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Electricity Generation under the Climate Change Situation in Latin America: Trends and Challenges

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ABSTRACT

In a scenario of energy inequality, countries require stability for development and quality of life for their inhabitants. This paper addresses the reality of access to electrical energy and the effect of climate change on the potential of renewables to propose strategies related to generation and transmission in Argentina, Chile, Colombia and Paraguay. This is done by analyzing quantitative and qualitative aspects of the electrical energy matrix: installed capacity and technology for generation and transmission together with the penetration of renewable energies. Among the results, actions address energy poverty, energy efficiency, smart investment in energy, and the readaptation of transmission infrastructure.

Keywords: Climate Change, Energy Efficiency, Energy Poverty, Renewable Energy
JEL Classifications: O57; Q41; Q48; I39

1. INTRODUCTION

Today, knowing the available energy balance is part of the agenda of many countries, regardless of their gross domestic product, as well as social and/or economic development Apostolović and Studović (2011).

The energy matrix must be understood, not only as electricity generation to meet demand, but also in terms of a country's capacity for economy development. In this sense, energy is much more than a key input, represents opportunities to promote positive improvements in people's life quality. de Chile (2022). The energy autonomy of a country is key to establishing future conditions that allow industrial growth, development of populated centers, and education with micro-generation and energy efficiency for lighting, heating, and cooking Luo et al. (2014).

Energy poverty is part of a problem to be addressed in Latin America. It occurs when a household does not have equitable access to high-quality energy services to cover its basic needs, or to allow economic development RedPE (2019a).

One of the key aspects to mitigate energy poverty is to guarantee access to electrical energy through generation and distribution. Latin America has different renewable sources of generation such as water, wind, solar radiation, geothermal, and biomass. These sources have allowed the penetration of clean energy to diversify the energy matrix and gradually replace fossil fuels Tang et al. (2021a). However, climate change is a factor that can affect the future supply of resources for renewable energy projects. The change in intensity and constancy of winds, decreased radiation, decrease in rainfall, loss of glaciers and eternal snow due to increased melting affect the potential of renewable resources Faggian and Decimi (2019).

An associated strategy to mitigate climate change by reducing power generation capacity is associated with smart technologies (power electronics, for example), together with effective control and monitoring systems to optimize energy supply by regulating effective energy required Jewell (2007).

The current focus on energy poverty forces a review of these aspects, with the challenge of aligning the strategies with the real actions to be developed in the context of the region González et al. (2021). This brings with it a look at climate change to estimate the future generation potential Fiorelli et al. (2018). Although progress has been made in the socioeconomic analysis of the solutions Pereira et al. (2015), importance is being given to joint science-industry work to build the technology that is required in the future Changxi and Gang (2012).

This paper outlines the current state of the electrical systems of Argentina, Chile, Colombia, and Paraguay, as a sample of Latin America. This paper also seeks to identify a combined strategy of inter-regional support, where governments, together with the private sector, can focus investment, to improve public policies and optimize the use of resources.

The rest of this paper is structured in five sections that address the following topics: in section 2 an energy review of the countries to be analyzed is presented, in section 3 the challenges of renewable energies in Latin America are analyzed, then the cross-cutting science-industry challenges for Latin America are evaluated in section 4. Section 5 analyzes the energy policy among the countries. In section 6 a discussion is presented about the guidelines to design public policies oriented to the use of energy.

2. ENERGY OVERVIEW OF THE COUNTRIES TO ANALYZE

Argentina, Chile, Colombia and Paraguay, in common with the rest of South America, share economies based on natural resources. This leads to the generation and use of energy by zones as described below.

Argentina has a principal electrical network of more than 20,296 kilometers called SADI-Argentine Interconnection System. 70% of the network is 500 kV lines reaching the main cities, ensuring supply to the majority of the population. Luo et al. (2014). The electricity generation is mainly with natural gas, followed by hydroelectric generation, with a nominal installed capacity of 42,882 MW, providing 12,607 GWh by June 2022, where it is important to monitor the operation factor, the logistical difficulty of promoting renewable energies, and how seasonality is affecting electricity generation Cossuta et al. (2022).

Chile has three electrical systems: SEN (National Electrical System), SEA (Aysén Electrical System), and SEM Magallanes Electrical System) with a generation capacity of 27,486 MW (November 2021). Renewable energy sources such as solar, wind, and hydro have been substituting hydrocarbon sources for 10 years as part of a strategy to mitigate climate change and the negative effects on the stability of the network due to decreased annual rainfall Rivera et al. (2022).

Colombia has a network with more than 24,000 kilometers of transmission lines and a generation capacity of 19,435 MW. Hydroelectric capacity represents 67% of the total, while the remaining is divided into gas, combined cycle, and coal plants as well as wind and solar photovoltaic generation. The percentage varies according to the time of year and the cycling occurrence of the El Niño/La Niña climatic phenomena. The national transmission system (STN) connects the most populated areas through transmission lines, compensators, substations and interconnection equipment that operate between 220kV and 500kV. 70% of the energy is distributed to residential users and small businesses while the remaining 30% is supplied to industrial users. The generation, transmission and distribution assets are owned by private companies. However, there is a central entity in charge of operating the STN and managing the wholesale energy market. There is an interconnection with Ecuador which is integrated into the wholesale energy market with a coordinated frequency control between both countries. Likewise, there is a weaker interconnection with Venezuela, which operates in isolation to avoid frequency oscillation problems Villegas Pico et al. (2012). An interconnection with Panama is planned using HVDC (high voltage direct current transmission) technology due to the distance and environmental limitations associated with protected areas of the Darién jungle. Likewise, investments in wind and solar generation are planned as well as the start of operation of the Hidroituango hydroelectric plant, with 2.0 GW of installed capacity Bravo-Lopez et al. (2022).

There are some areas in the Amazon and Orinoquía regions that are not connected to the STN. These non-interconnected zones make up >0.3% of the population, but they cover a large area of the territory and a key area from an environmental point of view since there are protected forests.

