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Renewable Electricity Supply: Alternative Energies for Remote Areas in Argentina

Gianfranco Bertolin[1], Ian Clos[2], Facundo Romero[3]

[#]Electronics Engineering, Universidad Tecnológica Nacional, Facultad Regional Paraná,

1033 Almafuerte Av., Paraná, Entre Ríos, Argentina

[1] gianfrancobertolin@alu.frp.utn.edu.ar

[2] ianclos@alu.frp.utn.edu.ar

[3] facundoromero@alu.frp.utn.edu.ar

***Abstract*- In Argentina, approximately 500,000 people in remote rural areas lack electricity due to infrastructure challenges. Access to reliable electricity is vital for well-being and socio-economic development. Geographic challenges in regions like southern Patagonia, the northern and western regions of Argentina hinder conventional grid expansion, leading to reliance on unsustainable energy sources. To address this scarcity, this paper proposes the use of renewable energy sources, such as solar, wind, and geothermal, offering sustainable solutions to provide affordable and reliable electricity to remote communities in Argentina. The objective of this paper is to analyze the lack of electricity access in remote areas and discuss the implementation of three alternative clean energy sources.**

To fulfill this objective, this paper is organized into three parts. Firstly, a description of the issues related to areas lacking electrical supply is provided. Next, the different solutions are presented. Finally, there is a brief viability analysis of the three proposed clean energy sources based on geographical and climatic characteristics is indicated. This paper is expected to contribute to the analysis of the viability of the implementation of renewable energy sources to provide electricity in remote areas.

***Keywords:* Electricity Access, Remote Areas, Renewable Energy, Renewable Energy Solutions.**

***Resumen*- En Argentina, aproximadamente 500.000 personas en zonas rurales remotas carecen de electricidad debido a problemas de infraestructura. El acceso a una electricidad fiable es vital para el bienestar y el desarrollo socioeconómico. Los desafíos geográficos en regiones como el sur de la Patagonia y las regiones norte y oeste de Argentina obstaculizan la expansión de la red convencional, lo que lleva a la dependencia de fuentes de energía no sostenibles. Para abordar esta escasez, este documento propone el uso de fuentes de energía renovables, como la solar, la eólica y la geotérmica, ofreciendo soluciones sostenibles para proporcionar electricidad asequible y confiable a comunidades remotas en Argentina. El objetivo de este trabajo es analizar la falta de acceso a la electricidad en áreas remotas y discutir la implementación de tres fuentes alternativas de energía limpia.**

Para cumplir con este objetivo, este trabajo se organiza en tres partes. En primer lugar, se proporciona una descripción de los problemas relacionados con las zonas que carecen de suministro eléctrico. A continuación, se presentan las diferentes soluciones. Finalmente, se indica un breve análisis de viabilidad de las tres fuentes de energía limpia propuestas en función de sus características geográficas y climáticas. Se espera que este trabajo contribuya al análisis de la viabilidad de la implementación de fuentes de energía renovables para proporcionar electricidad en áreas remotas.

***Palabras clave*: Acceso a Electricidad, Zonas Remotas, Energías Renovables, Soluciones Energéticas Renovables.**

I. Introduction

Currently, having secure, efficient, and high-quality energy services is essential for social well-being and equity. In Argentina, while 98% of households have access to electricity services, approximately 500,000 people still lack electricity, primarily in remote rural areas with challenging and costly network infrastructure [1, p.1]. For this reason, it is necessary to offer solutions to this lack of energy services.

The need to guarantee equal access to electricity is addressed by the United Nations in its Sustainable Development Goals (SDGs), Report, particularly SDG 7, which is called "Ensure access to affordable, reliable, sustainable, and modern energy for all" [2]. Achieving an improvement in the percentage of the population with access to electricity requires primarily clean energy sources.

The objective of this paper is to analyse the main concerns regarding lack of access to electricity in remote areas and discuss three possible alternative energy sources, a saber, energía geotérmica, solar y eólica. To this end, a literature review will be conducted and the results of the analysis will be presented, enabling engineers and others concerned with energy provision in these areas to choose the optimal method for obtaining electricity.

