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Situation of Electricity Integration in South America

Technical Note No.2

October 2024

1. Background

Latin America and the Caribbean face a reality marked by the increasingly visible effects of climate change. Atypical weather phenomena ranging from extreme droughts to floods have serious impacts on energy infrastructure, putting demand supply at serious risk.

This commits us to seek alternatives that allow, on the one hand, to create conditions according to the individual realities of the countries to face these effects and, on the other hand, to promote the joint effort of the region in the search for greater resilience of energy systems through the use of their energy resources for the benefit of all.

One of these alternatives, and perhaps the most sustainable, is woven around energy integration in its broadest sense. This involves not only the construction of interconnection infrastructure or joint uses between countries that share a border but also the creation of favorable spaces to share experiences and good practices and develop a joint work plan for our future as a region.

OLADE, as a regional energy organization, has among its main objectives, to work for regional integration jointly with its 27 member countries, incorporating the entire energy community of the region into this collective effort.

Thus, on December 15, 2022, the leaders of the region's energy sector, gathered at the LII Meeting of Ministers of the Latin American Energy Organization (OLADE) held in Panama City, and approved Ministerial Decision LII /D /566, which instructs OLADE to promote actions aimed at strengthening energy integration mainly with renewable energy sources in all activities and operations of the energy sector in Latin America and the Caribbean.

With this background, OLADE, as one of the actions that it has been carrying out with this disposition, prepared this document on the current state of electricity integration, the different sub-regional initiatives that are underway and their future prospects, a document that aims to create a space for discussion on the importance and need for integration to meet the challenges posed by the

transition to cleaner and less polluting economies, while ensuring the supply of an increasingly growing demand under conditions that are favorable to all stakeholders, with prices that are assimilable for the different local realities and that contribute to closing the gaps in energy access, access to education and work, and, fundamentally, to reducing the high levels of poverty and extreme poverty to which we cannot remain indifferent.

2. Previous studies and analyses

There is a wide spectrum of academic and consulting work developed mainly by the main cooperation agencies at the regional level such as OLADE, ECLAC and CIER with the technical and financial support of the IDB, CAF and the WORLD BANK or national agencies such as the EPE, which studied the potential impact of regional electrical integration over the course of the changing last decades.

The aforementioned documents that reflect the positions of the countries in the areas of regional political discussion allow identifying three stylized facts: i) The countries have consistently expressed their willingness to advance in regional electricity integration; ii) Regional energy integration would have positive results in terms of costs, energy security, and decarbonization; and iii) Despite the potential benefits, this willingness has not materialized in sufficient actions that allow a significant leap in integration. At the level of the Southern Cone countries, in the last decade, only two interconnection projects were advanced: the Uruguay/Brazil frequency converter and the Argentina/Bolivia interconnection. In the Andean Region, the construction of the interconnection between Ecuador and Peru is announced, which will open the doors to the Regional Andean Electricity Market (MAER, for its Spanish acronym) that could incorporate Bolivia and Chile in the future.

Among the latest studies carried out on the potential impact of greater regional integration, it is worth highlighting the modeling proposed by Tejeda (2017) on the role that could be played by the materialization of the main interconnection projects in the pipeline[1] within the framework of the energy transition and the massive incorporation of non-conventional renewable sources. The study identifies an hourly and seasonal complementarity in the unconventional renewable resources available to some contiguous areas of Latin America and models the results of the incorporation of the potential of renewables with and without new interconnections in a 2030 horizon. The results of the study identify significant benefits in terms of emissions reduction, investment volumes, and costs of electricity systems throughout the region if progress is made with interconnection projects.

Another important study analyzing the impact of integration, Cornalino (OLADE, 2020), based on the simplified modeling of the electricity systems of Argentina, Chile, Uruguay, Brazil, and Paraguay, showed that there was significant

[1] 500 kV interconnections between Peru and Ecuador, Peru and Brazil, Peru and Chile, Bolivia and Brazil, and Argentina-Paraguay-Brazil; 230 kV interconnections between Peru and Bolivia, and Arco Norte; and the 400 kV interconnection between Colombia and Panama and SIEPAC 2.

opportunity for efficiency gains from greater use of existing interconnections. This study does not incorporate new interconnections, but rather identifies the gains that could be accessed to the extent that exchanges are activated with lower cost differentials between systems (lower barriers). A relevant aspect is that modeling incorporates the increasingly recurrent effects of La Niña and El Niño.

The "Evaluation of the impact of climate change on electricity generation in the Southern Cone countries", carried out by the World Bank and Olade (2023), which models the impact that hydroelectric, wind and solar generation, as well as demand, could have on the basis of climate change scenarios foreseen for 2050. The model, which does not consider extreme events, but rather trends, indicates that one of the relevant strategies for dealing with changes in the availability of hydroelectric resources, which will be heterogeneous, is to advance in the process of regional energy integration through greater development of interconnections.