Paraguay has an annual electricity generation capacity close to 60,000 GWh/year, one of the largest in the world (9,000 kWh per inhabitant), where >17% is used by the national electricity grid because Brazil consumes a great part of this offer. This network is led by the National Electricity Administration (ANDE), the main vertically integrated electricity company in the generation, transmission, distribution, and commercialization of energy Ayala et al. (2022).

In Latin America, as in other parts of the world, renewable energy generation is increasingly driven by foreign investment and technological change Ugarteche and León (2022). Table 1 shows a comparison of electricity generation technology for the four countries analyzed, where there is evidence that each country takes advantage of its natural resources and reserves to establish the energy mix that allows them to grow its economy and social development Cossuta et al. (2022); Rivera et al. (2022); Bravo-Lopez et al. (2022); Ayala et al. (2022).

In fact, Paraguay stands out worldwide and in Latin America because electricity is generated 100% by renewable sources

Table 1: Types of technologies for electric generation, 2021

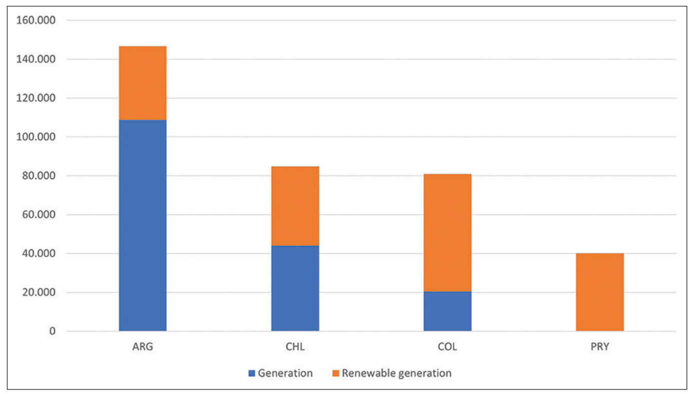
	Argentina (%)	Chile (%)	Colombia (%)	Paraguay (%)
Thermal Hydrocarbon	45	0	31.86	26
Diesel	2	13.96	0	0
Gas	6	13.26	0	0
Steam cycle	7	0	0	0
Coal	0	15.76	0	0
Nuclear	5	0	0	0
Solar	1	17.99	0.82	0
Wind	9	12.67	0.1	0
Hydraulics	24	24.7	67.21	35.0
Geothermal	0	0	0	0
Biomass	1	1.49	0	39.0

while Argentina has only managed to generate 25.8% of its electricity by 2021 from clean sources. However, Paraguay has the smallest electricity market, both in terms of installed capacity and generation, compared to Argentina, which is the largest producer of the countries analyzed (Figure 1). Therefore, in the four countries under analysis, the growth of the renewable energy sector is evident. This is a consequence of the decarbonization strategy to contribute to mitigate climate change.

As shown in Figure 2, renewable electricity generation has grown over the last 40 years (1981-2021) at rates ranging from 57% in the case of Argentina to 144% in the cases of Colombia and Chile. From the perspective of per capita energy consumption, this has tended to increase in the analyzed countries. However, in the last 2 years there has been a change in trend as shown in Figure 3. This change is evident in Paraguay where there was a reduction in power generation during the Covid-19 pandemic which led to lower consumption. While in the case of Chile, the pandemic let to on increase in the use of home energy Sánchez-López et al. (2022). If the metrics of the United Nations Organization are considered, which indicate that 1,200 kWh per person per year is the base consumption objective for development programs that alleviate energy poverty Day et al. (2016), in the case of the countries under analysis, all of them reached this threshold by 2012.

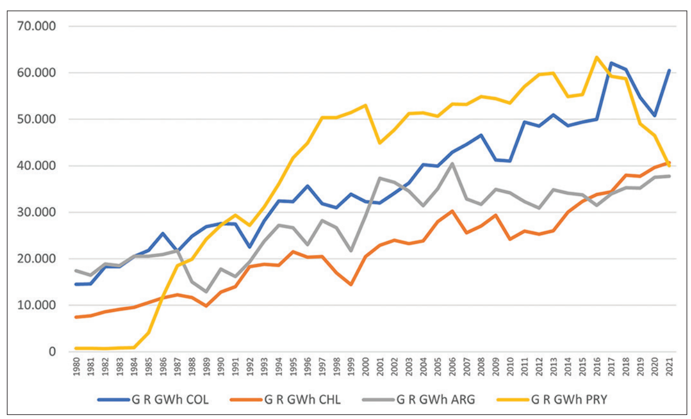
However, this does not mean there is not energy poverty, for two reasons. The first is that an average per capita indicator does not account for the inequality in access and consumption by the inhabitants of a country. The second is that energy poverty should be measured beyond consumption, considering aspects related to well-being Day et al. (2016) and to the multidimensional perspective Santillán et al. (2020).

Figure 1: Comparison of conventional versus renewable electricity generation (GWh), 2021



COL: Colombia, CHL: Chile, ARG: Argentina, PRY: Paraguay. Source: Macrodata (2022)

Figure 2: Renewable electric power generation (GWh) comparison, 1980-2021



G: Generation, R: Renovable, COL: Colombia, CHL: Chile, ARG: Argentina, PRY: Paraguay. Source: Macrodata (2022)

3. CHALLENGES FOR LATIN AMERICA-RENEWABLE ENERGIES

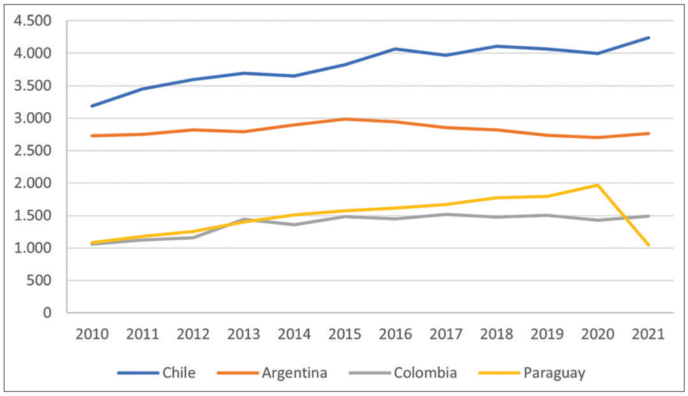
In this section, the development of strategies for renewable energies is reviewed for Argentina, Chile, Colombia, and Paraguay. This includes identifying the status of use and penetration of base technologies in the mapping of collected resources.