To fulfill this objective, this paper is organized into three parts. Firstly, a description of the issues related to areas lacking electrical supply is provided. Next, the different solutions are presented. Finally, there is a brief viability analysis of the three proposed clean energy sources based on geographical and climatic characteristics is indicated. This paper is expected to contribute to the analysis of the viability of the implementation of renewable energy sources to provide electricity in remote areas.

II. Lack of Access to Electricity in Remote Areas

The scarcity of electrical supply in remote areas of Argentina, such as the southern *Patagonia*, the northwest, and the central-west region known as *Cuyo*, poses a significant problem that negatively affects local communities. The lack of access to reliable electricity has direct consequences on the quality of life, socioeconomic development, and equal opportunities in these regions [3], as it will be described below.

Southern Patagonia is located in the south of Argentina. This region is characterized by its vast territory and low population density. These geographical and demographic conditions make it challenging to expand and connect the conventional electrical grid to remote areas. As a result, many Patagonian communities are isolated and heavily reliant on diesel generators and unreliable energy sources [4], leading to high operational costs and an adverse environmental impact.

The region known as *NOA* is located in the northwest of Argentina. It has many remote areas which also face a severe shortage of electricity supply. The lack of access to reliable electricity limits the development of rural communities and hampers the provision of essential services, such as education, healthcare, and communications [5, p.12]. These limitations particularly affect indigenous populations and those dependent on agriculture and livestock as livelihoods, impeding their economic and social progress.

In the *Cuyo* region, the scarcity of electricity in remote areas is also a relevant issue. Remote communities do not have access to essential services and must rely on rudimentary and costly methods of energy generation, such as diesel generators [6]. This hinders the development of local infrastructure, sustainable economic growth, and the improvement of people's quality of life in the region.

The lack of access to reliable electricity in these remote areas also creates a significant gap in equality opportunities. Access to electricity is crucial for economic and social development, enabling the implementation of proper lighting, heating, cooling, communications, education, and healthcare systems. Without a robust electrical infrastructure, communities face persistent challenges in their development and well-being.

Sustainable and affordable solutions are clearly needed to address the scarcity of electricity in these remote areas of Argentina. The use of renewable energy sources, such as solar, wind, and geothermal, can offer viable solutions to overcome these challenges and provide reliable, sustainable, and affordable electricity supply to the remote communities of southern Patagonia, the northwest, and Cuyo.

III. POSSIBLE CURRENT SOLUTIONS

This section will explore key strategies to address the problems previously described in this study. In particular, the focus is on three forms of renewable energy generation: wind, geothermal and solar. These solutions are presented as crucial opportunities to be applied in remote areas of Argentina, thus contributing to the transition towards more sustainable energy sources. These technologies will be carefully analyzed, highlighting their advantages, challenges and practical applications in the context of Argentina and its vast territory.

A. *Geothermal energy generation*

According to the International Renewable Energy Agency (IRENA), geothermal energy is the heat released from the core of the Earth [7]. Water or steam transports geothermal energy to the Earth's surface. In the case of electrical energy generation, it is necessary to have high or medium enthalpy resources, which are normally located in regions where tectonic plates are active. The main advantage of this energy is that, despite being a renewable energy source, it does not depend on climatic conditions.

According to the *Geothermal Quick Guide* brochure written by the International Geothermal Association (IGA) [8], the technologies used in electricity generation plants from geothermal energy allow the direct use of high temperatures of steam, steam-water mixtures using flash technology or geothermal water with intermediate temperatures (70 – 250°C) using binary technology.

Therefore, although there are different technologies depending on the geothermal source, the basic operating principle is based on the conduction of the geothermal fluid directly to the generation plant where the steam is used to operate the turbines. Once the geothermal fluid has been used, it is reinjected into the field to help maintain reservoir pressure.

