A review of solar and wind energy in Paraguay

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Abstract—In recent years, non-conventional renewable energies (NCRE) has increased substantially due to its abundance and advancement of support technologies. This paper describes a review of solar and wind energy in Paraguay, which includes its matrix energy, its potential to harness solar and wind power, the current installed technology and future projects.

Keywords—Renewable energy, solar energy, wind energy.

I. INTRODUCTION

In recent years, both installed power and the development of non-conventional renewable energies (NCRE) has increased substantially. In 2021, during a year of tentative economic recovery, a record 314.5 GW of new renewable power capacity was added – enough to power every household in Brazil. The global installed renewable power capacity reached 3146 GW, a record high [1].

The global wind industry, on the one hand, had its second-best year in 2021, with almost 94 GW of capacity added globally, trailing behind the 2020’s record growth by only 1.8%. Total global wind power capacity is now up to 837 GW, helping the world avoid over 1.2 billion tonnes of CO2 annually – equivalent to the annual carbon emissions of South America [2].

Solar photovoltaics (PV) generation, on the other hand, increased a record 156 TWh (23%) in 2020 to reach 821 TWh in total. It demonstrated the second-largest absolute generation growth of all renewable technologies in 2020, slightly behind wind and ahead of hydropower. Looming policy deadlines in China, the United States and Vietnam spurred an unprecedented boom in PV capacity additions – a record 134 GW. Solar PV is becoming the lowest-cost option for electricity generation in most of the world, which is expected to propel investment in the coming years [3].

In this context, this paper presents a review of solar and wind energy in Paraguay, considering the paraguayan matrix energy, the solar and wind energy potential, the already installed technology and future projects.

II. PARAGUAYAN ENERGY MATRIX

Paraguay’s energy matrix is characterized by a high supply of primary energy of renewable and local origin, specifically hydroelectric and biomass, as shown in Fig 1. According to the 2012 energy balance, 57% of said supply corresponded to hydroelectricity and 27% to biomass (firewood, charcoal and vegetable waste). The remaining 16% were hydrocarbons. However, when analyzing final consumption, biomass accounts for 46% of the energy consumed in the country, 16% for electricity and 38% for hydrocarbons. The structure of final biomass consumption shows that firewood occupies 60% of consumption. In 2012, 76.2% of the supplied energy reached the final consumption sector, while the remaining 23.8% was lost in transformation centers. While electricity consumption increased by 8.6% between 2011 and 2012, biomass energy consumption decreased by 0.7% [4].

On the other hand, the most outstanding aspect in terms of electricity generation infrastructure in the country is the abundant availability of hydroelectric energy. The country’s electrical energy production capacity (close to 60,000 GWh/year), is one of the largest in the world in terms of electricity generation per inhabitant (9,000 kWh per inhabitant), and less than 17% is used by the national electric market. Electric power is an important export element (according to the terms of the respective treaties) to the partner countries of the binational hydroelectric power plants of ITAIPU (14,000 MW shared equally by Paraguay and Brazil) and YACYRETÁ (3,200 MW shared equally by Paraguay and Argentina). The main national electricity company is the “Administracion Nacional de Electricidad” (ANDE); vertically integrated state company (participates in the generation, transmission, distribution and sale of electricity in the country). The other two public
sector companies have a binational legal nature since they are the companies that operate the ITAIPÚ (Paraguay/Brazil) and YACYRETÁ (Paraguay/Argentina) hydroelectric plants, in which Paraguay has a 50% stake in both cases, through ANDE.

The private company, CLYFSA (Compañía de Luz y Fuerza S.A.), is a distributor that operates in the town of Villarrica; it buys electrical energy in blocks from ANDE; its participation in the national electricity market is small compare with the main company. In the same way the Menonite Cooperative of Chaco region has a contribution that still is small. Given the high capacities in hydroelectric generation, the electrical energy generated in Paraguay is almost exclusively hydraulic.