3.1. Argentina

The energy development strategy has great possibilities for incorporating renewables, with feasibility in various areas of the vast country. Figure 4 shows the solar, wind, hydro, geothermal, bio-gas, and biomass potential. In summary, the penetration of clean energy in Argentina amounts to 35% of the total matrix distributed in the following proportion: 1% solar, 9% wind, 1% biomass, 24% hydro.

The situation for solar generation implies that, throughout the year, there are favorable climatic conditions for the use of solar energy, especially in the sub-Andean regions from Neuquén to

Figure 3: Comparison of energy consumption per capita (kWh), 2010-2021



Source: Macrodata (2022)

Figure 4: Distribution of potential renewable energy resources in Argentina

Source: Cossuta et al. (2022)

Jujuy. Currently, 37 solar parks are under operation, for example in the province of Jujuy is the Cauchari Solar Park, the largest in Latin America. This park alone injects 315 MW into the national grid Cossuta et al. (2022). In the case of wind energy, it had momentum in recent years from the regulatory framework applied to renewable energy, with the emergence of two wind turbines developed and manufactured in Argentina, approved, certified, and delivering energy to the grid Cossuta et al. (2022). Added to this is the potential throughout the country, with an emphasis on Patagonia along with the coastal zone and mountains in the south of the province of Buenos Aires. There are 95 hydroelectric plants are in operation with a total installed capacity of 10,834 MW Cossuta et al. (2022). Some capacity is shared with other countries (Yacyretá and Salto Grande), or national and private concessions. For geothermal energy, some areas with effective potential are currently under study, and it is also estimated that Argentina has a geothermal potential for electricity generation of more than 2 GW Cossuta et al. (2022).

3.2. Chile

The energy development strategy has a technological approach that allows for increased efficiency in both generation and distribution through the use of intelligent technologies such as power electronics for renewable energy applications Luo et al. (2014). In fact, the penetration of clean energies is up to 57% of the electrical matrix distributed as 18% solar, 12,7% wind, 0,2% geothermal, 1,5% biomass, and 24,7% hydro. Figure 5 shows the renewable potential in Chile.

Hydraulic power is the oldest generation source currently operating. This is due to the country's geography strongly marked by the presence of rivers and mountains, which allows the construction of dams Rivera et al. (2022). However, due to the age of technology (more than 40 years), it is not enabled by power electronics. In this regard, the Ministry of Energy in its 2050 Energy Policy proposes two focuses Luo et al. (2014): (a) the development of technologies that allow increasing the efficiency of existing plants and/or new plants under construction. Despite the decrease in river flow, electricity generation remains at relatively stable levels providing electricity to the entire population, (b) to develop technologies that facilitate the implementation of smaller power plants, but with the technical characteristics to generate energy efficiently, without greatly affecting the course of rivers and/or streams. This would allow generation to be distributed among various sources in the region Rivera et al. (2022).

The generation capacity from wind energy amounts to 3,729 MW with national coverage, due to the winds that blow in a westerly direction from the sea towards the continent, especially in the area of the north called "small north." Due to technological advances, these projects are being implemented with a converter inside each wind turbine to make an injection into the grid more efficient Rivera et al. (2022). Despite that, the generation capacity from solar is greater than wind energy with 5,294 MW with national coverage. There are three large solar installations Andes Solar, Conejo Solar, and Luz del Norte. It is important to mention that the inverters used in this type of application are not advanced, giving

Figure 5: Distribution of renewable energy resources potential in Chile

Source: Rivera et al. (2022)

an opportunity to incorporate new technology in order to improve efficiency, and open a niche for development and innovation in currently existing facilities Rivera et al. (2022).

For the central zone, the Ministry of the Environment in Chile warns of a potential increase in solar radiation, which is a great opportunity for this type of facility, allowing two main benefits:

- The renewal of the energy matrix, increasing the penetration of NCRE, and
- New means of enabling distributed generation Rivera et al. (2022).

3.3. Colombia

The energy development strategy is centralized in the planning of the generation system that is in charge of the Mining and Energy Planning Unit (UPME), which indicates the power levels required to supply the demand for electrical energy (expected and real) throughout the country Bravo-Lopez et al. (2022). In summary, the penetration of renewable energy amounts to 68.1% of the total matrix, as shown in Figure 6.

The situation for solar energy is an important potential that is distributed throughout the national territory, oscillating between

Figure 6: Distribution of the potential of renewable energy resources

Source: Colombia Bravo-Lopez et al. (2022)

2.5 kWh/m^2 and 6 kWh/m^2. The areas with the greatest potential are in the north. Thus, in that region of the country, there are large solar plants, in addition to three plants located in the central zone. Each plant has 19.9 MW of net effective capacity, which contributes to the 146 MW installed solar generation that represents 0.82% of the total installed capacity Bravo-Lopez et al. (2022). The energy expansion plan projected by UPME for the year 2019 is 5,123 MW in phase 1 (pre-feasibility) and phase 2 (feasibility). The accumulated capacity potential currently amounts to 11,713 MW, distributed in 2,660 MW (phase 1), and 9,053 MW (phase 2). Regarding the situation for wind energy, it should be noted that the most significant potential is again concentrated in the north of the country, where wind speeds can reach values above 15 m/s Bravo-Lopez et al. (2022). Even though wind power penetration is low (0.1% of the total energy matrix), 24 projects are currently being studied by UPME with 775 MW (phase 1), and 3,946 MW (phase 2).