This concise presentation delves into three primary technologies employed in geothermal energy generation: direct dry steam plants, flash plants, and binary plants. Each of these technologies harnesses the Earth's natural heat and steam in a distinctive manner to produce electricity sustainably and efficiently.

1. *Dry Steam Plants (Direct Dry Steam)*

A direct dry steam plant is a technology used to harness geothermal energy. In this case, the conversion device is a steam turbine designed to be used directly with low pressure and high volume of fluid extracted directly from the geothermal field, as stated in [9]. Direct dry steam plants commonly use condensing turbines. The steam condensate is reinjected (closed cycle) or evaporated in wet cooling towers. This type of geothermal generation plants use steam at 150°C or higher, and, generally, the steam entering the turbine must be 99.995% dry to avoid scaling or erosion in the turbine. The size of this type of plants ranges from 8 Mega Watts (MW) to 140 MW.

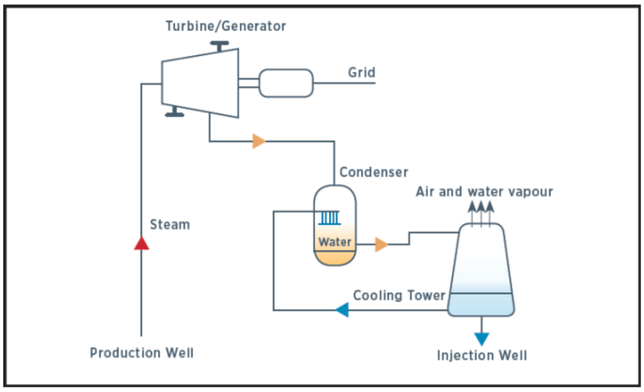

Fig. 1. Dry steam plant scheme. [9]

2. *Flash Plants*

A flash plant is another technology used to harness geothermal energy. These types of plants are very similar to dry steam plants. However, the steam is obtained from a separation process called flashing. The steam obtained is directed to the turbines, and the resulting condensate is sent to be reinjected into the reservoir or to continue flashing at a lower pressure. The temperature of the fluid drops if the pressure decreases, so flash plants work best when temperatures are higher than 180°C. Flash plants vary in size depending on the climate, they are single-flash (0.2 – 80 MW), double-flash (2 – 110 MW) or triple-flash (60 – 150 MW).

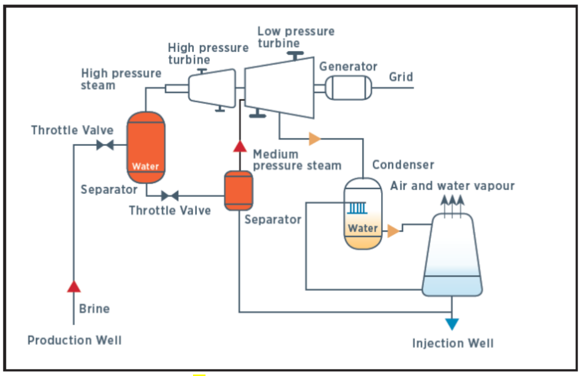

Fig. 2. Flash plant scheme [9]

3. Binary Plants

A binary plant is another technology used to generate geothermal energy. These plants are normally applied in low or medium enthalpy geothermal fields where the resource is used, through heat exchangers, to heat a process fluid in a closed circuit. The process fluid can be an ammonia/water mixture for Kalina cycles or hydrocarbons for organic Rankine cycles (ORC). These fluids have boiling and condensation points that better match the temperature of the geothermal resource. Typically, binary plants operate at temperatures between 100°C and 250°C. Although it is possible to work with temperatures below 100°C, the efficiency of electricity generation decreases. The size of binary plants varies between 1 MW to 50 MW.