Although the conclusions of the different studies coincide in terms of the central role of regional integration for the future in terms of the environment, energy security, and costs, the countries have had a tendency to plan and promote the development of their systems based on criteria oriented towards energy sovereignty and security, understood in the sense of eliminating or minimizing dependence on electricity supplies from neighboring countries. It can be noted that the incorporation of non-conventional renewables, as well as LNG liquefaction terminals in some countries, has allowed the development of higher levels of security and diversification of the electricity matrix, which could explain the lower focus on projects of great technical, financial, environmental and regulatory complexity.

The evolution of integration initiatives led, particularly in the Southern Cone, to a change in the approach and the points of greatest concern linked to regional energy integration, turning towards a more pragmatic and less ambitious approach. The most recent studies carried out and the SIESUR technical tables have paid greater attention to finding mechanisms that allow better use of the existing infrastructure, increasing the exchanges that had been observed until 2019.

In regulatory terms, particularly in the reports prepared by OLADE-IDB-CIER in 2020 within the framework of SIESUR, the regulatory discussion agenda was adjusted, leaving in the background problems such as regulatory convergence or the possibility of entering into long-term firm contracts, to move forward with the solution of short-term problems; assuming as a given that the exchanges would be fundamentally interruptible, based on surpluses and that they would be carried

out on existing infrastructure. The same concept is repeated in the recently approved SINEA regulations for the future Andean Regional Electricity Market (MAER).

3. Energy integration from a regulatory perspective

The South American electricity integration process is characterized by a strong presence of bilateralism, and although various initiatives have been promoted to achieve subregional electricity integration, no significant progress has been made in terms of subregional policies and regulatory frameworks that would allow these aspirations to materialize in terms of infrastructure and operation.

In the context of this bilateralism, treaties have been signed to coordinate the objectives of national policies with the commitments assumed for interconnection, to harmonize certain regulations that guarantee the operability of the infrastructure, to establish mechanisms for conflict resolution and to approve regulations that make exchanges viable.

In this scenario, the subregion is also converging towards a *regulatory approach*, an integrationist trend characterized by the establishment of independent regulatory bodies, in which collegiate bodies of technicians and experts make binding decisions for all parties. The application of this integration model requires a high degree of interdependence between the parties, and even a certain level of supranationality, as is the case of the Andean Community of Nations (CAN, for its acronym in Spanish), an organization that has made significant progress in the approval of Community regulations that must be complied with by its members. The Southern Common Market (MERCOSUR, for its acronym in Spanish) also proposes the approval of general principles applicable to the interconnections to be established between its members.

An analysis of the agreements underpinning the existing electrical interconnections in South America shows that, despite the efforts made by multilateral integration organizations, in practice the process of electrical integration in the subregion has materialized from a bilateral perspective.

Although it is evident that bilateralism has worked to build solid energy links between some South American countries, the establishment of a regional integration system, with institutions, policies and regulations, would allow better access to investment for new infrastructure, technological development and other conditions required for the achievement of common benefits, diversification of supply and demand, security of supply and optimal use of resources and existing infrastructure.

4. Regional electricity integration initiatives

There are several integration initiatives in the region, the most important of which is SIEPAC in Central America, which has managed to consolidate a subregional market with infrastructure, regulations and institutions.

In the context of South America, there are three integration initiatives that are in the process of construction and development:

- SINEA (Andean Electrical Interconnection System) that brings together Bolivia, Chile, Colombia, Ecuador and Peru;
- SIESUR (Energy Integration System of the Southern Cone Countries) involving Argentina, Brazil, Chile, Paraguay and Uruguay with the possible incorporation of Bolivia; and,
- Arco Norte that seeks the interconnection of Brazil with the countries of the northern coast of South America (Guyana and Suriname) to which French Guiana would be incorporated.

At the SINEA level, there are noteworthy advances. By Resolution 2402 signed by the Secretary General of the CAN (May 2024), the Operational, Commercial and Regional Coordinator Regulations, regulatory instruments of the Andean Regional Electricity Market (MAER), were adopted. Additionally, the construction of the new 500 kV electrical interconnection between Ecuador and Peru was announced. Once this line is operational, Colombia, Ecuador, and Peru will be interconnected, giving way to surplus exchanges that will be activated based on a price comparison scheme at the border nodes.

For its part, SIESUR approved the 2023-2032 Roadmap that includes short, medium and long-term actions, organized into 3 strategic axes: (i) Regional institutional and regulatory strengthening; (ii) Strengthening and development of the regional interconnected system; and (iii) Mitigation of Foreign Exchange Risk. SIESUR has incorporated into its agenda, the holding of dialogue tables and workshops with the participation of the different actors of the electricity sector at the level of authorities and managers of public policy and also the operators. This has facilitated a fluid dialogue that has made it possible to identify critical nodes that are easy to solve. The result has been positive, evidenced by an increase in the intensity of exchanges.

A project expected for many years is the interconnection between Colombia and Panama, which will allow the interconnection of the Andean Region with Central

America, a complex project due to environmental aspects and relations with native communities. In 2024, there were important advances that have not been achieved so far.