Regarding hydraulic energy, Colombia has five large hydrographic areas. Each of these areas offers very different flows, according to the national water study (ENA) carried out in 2018, where the largest offer in volume with 728,247 million cubic meters in the Amazon area where the average flows add up to 23,092 m^3/s Bravo-Lopez et al. (2022). This is confirmed by the fact true there are more than 150 hydroelectric plants and nearly 34 projects under construction. These will add 1,054 MW, equivalent to 10% of the current energy matrix. In the case of geothermal energy, a part of the territory is located on the Pacific Ring of Fire, where the natural temperature gradients of the subsoil have high values, representing a future potential that to date only has a pilot plant of 100 kW of installed capacity in the municipality of San Luis de Palenque, in the department of Casanare. The generation potential in areas of the Nevado del Ruiz Mejía et al. (2012) volcano is currently being studied. Regarding biomass, there is a potential for the use of agricultural, livestock, and forestry residues in collection centers and markets Bravo-Lopez et al. (2022). Despite the fact that its penetration has been low, three new projects are currently under study, with 1.06 MW (phase 1), and 29.8 MW (phase 2).

In general, Colombia's energy matrix is clean, taking into account that the country contributes >0.2% of greenhouse gas emissions, according to figures from the World Bank The World Bank (2022). However, it should be noted that the country is exposed (like all the countries in the southern hemisphere) to changes in climatic conditions. Due to unusual warming of surface waters in the Pacific Ocean that can vary annual rainfall there is an impact on the volume of water in reservoirs Bravo-Lopez et al. (2022). A complementarity has been demonstrated between the water resource with respect to the wind and solar resources. Thus, the cloudiness decreases when El Niño phenomenon occurs. This causes a decrease in water contributions and an increase in the peak hours of solar radiation and an increase in wind energy. In this way, the introduction of non-conventional renewable energy is driven by a need to diversify the energy matrix in order to increase energy security and sovereignty.

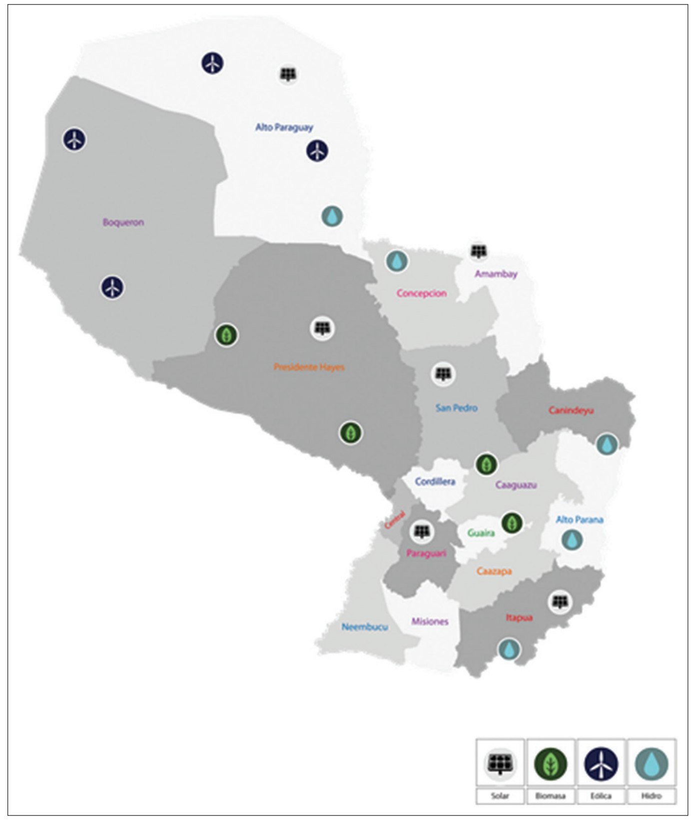
The demand for electrical energy in Colombia is relatively lower than that of the other OECD countries. However, it should be noted that most homes cook with natural gas. Nearly 40 million Colombians in 10.7 million homes use natural gas. The average use of gas per family is 0.495 MBTU-month. Similarly, much of the public transportation system runs on natural gas. The majority of homes in the Andean region where the two main cities are located (Bogotá with a population of 8 million and Medellín with 5 million) do not require a heating or air conditioning system.

3.4. Paraguay

The energy development strategy has a future focus, but being a large hydroelectric generator, it has lower penetration of renewables such as wind or solar. The total installed capacity of solar and wind energy in the year 2022 reached approximately 0.28 MW; which corresponds to 0.001% of non-combustible renewable sources Ayala et al. (2022). So the penetration of renewable energies amounts to 74% of the total matrix, 39% biomass, and 35% hydro, as can be seen in Figure 7. It should be noted that electric power is an important export element (according to the terms of the respective treaties) with the partner countries of the Itaipu (14,000 MW shared with Brazil) and Yacyretá (3,200 MW shared with Argentina) binational hydroelectric plants Ayala et al. (2022).

In this regard, wind energy in the Chaco area could be used for rural electrification. In areas close to Itaipu there is better wind potential, where it is feasible to use hybrid systems for energy purposes Ayala et al. (2022). For wind energy, the possibilities are less since there is no regularity of the winds during the year in rural areas, as recommended for micro generation Ayala et al. (2022).

Figure 7: Distribution of potential energy resources



Source: Paraguay Ayala et al. (2022).

For solar energy, it has projects with a social focus on indigenous communities, a radiation survey expressed in global horizontal radiation (GHI), direct normal radiation (DNI), and diffuse horizontal irradiation (DHI) showed attractive values for scale investment. In addition, solar energy is within the master plan of the National Electricity Administration (ANDE) as a priority to incorporate throughout Paraguay including battery bank substations and solar panel banks with total inverters of approximately 220 MW Ayala et al. (2022). In hydraulic energy, it is expanding smaller-scale projects. However, it must be considered that the total installed power of these new sources is approximately 360 MW, where the strategy associated with this expansion is based on increasing the autonomy of alternative generation around the country Ayala et al. (2022); Nacional de Electricidad (2021a).