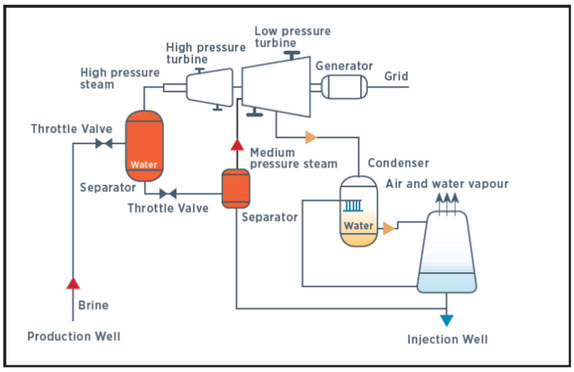

Fig. 3. Flash plant scheme [9]

B. Solar Energy Generation

Solar generation systems uses solar panels, which are capable of converting solar energy into electrical energy. The operating principle is through the absorption of photons from sunlight by photovoltaic cells. Electrons are released from silicon atoms and extracted through a network of metal conduits that generate a current flow. This current is direct current [10].

This energy is controlled by a charge controller and then stored in a battery bank. Since they provide energy in the form of direct current (DC) and most household appliances use alternating current (AC), this energy must be converted from DC to AC using a DC/AC converter to use the energy stored in the batteries.

Among the feasible options to implement a solar generation system in Argentina, the Solar Home Systems (SHSs) are an effective alternative. The solar home energy system represents an evolution of three generations (3G-SHS) [11], with the latest generation depicted in Fig. 4 below. The 3G-SHS utilizes a compact, efficient, and integrated design technology.

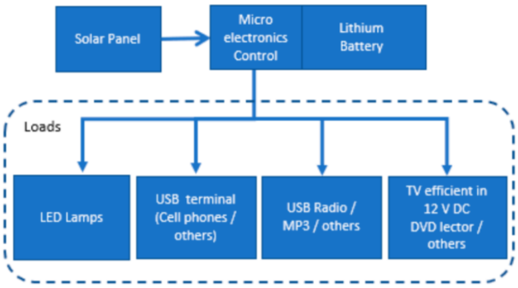

Fig. 4.3G-SHSs system. [11]

This system consists of a single component as shown in Fig.5 [11]. It includes the connection for the solar panel, a rechargeable high-density lithium battery with a compact size, a microcontroller capable of controlling the battery's charging and discharging, connected to a screen to provide information about the battery's status and panel states, among other relevant data. It also features plug-and-play outputs for connecting LED lamps, USB terminals for charging mobile phones, and other connectors.

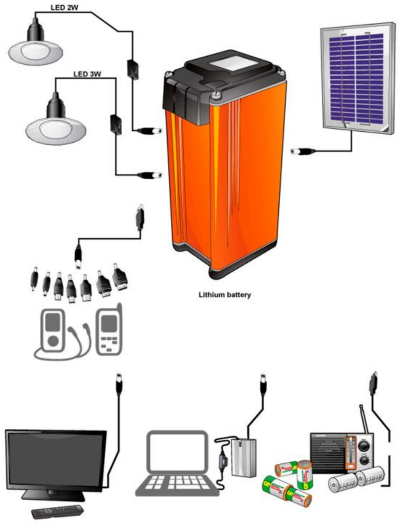

Fig. 5. Components of 3G-SHSs [11]

C. Eolic Energy Generation

Eolic power generation harnesses the kinetic energy inherent in the wind and efficiently converts it into electrical energy. As stated in [12], in a typical wind power generation system, a series of key components are employed to facilitate this energy conversion process. These components include the rotor equipped with turbine blades, and, in some instances, a gearbox. Integral to the system are also an electric generator, a power electronics converter, and a transformer, as illustrated in Fig. 6 below.

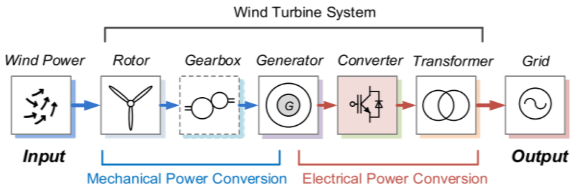

Fig. 6. Wind turbine system [12].

