	25	%	-
Solar photovoltaic subsystem parameters			
Initial Investment (I_{inic})	3,380.00	U$D/kW	(1)
Replacement cost	3,380.00	U$D/kW	(1)
Operation and maintenance cost (O&M)	0.3% do I_{inic}	U$D/kW-year	(2), (3)
Panel life time	25	Years	-
Eolic subsystem parameters			
Manufacturer	Southwest Windpower	-	(4)
Wind turbine model	W 500	-	(4)
Power	3	kW	(4)
Initial Investment	2,145.00	U$D/kW	(2)
Replacement cost	60% do I_{inic}	U$D/kW	(5)
Operation and maintenance cost (O&M)	31.00	U$D/kW-year	(2)
Life time of the wind turbine	20	years	-
Hub height	22	meters	-
Cut-in speed	3.5	m/s	(4)
Battery parameters			
Model	Surrette 4KS25P		-
Tension	12	V_{DC}	-
Nominal capacity	1,900	Ah	-
Capacity to deliver energy during lifetime	10,600	kWh	-
Initial Investment	120.44	U$D/kWh	(3)
Replacement cost	95% do I_{inic}	U$D	(5)
Operation and maintenance cost (O&M)	2.5% do I_{inic}	U$D/year	(5)
Battery minimum life time	4	years	-
Inverter parameters			
Nominal capacity	10	kW	
Initial Investment	7,000.00	U$D	(6)
Replacement cost	7,000.00	U$D	(6)
Operation and maintenance cost (O&M)	0.9% do I_{inic}	U$D/year	(5)
Inverter life time	25	years	-
Generator parameters			
Nominal capacity	10	kW	-
Initial Investment	5,590.00	U$D	(7)
Replacement cost	5,500.00	U$D	(7)
Operation and maintenance cost (O&M)	0.02	U$D/kWh	-
Generators life time (in operating hours)	15,000	hours	-
Minimum load	30	%	-
Fuel parameters			
Fuel cost	1.40	U$D	(8)

(1)(SOLARBUZZ, 2011)' (2)(U.S. EPA, 2011), (3)(MACEDO, 2005), (4)(SOUTHWEST WINDPOWER, 2011), (5)(CAMERLYNCK, 2004), (6)(SIEMENS, 2011), (7)(YAMAHA, 2011), (8)(PREÇOS DOS COMBUSTÍVEIS, 2011)

Table 6. HPS simulation results

	Eolic-solar-diesel	Eolic-diesel	Solar-diesel	Eolic-solar	Unit
System Configuration					
Wind Turbines (WT)	5x3	8x3	-	3x3	kW
Photovoltaic Panels (PP)	12	-	14	60	kWp
Diesel Generator (DG)	10	10	10	-	kW
Battery	30x228	30x228	30x228	50x380	kWh
Inverter	10	15	10	30	kW
Contribution of each energy resource					
WT	25,916 (55%)	41,466 (81%)	-	15,550 (16%)	kWh/year
Capacity factor of WTs	19.7	19.7	-	19.7	%
PP	15,905 (34%)	-	18,555 (48%)	79,523 (84%)	kWh/year
Panel's Efficiency	15.1	-	15.1	15.1	%
DG	5,579 (12%)	9,784 (19%)	20,154 (52%)	-	kWh/year
Excess Energy	11,353 (24%)	15,158 (29.6%)	2,197 (5.67%)	58,803 (61.8%)	kWh/year
Renewable shear	88.2	80.9	47.9	100	%
Fuel consumption	2,033	3,463	6,971	-	ℓ/year
DG operating hours	798	1,271	2,416	-	hs/year
Autonomy	41.3	41.3	41.3	68.8	hours
Costs					
Total Investment	126,485.00	98,330.00	87,370.00	295,027.00	U$D
Replacement cost	37,954.00	46,302.00	39,091.00	49,405.00	U$D
O&M	23,427.00	25.,275.00	15,817.00	35,597.00	U$D
Fuel	44,469.00	75,734.00	152,465.00	-	U$D
Generated Energy Cost	0.472	0.499	0.619	0.771	U$D/kWh

For the optimum operation point of the *wind-solar-diesel* system, it has result in a share of diesel generation of only 12%, operating 798 hours per year, equivalent to 2.2 hs/day. This value, in addition to fuel saving, increases the life of the generator, reaching, in this operating condition, a life of almost 19 years. The same occurs in the *wind-diesel* configuration, which gets 3.5 hours of daily operation, with a life of 12 years. Yet in the *solar-diesel* configuration, the diesel generation share has increased significantly, working 6.6 hs/day, with a life of 6 years. This fact should be taken into account, although the generator initial investment is the lowest among all system components.