Finally, an energy strategy for development must have an approach oriented to "neighboring countries" where the resources and potential per country predominate:

Argentina maintains a generation alliance with Paraguay in the Yacyretá hydroelectric plant, establishing one of the two inter-country alliances in energy Cossuta et al. (2022).

Chile has natural barriers, mountains, desert, ice, and sea thus energy integration with neighboring countries is difficult, it has a commercial relationship with Argentina that did not continue due to political decisions Rivera et al. (2022).

Colombia's system connects the most populated areas of the country. In addition to having a solid interconnection with Ecuador and a weak one with Venezuela, it is expected to interconnect with Panama through High Voltage Direct Current (HVDC) technology. Bravo-Lopez et al. (2022).

Paraguay´s system is based on two public companies in the sector that have a binational legal nature, since they are the companies that operate the Itaipu hydroelectric plant (Paraguay/Brazil), and the Yacyretá hydroelectric plants (Paraguay/Argentina), in which Paraguay has a 50% stake in both cases, through ANDE Ayala et al. (2022).

4. TRANSVERSAL SCIENCE INDUSTRY CHALLENGES FOR LATIN AMERICA

Transversal challenges require a multisector vision of energy from its conception to its transformation and use where science has been impacted by the progress of renewable energy, and in the last stage by smart technologies for storage and power change Liu et al. (2018). In this context, some challenges in each country stand out, as reviewed below.

In the case of Argentina, it has an electrical transmission and distribution network that covers the country, providing access to lighting at low costs for the entire population. However, the use of enormous gas reserves has prevailed, generating a significant dependence on energy for heating and cooking food. After changes in the public subsidy policy, a significant percentage of the population is in the situation of energy poverty Cossuta et al. (2022).

Even though it has renewable resources, it is unfeasible to invest in generation and transmission due to the distance to the populated centers with the greatest demand for energy for residential and industrial use. The adoption of technology to improve transmission and distribution is a path to be explored, together with directing part of the renewable energy installation to power electronics Tang et al. (2021b).

In the Chilean case, it has an important network of interconnected systems throughout the long country. However, close to 25,000 households (0.39% of the country's total) still do not have access to electricity, while 10,000 households still use diesel or other generators to obtain electricity. Close to 17% of Chilean households limit their electricity spending to meet other needs, and 23% of households spend excessively on energy due to poor thermal insulation conditions in their homes Rivera et al. (2022). Finally, the average duration of power supply interruptions in 2020 at the national level was 12.1 h Rivera et al. (2022).

A challenge for Chile is to make small-scale investments to anticipate climate change, and its impact on water sources dependent on annual rainfall. The volumes of water to be dammed head to be more efficient, adapting the generation technologies Rivera et al. (2022).

As for adopting technology as a mitigation measure, Chile is mainly used in wind energy applications PI (Proportional Integrator) or PID (Proportional Integrator Derivative) controllers to handle each wind turbine. For solar energy, Chile usually uses a Maximum Power Point Tracker (MPPT) device Rivera et al. (2022).

In recent years, public policies have explored promoting the production of green hydrogen associated with independent and hybrid systems. Given the existing water reserves and the capacity of various areas of the country, they are even evaluating the option of exporting Luo et al. (2014).

In the case of Colombia, it has a wide network in the country within the most inhabited sector and with the greatest development in recent years. Regarding power technology, it currently has three types of Flexible Alternate Current Transmission (FACT) devices: a) Static Var Compensator (SVC), b) Static Synchronous Compensator (STATCOM), and Series Compensator. It also has Thyristors Switched Capacitor (TCSC) for transmission, as well as storage devices in non-conventional energy projects as a backup for contingency. The case of hydrogen where exploration is beginning with the hydrogen roadmap (blue and green) in Colombia. A pilot project began in 2022, with the entry of a 50 Kw Proton Exchange Membrane (PEM) technology electrolyser and 270 solar panels which use water from the refinery to produce 20 kg of high-purity green hydrogen per day Bravo-Lopez et al. (2022).

However, around 1,700 small towns hosting around 128,587 people (0.3% of the country's population) do not have 24-h energy service. They are often partially serviced with diesel plants operating only 4–6 h per day. These peoples are distributed throughout large areas of the territory, especially in the Amazon and Orinoquia regions Bravo-Lopez et al. (2022). A challenge for Colombia lies in bringing energy to those towns incorporated after the signing of the Peace Agreement, where the distances to interconnect the system are economically unfeasible Bravo-Lopez et al. (2022). In addition, the ecological richness of jungle areas makes it unfeasible to build transmission lines that imply felling in the easement zone or electrical safety zone of the line. For this reason, the use of microgrids is key to the development of these areas Bravo-Lopez et al. (2022).

In the Paraguayan case, it has a network with country coverage, which requires increasing transmission. For this reason, the potential of renewables in rural areas, where there is no economic feasibility to transmit energy over distances, the only viable option is small generators. Likewise, the low penetration of electricity in homes for uses other than lighting generates a dependence on biomass, precarious access to technology, and lower life quality Ayala et al. (2022). For these reasons, the ANDE master plan projects new 66 kV transmission lines for the new generation systems which involve approximately 300 km of coverage to improve the availability of electrical energy for the population considering newly available sources of generation, being mostly renewable solar photovoltaic and hydroelectric Nacional de Electricidad (2021a). In addition, new transmission lines are being considered to reinforce the Paraguayan national system (66 kV (330 km), 220 kV (350 km), and 500 kV (1050 km)) Nacional de Electricidad (2021b).

Paraguay's challenge is based on stimulating investment in medium-scale hydroelectric projects that supply isolated areas with reservoir capacities due to their natural potential, and thus increase the autonomy of generation closer to consumption centers, and not affect the commercial relationship of exported energy as is the case with Brazil Nacional de Electricidad (2021a).

5. ENERGY POLICY AMONG THE ANALYSED COUNTRIES

The countries have prepared strategies in accordance with their energy development situation, priorities, option for renewables, and a list of incentives that expedite the updating of the generation, transmission, and distribution matrix.