The wind turbine blades play a pivotal role in capturing the kinetic energy present in the wind and effectively channelling it for subsequent conversion into mechanical power by the wind turbine [16]. This phase of conversion takes place within the generator, which comprises an electrical machine driven by the rotor. Additionally, the gearbox assumes a critical responsibility in establishing an efficient rotational relationship to facilitate energy generation. Subsequently, in the phase of electrical energy conversion, the converter is tasked with transforming direct current (DC) into alternating current (AC). This AC power is then adapted to the requisite voltage for distribution through the transformer.

There are two types of wind turbines. They are horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT) Fig.7

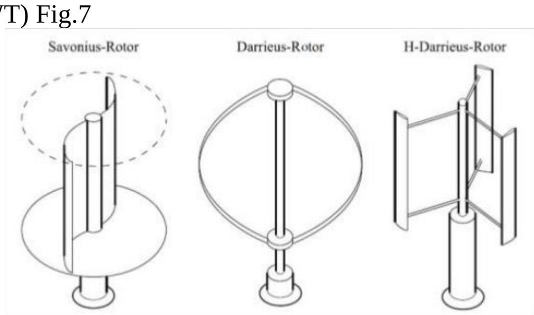

Fig. 7. Types of vertical axis turbines [13]

1. *Vertical axis wind turbines (VAWT)*

VAWTs offer a number of advantages over traditional horizontal-axis wind turbines (HAWTs). They can be packed closer together in wind farms so more turbines can be installed in a given space. They are quiet and omni-directional, and they produce lower forces on the support structure. VAWTs do not require as much wind to generate power, thus allowing them to be closer to the ground where wind speed is lower being closer to the ground, they are easily maintained and can be installed on chimneys and similar tall structures [13]. Given these advantages, this type of generators is completely suitable for installation in homes or premises where the electrical service is unavailable.

2. *Horizontal axis wind turbines (HAWT)*

HAWT consists of blades that extract wind energy on horizontal axis and are parallel to the ground. By facing the wind flow perpendicularly, the blades work and turn due to aerodynamic lift. HAWT is the most popular choice of wind turbine and has received more funding for research and development since it offers significant advantage over VAWT. HAWT have a greater efficiency then VAWT when extracting energy from the wind force due to its design that allows it to extract the energy through the full rotation of the blades when placed under consistent wind flow [14].

However, a HAWT has a major disadvantage, which is the fact that it must always aim at the wind direction to work efficiently. With unpredictable wind direction, extra mechanism is required to make sure the blades will always be facing the wind direction to extract maximum power output. Because of this disadvantage, HAWT works excellently in environments with consistent and low turbulence wind as it does not need to change its orientation too frequently. [14].

IV. Energy Generation Systems: Viability Assessment

In this section, the methods of renewable energy generation that are deemed most suitable for each of the regions will be chosen, taking into account their geographical and climatic characteristics.

A. *Northwestern Argentina*

Argentina exhibits notable variations in solar radiation and cloud cover throughout the year and in its different provinces. In the northwest, provinces such as Jujuy, Catamarca and San Juan enjoy the highest levels of solar radiation, with values ranging between 6 and 7 kW/m² during the summer months. In contrast, in Tierra del Fuego, in the south of the country, the lowest levels of radiation are recorded, with average values of around 2 kW/m² throughout the year as shown in Fig. 8 (a).

Regarding the Effectiveness of Cloud Cover (ECC), an intriguing pattern is observed. Nationally, ECC values tend to be higher in winter, averaging 24% in June. However, some provinces in northwestern Argentina, such as Jujuy, experience ECC peaks in summer, with values that can exceed 30% in January. This coincides with a significant decrease in solar radiation in Jujuy between November and March due to greater cloudiness during the rainy season as shown in Fig. 8 (b).