In addition to the already mentioned binational plants, ANDE owns the Acaray hydroelectric plant located in eastern Paraguay, which takes advantage of the hydraulic potential of a tributary of the Paraná River with a capacity of 210 MW. ANDE also has small capacities in thermal generation in the Chaco region that as a whole gets 6.1 MW. According to the values of electric power production, Paraguay occupies one of the first places in the world for electric power production per capita. This is thanks to the production of binational hydroelectric power plants, mainly from ITAIPU. ANDE, in addition to supplying itself from its own generating park, buys energy from binational hydroelectric plants [5].

At the same time, wind energy has not been widely used in Paraguay, at least in terms of electricity generation. Its availability (and its variability) is decisive in the feasibility of its use as a renewable source. Various studies carried out show possibilities of use in the areas of Pedro Juan Caballero and Ciudad del Este. The Chaco stations have very low average speeds (even less than 2 m/s). However, various studies related to rural electrification cite the Chaco as the region with the greatest potential for the exploitation of wind energy (and the empirical experience of visits to the region as well). These studies indicate that in the Chaco there are places with wind potential for electricity generation, mainly on a small scale, which would use battery banks for energy storage. Also in some areas of western Chaco there is potential for a larger scale, such as wind farms, but with a greater implication, since for this there must be transmission lines for the energy produced. The electrical energy produced by the force of the winds would benefit not only remote populations that do not have access to the network, but also, since it is an alternative and renewable energy, it would have a very low impact on the environment. From an average speed of 5 m/s the wind option becomes attractive. The maximum average speed (monthly) registered in the stations of the Meteorology Directorate network is 5.9 m/s, in the month of June, in Capitan Miranda, Itapúa. The possibility of using hybrid systems for energy purposes could make the use of wind energy more attractive, so the option should not be ruled out. Today, there are individual private farms in isolated areas (especially in Chaco), wind turbines are up to 15 kW, offered by local companies, mostly of Chinese origin. The results themselves are very good, and they represent a legitimate option for self-supply [6].
It can also be considered that there are some small solar plant projects implemented by the government in Paraguay. For example: 32 photovoltaic solar generation systems were installed, in 35 energized indigenous community centers as shown in Fig. 2. They include cold equipment for the preservation of vaccines and medicines, lighting and water pumping, battery charging, etc. They also include energy service available for lighting, public lighting, audiovisual equipment, computers, refrigerators, pumping system and water treatment, cell phone chargers and nebulizers. Another example was the first hybrid wind-solar power plant, at the headquarters of the 1st. Cavalry Division, in Joel Estigarribia, Department of Boqueron. The PV panels are presented in Fig. 3 [6], [7]. At last, there is a 15 KW three-phase wind generator with a PV panel system installed in the university campus for academic purposes, depicted in Fig. 4 and Fig. 5 [8].

### Table I

<table>
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<tr>
<th>Location</th>
<th>Coordinates</th>
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<th>DNI [kW/m²]</th>
<th>DHI [kW/m²]</th>
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### III. Potential Solar and Wind Energy in Paraguay

Table I presents relevant data, regarding the average solar irradiation per year in terms of global horizontal irradiance (GHI), direct normal irradiance (DNI) and diffuse horizontal irradiance (DHI), on the potential of solar energy in different locations (capitals of each department) in Paraguay [9]. As can be observed, GHI is pretty high in most of the country and very similar as well, as for DNI the highest values can be found in some locations in Chaco region and in the capital Asuncion, but overall the values in all over the country are also high, making solar energy a valid choice for alternative energy.

At the same time, Table II shows the average wind speed...
TABLE IV
ANDE SOLAR GENERATION WORKS PLAN 2021-2040