5.1. Electricity Generation Matrix Versus Energy Use Matrix

It is a reality that the structure of energy use is independent of the installed generation capacity. From this perspective, it is common for many Latin American countries to have a low penetration of electricity as a source for heating and cooking food, where the type of energy used is based on a cost-efficiency decision, and income level to consider an indicator.

It is important to understand the existing gap between energy generation and use to address the reality of energy poverty associated with communities as well as energy efficiency associated with industrial use as part of the development model of a country's economy.

In the case of Chile and Paraguay, a direct relationship can be seen between the use of biomass for heating and cooking in areas with good access to electricity, but little adoption of technology and the high costs compared to the income of an average family Rivera et al. (2022); Ayala et al. (2022).

In the case of Colombia, there is a penetration of the use of electricity in the cities, and in the case of Argentina, the important penetration of gas.

5.2. Energy Policy of the Analyzed Countries

Argentina has published Energy Scenarios 2030, developed in 2019 by the Argentinian Government. Different scenarios applied to a set of models that represent energy consumption, the electrical system, the refining park, and the integrated energy system are addressed. In this sense, the energy policy as a whole considers electricity, gas, oil in different sources of demand: housing, transport and industry (Subsecretaria de Planeamiento Energético, 2019).

Chile has prepared Energy 2050, Chile's energy policy developed in 2015 and updated in 2020 by the Ministry of Energy of the Central Government (Gobierno de Chile, 2015). Base energy is addressed as a development engine for the country, enhancing the reliability of the energy system, with a reliable network that allows social inclusiveness and environmental protection, but will require energy efficiency and market competitiveness Luo et al. (2014). Priority is given to promoting renewable energy, the interconnection of a single transmission system, together with promoting social equity in energy, without losing the efficiency of the integrated generation, transmission, and distribution system.

Colombia has prepared National Energy Plan Colombia: Energy Ideario 2050, developed in 2015 by UPME Mining Planning Unit-UPME of the Central Government. This document presents guidelines for the future development of the energy sector, the basis for developing and implementing energy policy Unidad de Planeación Minero UPME (2015). It is important to emphasize that it addresses the role of the supply of hydrocarbons, coal and sources of electricity generation for growth and the recomposition of the productive structure for the country, with a long-term vision. The country is committed to an energy transition in the medium term.

Paraguay has prepared Paraguay 2040 Energy Policy, developed in 2016 by the cabinet of the Vice Minister of Mines and Energy of the central government. It meets objectives for the national energy sector, defined for each of the subsectors: electricity, binational hydroelectric entities and electrical integration, bioenergy and other alternative sources and hydrocarbons de viceministro de Minas y Energia (2016). It should be noted that the current policy is applied accompanied by the National Electricity Administration (ANDE), a public company that manages binational generation agreements, and accompanies development policies in energy matters.

6. DISCUSSION AND GUIDELINES TO DESIGN PUBLIC POLICIES ORIENTED TO THE USE OF ENERGY

6.1. Energy Poverty

Energy poverty is related to the concepts of access, equity and quality, which are subject to fundamental and basic energy needs, as well as their potential satisfiers and associated energy services. This constitutes the sociocultural threshold, the need to observe how the energy demand in the country is built and how it is converted into energy operation, taking into account the different geographic and demographic conditions Salinas et al. (2022). As an example, in Chile, the Energy Poverty Network (RedPE) uses nine indicators for its measurement, which are focused on access and equity of energy service, highlighting RedPE (2019b):

- Source of energy and appliance used for cooking,
- Domestic hot water system,
- Access to electricity,
- System average outage duration index,
- Source of energy and appliance used for heating,
- Energy efficiency of the home,
- Thermal comfort,
- Excessive expenditure of energy, and
- Sub-expenditure of energy.

In summary, a home is in a condition of energy poverty when it has at least four indicators below the minimum indicated threshold. In order to understand the problem of energy poverty, three aspects are discussed below that explain the base conditions for having a minimum acceptable level in:

- Access to energy service,
- Equity of energy service, and
- Quality of energy service.

6.1.1. Access to energy service

Corresponds to a dimension related to barriers in accessing energy, expressed in connectivity, supply, and appropriate technologies. In such a case, geographic, infrastructure, and technology limitations must be considered. Having access to electrical service is relevant for the progress of people since the positive effect on socioeconomic development, educational and employment opportunities of the members of a household has been demonstrated, when they have access to electricity, information technologies, and an environment free of atmospheric pollutants Salinas et al. (2022). In summary, having access to energy contemplates ensuring aspects such as food and hygiene, lighting, electrical devices, and air conditioning of the home, where each one has indicators and parameters that are measured to size the problem of energy poverty related to energy access to electrical services.

6.1.2. Energy service equity

Corresponds to a dimension related to economic income and access to energy services where two aspects are considered within this dimension. The first is excessive spending on energy services with respect to monthly income, these are affected by the quality and cost of energy sources, the quality of buildings and their thermal coatings. The second aspect considers thermal and lighting comfort, as well as the ability to access energy sources and associated goods Salinas et al. (2022).

6.1.3. Quality of energy service

Corresponds to a dimension that addresses the tolerance limit regarding the used energy sources, the required energy services, housing conditions, access, and stability of the energy supply.

The energy efficiency of homes, air conditioning, and the stability of the energy supply are more relevant since they are directly related to the current projections of climate change and the risks of socio-natural disasters RedPE (2019b). It is proposed to carry out work that addresses issues of public health, environment, energy, social development, and housing to design initiatives that address the three aspects described above. A challenge in this matter is obtaining information to manage a database, with relevant indicators on the current state of the localities in the context of energy services, in order to carry out public policies focused on overcoming energy poverty.

6.2. Energy Efficiency

Corresponds to the result of the use and optimization of energy based on the design and architecture of construction systems for habitable spaces, the configuration of consumer equipment, the incorporation of sensor-type control devices, remote action, and digitization of systems for establishing levels of automation or "intelligence" that allow planning at different scales from a home, neighborhoods, to cities RedPE (2022).