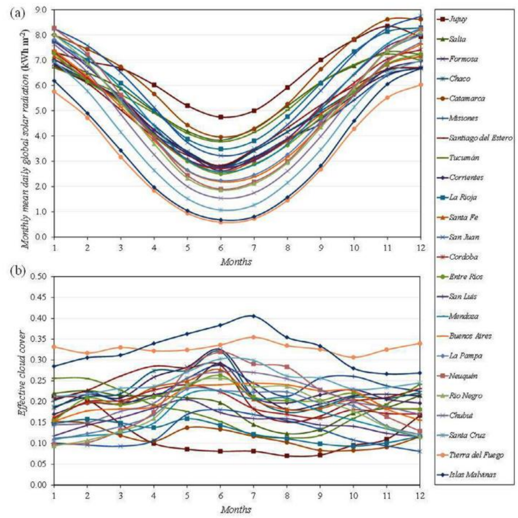

Fig. 8. Monthly mean daily solar radiation (a) and ECC (b) for the provinces of Argentina [15].

This data is essential for planning solar energy projects and provides a deeper understanding of regional climate conditions in Argentina. The country has great potential for solar energy, but the geographic and seasonal variability in solar radiation and ECC must be carefully considered in decision-making and planning of renewable energy projects.

According to the type of climate and geographical topology of the mountainous area of the northwestern Argentina, the most optimal and viable solution is the generation of solar energy based on the third generation SHS system.

B. Cuyo region

In the *Cuyo* region, the existence of magmatic bodies located at higher levels of the crust generates thermally anomalous areas that indicate a possible high geothermal potential. This characteristic of the Andes Mountains, added to those presented by the extensive regions where extensive sedimentary basins with geothermal aquifers extend, give Argentina great opportunities for the use of low and high temperature geothermal resources. In addition, this region also has favorable sun exposure throughout the year.

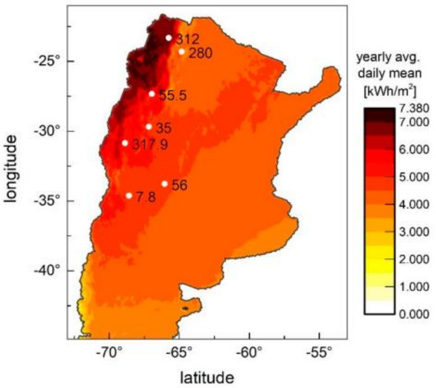

Fig. 10. Distribution of photovoltaic plants in Argentina, grouped by provinces. The total power in MWp in each province is indicated next to each location point. The color map indicates the yearly average of daily solar radiation on a horizontal [5].

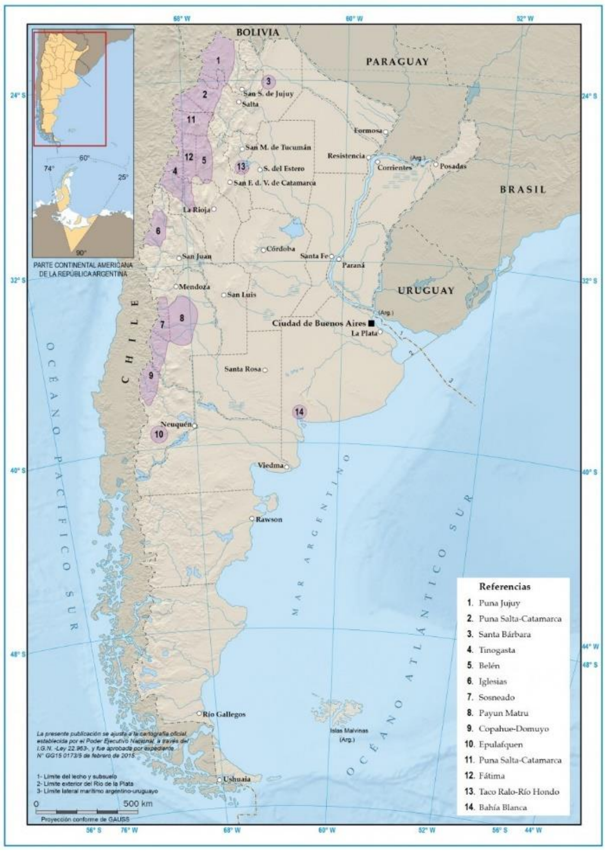

Fig. 11. Geothermal potential map [15]

Combining geothermal and solar energy can be highly beneficial, as geothermal energy provides a constant generation base, while solar energy can increase generation capacity during sunny days, improving the reliability of electricity supply in the region. This combination may be the most effective solution to meet the region's energy needs and increase the resilience of its energy infrastructure.