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<th>Power Plant</th>
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<th>Description</th>
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<th>Investment (USD)</th>
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<tr>
<td>Villa Hayes</td>
<td>2022</td>
<td>100 MW-400 MWh Li-ion battery bank</td>
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<tr>
<td>Loma Plata</td>
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<td>Horqueta</td>
<td>2035</td>
<td>100 MW-400 MWh Li-ion battery bank</td>
<td>North</td>
<td>85,875,000</td>
</tr>
<tr>
<td>Vallemi</td>
<td>2036</td>
<td>100 MW-400 MWh Li-ion battery bank</td>
<td>North</td>
<td>85,875,000</td>
</tr>
<tr>
<td>Carayao</td>
<td>2037</td>
<td>100 MW-400 MWh Li-ion battery bank</td>
<td>Central</td>
<td>85,875,000</td>
</tr>
<tr>
<td>Paranambu</td>
<td>2038</td>
<td>100 MW-400 MWh Li-ion battery bank</td>
<td>East</td>
<td>85,875,000</td>
</tr>
<tr>
<td>San Patricio</td>
<td>2039</td>
<td>100 MW-400 MWh Li-ion battery bank</td>
<td>South</td>
<td>85,875,000</td>
</tr>
<tr>
<td>Yguazu</td>
<td>2040</td>
<td>200 MW-800 MWh Li-ion battery bank</td>
<td>East</td>
<td>171,750,000</td>
</tr>
</tbody>
</table>

(AWS) and annual average power density (AAPD) in the same locations [9]. As can be seen, the average wind speed at 60 m is fairly similar in all the locations, being barely higher than 5 m/s, where Pedro Juan Caballero stands out with 6.37 m/s. As for 120 m, Pedro Juan Caballero and Caacupe locations present better speed than the rest, showing wind energy to be a valid alternative, specially on those locations.

IV. ALTERNATIVE INSTALLED POWER ENERGY IN PARAGUAY

This section describes the non-conventional renewable energy installed systems in the country until August 2022. Table III describes the existing installed PV solar power systems in KW and separated by location. This data was gathered through three of the most important private companies dedicated to this area in the country which are Energy Green S.A., Solar Makers S.R.L. and Kuarahy S.R.L.

Fig. 6 shows the accumulated installed capability grouped by four geographic areas. The Chaco region is comprised of 3 departments (i.e. Presidente Hayes, Boqueron and Alto Paraguay) and is the farthest region from the interconnected national system (SIN for its acronym in Spanish). Central is the most densely populated department in the country with around of 30 % of the total population according to the national directorate of statistics. Asunción is the capital and the denominated Oriental group all the others (14 departments in total).

As can be seen in Fig. 6, until 2022 Chaco was the region with more installed power, which is expected owing to lack of reach of the SIN in that part of the country. However, nowadays the installed capability is comparable with the power installed in Oriental region that had a significant increment between 2021 and 2022. In general, all the zones show an increment in the installation of PV systems, even those that have connection to the SIN.

Finally, Fig. 7 summarizes the data in a tendency graph, showing an exponential growth of installed PV power in the last 5 years in the country.
V. Future Projects

This section presents the projects that is under development, contemplated in the generation works plan 2021-2040 from ANDE. Table IV shows the great number of hybrid photovoltaic (PVH) and PV parks that are under development, which indicates the tremendous work that must be addressed. It should be considered the great investment in this ambitious project aiming at renewable energies from various sources [10].

VI. Conclusion

In this paper, a review of solar and wind energy in Paraguay is presented. By considering the Paraguayan energy matrix, its potential solar and wind energy in terms of radiance and wind speed, the already installed systems and the future projects for new power plants for non-conventional renewable energies, it shows a potential growth in terms of generation of electricity in Paraguay. The lack of great non-conventional renewable energy plants could be related mainly to the significant amount of available hydroelectric energy in the country but even in these conditions there are several projects that look for prevent the lack of energy in the close future. Related to PV solar generation systems, it can be noted the increasing interest on this technology.

In past times the PV solar projects were mainly installed in areas disconnected to the SIN. However, nowadays, even the areas with access to the SIN are showing an increment in PV solar installations highlighting the Oriental region and Asuncion. Analyzing the ANDE solar generation works plan, the expected increment in medium and large scale installations is important, between 2021 and 2040 several projects are planned to be implemented and this situation would modify significantly the energy matrix in the country.

Regarding the wind energy generation, it can be noted that there are not significant installed capability but there are still some zones where this technology can be satisfactory implemented when required.

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