Energy efficiency in Latin America is a concept based on income level and urban-rural accessibility. The amplitude is determined by the level of income per capita of the countries, the quality of the house in terms of thermal insulation as the main variable for the highest level of energy consumption, public policies that plan the sources of generation in the medium and long term and its incorporation into the transmission networks, along with establishing levels of access at a competitive cost. Therefore, it is proposed to design laws and public programs aimed at promoting the regulation of energy markets, encouraging the coverage of electrical systems and access to information and communication technologies to ensure universal and equitable access to the entire population. An integrated challenge aims to promote an education plan that explains the importance of energy savings in homes, and the aggregate impact on the country's energy efficiency.

6.3. Smart Investment in Energy

Investment relates to the design, planning, and implementation process to optimize the use of energy from the type of electricity generation technology to activate the load levels and energy storage associated with renewable energies through power electronics Rivera et al. (2022). Therefore, it is proposed to focus on public policies that encourage private investment with planning in terms of technologies that can improve the living conditions of thousands of people considering economies of scale. An integrated challenge aims to promote the efficient development of distributed generation and battery storage systems in homes and public centers, ensuring backup networks in those areas where the most vulnerable population is concentrated.

6.4. Readjustment of the Transmission Infrastructure

When carrying out a comparative analysis of the energy matrix between Argentina, Chile, Colombia, and Paraguay, three growth phases are evidenced in the last 50 years: (1) based on existing natural resources, (2) given the growing demand for industrial and residential growth, it intensifies thermal generation with the added consumption of hydrocarbons, and (3) it is aimed at diversifying the incorporation of renewables for sustainability purposes, as the technologies become more accessible.

It is important to understand that the evolution of generation has also influenced transmission and its infrastructure associated with coverage with optimized charging capacity to large population center. Industrial developments such as mining which have led to investment due to growth in energy demand RedPE (2019b).

Today, losses in transmission and the atomization of electricity generation can guide the responses to the efficiency of energy use by establishing different operating conditions. Therefore, it is proposed to carry out collaborative work between governmental, public, private, and non-profit institutions to propose objectives and public policies.

One challenge is to design an integrated transmission plan that considers energy poverty and climate change to interconnect off-grid areas in countries, and to ensure access to quality energy service.

7. CONCLUSIONS

Argentina, Chile, Colombia, and Paraguay have a mixed electricity generation model (hydrocarbons and renewables) based on available energy resources, serving mainly populated areas, with transmission networks distributed by demand. Greater progress is noted in Chile, Colombia, and Paraguay to where renewable energy projects aim to mitigate the effects of climate change and reduce disconnection in remote areas. However, despite all the efforts to maintain an electrical generation matrix where a large part of the inhabitants have access to electricity, there is a lag in the use of electrical energy to heat homes and/or cook food due to a lack of access to technology, low family income, or disconnection from the matrix. This gap largely determines the level of energy poverty in the analyzed countries, and the lack of effectiveness of public policies that mitigate this effect where it is necessary to improve access, equity, and quality of energy in terms of a primary matrix.

To increase coverage in different areas, it is proposed to promote microgrids as an electricity generation strategy, evaluating the high potential for small hydro, solar and wind energy where applicable. Promoting smart investment in base energy with renewables requires a storage strategy when load peaks differ from consumption, together with redesigning the transmission infrastructure that promotes a policy at the continental level with corridors associating integrated generation capacities, exchanges of power by feeding zones, and resource swaps for generation. Finally, the promotion of public policies led by an interregional table that analyzes the energy situation can address structural problems via a public-private-academic alliance through a cooperation agenda in investment in new projects, operational cost benchmark, and social and environmental license protocols to operate.

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REFERENCES

Apostolović, M.R., Studović, M.Ž. (2011), Actual State, Future Trends and Desirable Directions of Electricity Sector Development in the Region of South-East Europe. In: 2011 8th International Conference on the European Energy Market (EEM), p.911-916.

Ayala, M., Toledo, S., Ramirez, G., Prado, A., Caballero, D., Rivera, M., Wheeler, P., Gregor, R. (2022), A Review of Solar and Wind Energy in Paraguay. In: 2022 IEEE International Conference on Automation/XXV Congress of the Chilean Association of Automatic Control (ICA-ACCA), p.1-5.

Bravo-Lopez, M., Marin, S., Terrrero-Barrento, J.R., Garcés, A., Molina, A., Rivera, M., Wheeler, P. (2022), An Overview of the Colombian Power System. In: 2022 IEEE International Conference on Automation/XXV Congress of the Chilean Association of Automatic Control (ICA-ACCA), p.1-6.

Changxi, Z., Gang, W. (2012), Research on Policy of New Energy Technology Development. In: World Automation Congress 2012, p.1-3. Available from: https://ieeexplore.ieee.org/document/6321324

Cossuta, P., Moutin, M., Mechoulam, A., Barbero, S., Aguirre, M. (2022), Climate Change in Argentina, Renewable Energies and their Implications. In: 2022 IEEE International Conference on Automation/XXV Congress of the Chilean Association of Automatic Control (ICA-ACCA), p.1-5.

Day, R., Walker, G., Simcock, N. (2016), Conceptualising energy use and energy poverty using a capabilities framework. Energy Policy, 93, 255-264.

Energia, G.D. (2016), Política Energética Paraguay 2040. En Gobierno Central. Available from: https://www.itaipu.gov.py/es/pagina/politica-energetica-nacional-2040-0

Faggian, P., Decimi, G. (2019), An Updated Investigation about Climate-change Hazards that Might Impact Electric Infrastructures. In: 2019 AEIT International Annual Conference (AEIT), p.1-5.

Fiorelli, M., Sanseverino, E.R., Massaro, F., Favuzza, S., Ippolito, M., Zizzo, G. (2018), The Energy Market Impact of Climate Change on Electricity Generation in Europe. In: 2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), p.1-4.