Referring to system's autonomy, the settings including diesel generator have a service capacity without the presence of energy sources of 41.1 hour (almost 2 days), since the solar-wind system has a battery life of 68.8 hours (almost 3 days). At first this fact seems contradictory, as one expects a configuration to provide an energy source independent of weather conditions (diesel) to have greater autonomy. However, to obtain a shortage capacity of 0%, as considered, the systems with diesel generation must have a large storage capacity. Table 6 shows that the number of batteries for systems that use diesel generation is 30 units, while the wind-solar system requires 50 units.

Another aspect that must be analyzed in Tab. 6 is the excess energy, which corresponds to the surplus of generated power that is not absorbed by the load or stored in the batteries. Diesel generation systems have a relatively low excess energy in the range of 6% to 30%; on the other hand, the wind-solar system reaches a value of 62%. This high value is a result of the system being over-sized to meet the energy demand on the few days throughout the year when natural resources are not available. However, most of the time these resources are available, resulting in a large excess of energy which, if not used, results in energy and financial waste.

An extremely important economic data is the cost of energy generated (Tab. 6), given in U$D/kWh. This is crucial to assess the financial viability of a project. It is observed that the wind-solar-diesel system poses the lower energy cost, with a value of 0.472 U$D/kWh, although this system has the second most expensive total investment, with a value of U$D 126,845.00. This low value of energy is mainly related to two factors: a lower share of diesel generation (12%) and low excess energy (24%).

Currently, in Argentina the electricity tariff is subsidized by the government, ranging from 0.052 to 0.060 U$D/kWh for residential consumers, depending on the region of the country. Argentinian's tariff values are the lowest in Latin America, appearing below countries like Brazil (U$D 0.112), Peru (U$D 0.110), Mexico (U$D 0.090) and

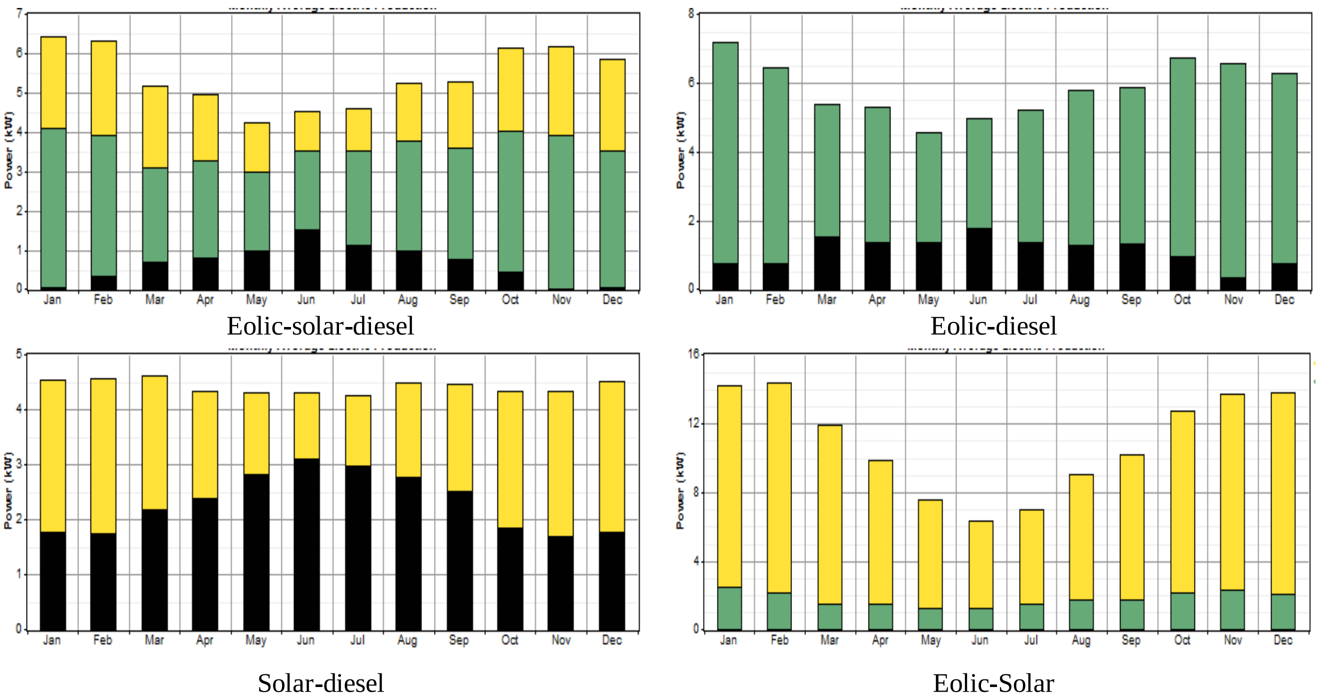
Ecuador (U$D 0.080) (ELECTROSECTOR, 2010). Rural electricity tariffs in Argentina do not receive the same subsidies, reaching approximately 0.213 U$D/kWh in the central region of the country (BLOGSURSOLAR, 2009).