C. Southern Patagonia

The vast expanse of Argentine Patagonia endows it with significant potential for wind energy generation. This can be carried out utilizing both vertical-axis wind turbines (VAWT) and horizontal-axis wind turbines (HAWT). This region is characterized by consistent and high-speed winds, making it an ideal climatic setting for the efficiency of HAWT.

Its open and elevated geography, along with the sparse population density in many areas, facilitates the installation of wind farms without displacing local communities or disrupting agricultural activities. This not only mitigates social and environmental impacts but also makes the installation of small-scale VAWT generators in urban areas or residential settings viable.

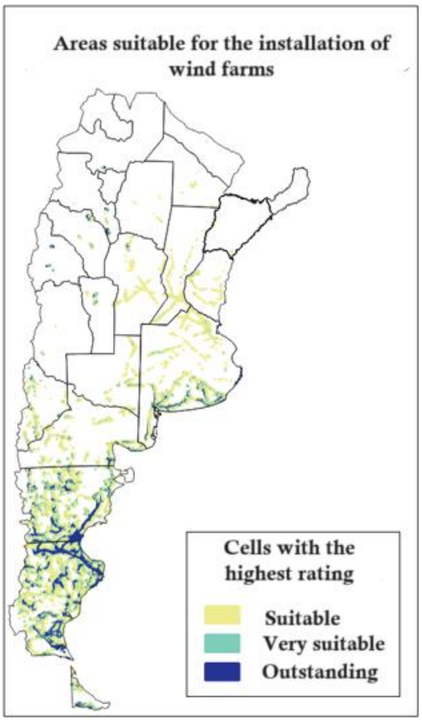

Fig. 12. Eolic potential map [16]

The strategic deployment of VAWT generators in Argentine Patagonia would not only contribute to the reduction of greenhouse gas emissions and the attainment of renewable energy objectives but would also enhance the energy security of the region and the nation. This combination of natural resources and favorable geographical conditions positions Patagonia as a potential hub for wind energy generation, emphasizing its contribution to environmental sustainability and local economic growth.

V. Conclusion

In conclusion, Argentina's remote areas with inadequate access to electricity face pressing challenges. Renewable energy sources, including geothermal, solar, and wind power, present viable solutions. However, the choice of energy source should be tailored to the specific geographic and climatic conditions of each region to maximize efficiency and sustainability. By adopting these renewable technologies, Argentina can work towards closing the electricity gap in remote areas while contributing to a more sustainable and equitable energy future.

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Gianfranco Bertolin is an Electronics Engineering student at UTN FRP: gianfrancobertolin@alu.frp.utn.edu.ar. Ian Clos is an Electronics Engineering student at UTN FRP: ianclos@alu.frp.utn.edu.ar. Facundo N. Romero is an Electronics Engineering student at UTN FRP: facundoromero@alu.frp.utn.edu.ar

The present manuscript is part of the research activities in the Inglés II lesson at Universidad Tecnológica Nacional, Facultad Regional Paraná. Students are asked to research into a topic so as to shed light on a topic of their interest within the National Academy of Engineering's Grand Challenges or the United Nations' Sustainable Development Goals frameworks. If sources have not been well paraphrased or credited, it might be due to students' developing intercultural communicative competence rather than a conscious intention to plagiarize a text. Should the reader have any questions regarding this work, please contact Graciela Yugdar Tófalo, Senior Lecturer, at gyugdar@frp.utn.edu.ar