Gobierno de Chile. (2015), Energía 2050 Política Energética de Chile. En Ministerio de Energía. Available from: https://www.energia.gob.cl/sites/default/files/energia_2050_-_politica_energetica_de_chile.pdf

González, A., Pereira, G., Ríos, R., Llamosas, C., Oxilia, V., Blanco, G. (2021), Multidimensional Composite Energy Poverty Index Based on a Regional Average Benchmark. Study Case: Argentina, Brazil, Uruguay, and Paraguay. In: 2021 IEEE CHILEAN Conference on Electrical, Electronics Engineering, Information and Communication Technologies (CHILECON), p.1-8.

Jewell, W.T. (2007), Electric Industry Infrastructure for Sustainability: Climate Change and Energy Storage. In: 2007 IEEE Power Engineering Society General Meeting, p.1-3.

Liu, Y., Yao, L., Yu, R., Chen, N., Sun, B. (2018), Research on VSC-Based DC Collection system for Large Scale Renewable Energy Generation Clusters. In: 2018 International Conference on Power System Technology (POWERCON), p.2745-2751.

Luo, Y., He, J., Liu, H., Wu, L. (2014), Application of the Distributed Generation, Micro and Smart Power Grid in the Urban Planning. In: The 4th Annual IEEE International Conference on Cyber Technology in Automation, Control and Intelligent, p.634-637.

Macrodata. (2022), Energy and Environment Statistics. Available from: https://datosmacro.expansion.com/energia-y-medio-ambiente

Mejía, E.L., Velandia, F., Zuluaga, C.A., López, J.A., Cramer, T. (2012), Structural analysis northeast of nevado del ruiz and contribution to geotermal exploration. Boletín de Geología, 34, 27-41.

Nacional de Electricidad, A. (2021a), Plan Maestro de Generación 2021-2040. En ANDE. Available from: https://www.ande.gov.py/documentos/plan_maestro/plan%20maestro%20de%20generacion%20%202021-2040.pdf

Nacional de Electricidad, A. (2021b), Plan Maestro de Transmisión

2021-2030. En ANDE. Available from: https://www.ande.gov.py/documentos/plan_maestro/plan%20maestro%20de%20transmision%20%202021%20-%202030.pdf

Pereira, L.C., Dos Santos Lusvarghi, S.A., Arango, L.G., Arango, H., Bonatto, B.D. (2015), Socioeconomic Analysis of Incentive Public Policies for the Use of Renewable Energy Per Consumer Class in Brazil. In: 2015 IEEE PES Innovative Smart Grid Technologies Latin America (ISGT LATAM), p.57-62.

RedPE. (2019a), Acceso Equitativo a Energía de Calidad en Chile: Hacia un Indicador Territorializado y Tridimensional de Pobreza Energética. En Red de Pobreza Energética, Vol. Documento de Trabajo n 5, p.58.

RedPE. (2019b), El acceso desigual a energía de calidad como barrera para el desarrollo en Chile. En Red de Pobreza Energética. Policy Paper. Universidad de Chile. Available from: https://uchile.cl/dam/jcr:27b36573-0890-4778-94b4-05e70ecf4505/11-28-2019-policy-paper-redpe-digital-final.pdf

RedPE. (2022), Una Mirada Multidimensional a la Pobreza Energética en Chile. En Red de Pobreza Energética, Universidad de Chile Vols. Santiago, Chile, p.53. Available from: https://generadoras.cl/documentos/estudios/reporte-n1-una-mirada-multidimensional-a-la-pobreza-energetica-en-chile

Rivera, M., González, N., Salinas, M. (2022), Estado Actual del Cambio Climático en Chile y el Uso de Tecnologías Inteligentes Para su Mitigación. United Kingdom: En ICCA ACCA 2022.

Salinas, M., Rivera, M., Silva, M. (2022), Propuesta de Soluciones Tecnológicas Para Enfrentar la Pobreza Energética y Mitigar el Cambio Climático en el Contexto de las Energías Renovables y Tecnologías Inteligentes. [Industrial Civil Engineering Thesis]. Universidad de Talca. Available from: https://dspace.utalca.cl/handle/1950/13408

Sánchez-López, M., Moreno, R., Alvarado, D., Suazo-Martínez, C., Negrete-Pincetic, M., Olivares, D., Sepúlveda, C., Otárola, H., Basso, L.J. (2022), The diverse impacts of COVID-19 on electricity demand: The case of Chile. International Journal of Electrical Power and Energy Systems, 138, 107883.

Santillán, O.S., Cedano, K.G., Martínez, M. (2020), Analysis of energy poverty in 7 Latin American countries using multidimensional energy poverty index. Energies, 13(7), 1608.

Subsecretaria de Planeamiento Energético, G.C. (2019), Escenarios Energéticos 2030. En Dirección Nacional de Escenarios y Planteamiento Energético. Available from: https://energia.gob.cl/pelp/escenarios-energeticos

Tang, Q., Wu, J., Xiao, J., Zhou, F., Wu, X. (2021a), A Case Study of Renewable Energy Resources Assessment Results in Argentina. In: 2021 IEEE 4th International Electrical and Energy Conference (CIEEC), p.1-5.

Tang, Q., Wu, J., Xiao, J., Zhou, F., Wu, X. (2021b), A Case Study of Renewable Energy Resources Assessment Results in Argentina. In: 2021 IEEE 4th International Electrical and Energy Conference (CIEEC), p.1-5.

The World Bank. (2022), CO_2 Emmisions (kt) - Colombia. Available from: https://data.worldbank.org/indicator/en.atm.co2e.kt?locations=co

Ugarteche, O., León, C.D. (2022), China and the change of the energy matrix in Latin America: A global political economy approach. Brazilian Journal of Political Economy, 42, 442-459.

Unidad de Planeación Minero UPME, G.C. (2015), Plan Energético Nacional Colombia, Bogota. En Ideario Energético 2050. Available from: https://www1.upme.gov.co/demandayeficiencia/paginas/pen.aspx

Villegas Pico, H., McCalley, J.D., Angel, A., Leon, R., Castrillon, N.J. (2012), Analysis of very low frequency oscillations in hydro-dominant power systems using multi-unit modeling. IEEE Transactions on Power Systems, 27(4), 1906-1915.