Comparing the *wind-solar-diesel* energy cost, 0.472 U$D/kWh, with the tariff for rural consumers, 0.213 U$D/kWh, it can be verified that there still is a big difference, which could make the use of this renewable power generation system unviable. However, the State duty is to provide access to electricity to all citizens, regardless of social class and place of residence. Moreover, the cost of delivering electricity by conventional means (aerial transmission lines) in the studied area, which lies 30 km from the SADI (Argentine Interconnection System), is approximately 7,500 U$D/km (BLOGSURSOLAR, 2009), thus resulting in a total investment of U$D 225,000.00.

As the initial investment for *wind-solar-diesel* system is U$D 126,485.00, and considering that within 12 years the batteries reach their useful life and must be replaced, resulting in an additional cost of U$D 26,500.00, and still adding up the fuel cost (U$D 2,850.00) and O&M (U$D 18,000.00) during this period, the economy savings achieved by the use of this system is U$D 51,165.00. Obviously these are estimated results, but they already show the region potential to use their natural resources.

From the simulations, it could be seen that the best alternative for the region under study is the installation of a *wind-solar-diesel* HPS. But for other regions of Argentina, additional configurations can be the best option, as it is expected that in the Patagonia region, which has an excellent wind potential and a solar resource of low quality, *wind-diesel* hybrid configuration would obtain the best results.

Figure 7 presents the graphs that contain the share of energy generated for each of the sources used, for the four simulated configurations. The greater participation of diesel generation during the months of April to August, where natural resources are scarce, is evident. It is also worth noticing that in the months of greatest existence of renewable resources (September-March), the system increases its production to cover the lack of energy during the rest of the year.



References: Solar Eolic Diesel Generator

Figure 7. HPS's average monthly electric generation for the four different configurations simulated

6. CONCLUSIONS

In the first stage of this study, using of general weather information, the solar and wind renewable resources along the Argentinian territory were described. From this analysis, it could be concluded that the region with the best conditions for the installation of an HPS is the General Pueyrredón district. With an average daily global irradiation on horizontal plane ranging from 2.0 (kWh/m^2/day) and 6.5 (kWh/m^2/day) and an average wind speed ranging from 6 to 8 m/s, there is a great combination of solar and wind resources, with levels above the technically advisable range. From these resources, an average energy availability throughout the day was estimated at 0.22 (kWh/m^2), considering the joint use of both energy sources (wind and solar).

In the next stage, the operation of an HPS to provide energy to a typical rural community of Argentina was simulated. For this purpose the HOMER® software was used. In order to run the simulations, was used more detailed weather information obtained from meteorological stations located in the region under study and typical summer-winter load curves of a home with rural consumption habits.

Four simulations were performed, considering different possible combinations for the HPS: *wind-solar-diesel*, *solar-diesel*, *wind-diesel* and *wind-solar*. From the modeling results, it could be concluded that in the existing local conditions, the *wind-solar-diesel* HPS configuration generates the cheapest kWh, with an estimated cost of 0.472 U$D/kWh. The optimum system configuration has a 55% share-input of wind energy, 34% of solar energy and 12% of diesel and autonomy for almost two days due to the use of a 30-unit battery bank that provides 225 kWh. This low cost of generated energy is mainly related with two factors: a lower share of diesel generation and energy surplus (24%).

The final cost per kWh generated obtained from the simulations is still very high compared to current values in the Argentinian electricity market for residential users, which range from 0.052 to 0.060 U$D/kWh. However, when considering an isolated rural community, 30 km away from the nearest electric grid, and comparing the cost of extending conventional network with the installation and operation of a wind-solar-diesel HPS, it could be seen that the latter option is feasible, reaching economy savings of over 51,000.00 U$D at the end of the project life (25 years). Another conclusion obtained from the analysis is that the configuration that resulted in the most expensive generated kWh cost, the wind-solar HPS, can also be considered in extremely isolated and difficult-to-access locations, where leading a conventional power grid would become financially unavailable.

Argentina has a large potential for the use of natural resources like wind and solar photovoltaic for energy production that has not been capitalized yet, representing a viable alternative to provide electricity in isolated rural communities.

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8. RESPONSIBILITY NOTICE

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