5. Electrical interconnection infrastructure

Years ago, in the different spaces and forums where regional integration was discussed, the principle of the 3Rs was popularized as the foundation of integration: "*rules, grids and resources* (in Spanish: reglas, redes y recursos)". This principle has not lost its validity and rather has been strengthened by having incorporated a fourth R that is perhaps the most important of all: "*backup* (in Spanish: respaldo)" at the highest political and decision-making level.

Integration without infrastructure (grids) would remain only in the space of dialogues and good intentions. Networks are one of the pillars on which integration is built and that is why it is important to sweep the interconnection infrastructure in South America.

Figure 1 Map of Electrical Interconnections - South America

5.1. Infrastructure in the countries of the Andean Region

Colombia and Ecuador have 3 international links in operation, the oldest at 138kV (radial operation[2]) and two links at 230kV (synchronous operation[3]), while between Ecuador and Peru there is a single link at 230kV that operates radially.

[2] Radial Interconnection Line: it is connected to the electrical system of one or another country according to the need for import or export.

[3] Synchronous Interconnection Line: links the electrical systems of two countries that can operate interconnected.

The materialization of the subregional market between Colombia, Ecuador and Peru will be complete once a new Ecuador-Peru interconnection of 500 kV and 500 MW of capacity is operational, which is in hiring process. The interconnections between Colombia and Venezuela are out of operation, as is the interconnection between Brazil and Venezuela.

Table 1 Andean Countries - Main Interconnections

Countries	Location	Voltage kV	Power MW	Frequency Hz	Length Km	Status
Co-Ve	Cuestecita (Co) – Quatricentenario (Ve)	230	150	60	128	Non-operational
	San Mateo (Co) – El Corozo (Ve)	230	140	60	48.5	Non-operational
	Tibú (Co) – La Fría (Ve)	115	36	60		Non-operational
Co-Pa	Cerromatous (Co) – S.E. Panama II (Pa)	300	400	60	500	Under study
Co-Ec	**Jamondino (Co) – Pimampiro(Ec)**	**230**	**250**	**60**	**139**	**In operation**
	Jamondino (Co) – Pimampiro(Ec)	**230**	**250**	**60**	**132**	**In operation**
	Ipiales (Co) – Tulcan (Ec)	**138**	**35**	**60**	**17**	**In operation**
	Jamondino (Co) – El Inga (Ec)	500	1500	60	515	Under study
Ec-Pe	**Machala (Ec) – Zorritos (Pe)**	**230**	**100**	**60**	**104**	**In operation**
	S.E. Chorrillos (Ec) – Frontera/Piura Nueva/-S.E. La Niña (Pe)	500	500	60	574	Under hiring process
Br-Ve	Boa Vista (Br) – El Guri (Ve)	230/400	200	60	676	Non-operational
Bo-Pe	La Paz (Bo) – Puno (Pe)	230/220	150	50/60	278	In inventory
Pe-Cl	Tacna/Los Héroes (Pe)–Arica/Parinacota (Cl)	220	200	60/50	55	Under study
	Tacna/Montalvo (Pe)–Arica/Cruise(Cl)	500	1,000	60/50	600	Under study
Bo-Cl	Laguna Colorada (Bo) – Chuquicamata (Cl)	220	150	50	194	Under study

Source: Own elaboration with information from CIER and the countries involved

There are some projects that are at the study level, such as the interconnection lines between Chile and Peru, and others that were mentioned in some of the studies that have been developed, such as the Jamondino-El Inga line that would allow the interconnection in 500 kV between Colombia and Ecuador, on which there is no progress.

5.2. Infrastructure in Southern Cone countries

The countries of the Southern Cone have an important interconnection infrastructure that allows all countries with a common border to be interconnected with each other. Bolivia is studying interconnections with Brazil and Paraguay and a second interconnection with Argentina.

Table 2 Southern Cone Countries - Main Interconnections

Countries	Location	Voltage kV	Power MW	Frequency Hz	Length Km	Status
Ar-Cl	**Cobos (Ar) - Andes (Cl)**	**345**	**643/200**	**50**	**408**	**In operation**
	Río Diamante (Ar) - Los Condores (Cl) - Ancoa (Cl)	500/220	435/735	50	350	Under study
	Rodeo (Ar) - S.E. Nueva Pan de Azúcar (Cl)	400	1000	50	250	In inventory
	Santa Cruz (Ar) - Aysén (Cl)	220	200	50	175	In inventory
	Santa Cruz (Ar) - Punta Arenas (Cl)	220	200	50	200	In inventory
Bo-Ar	**Yaguacua (Bo)-Tartagal (Ar) (Juana Azurduy)**	**132**	**120**	**50**	**120**	**In operation**
	San Juancito (Ar) – Salvador Mazza (Ar) – Yaguacua (Bo)	500		50		Under study
Bo-Py	Bolivia – Paraguay Interconnection	220		50	400	Under study
Bo-Br	Bolivia – Brazil Interconnection	500		50/60	284	Under study
Ar-Py	**Outputs from Yacyretá Power Plant (Binational Hydroelectric Plant)**	**500**	**3200**	**50**	**0**	**In operation**
	Clorinda (Ar) - Guarambaré (Py)	**220/132**	**80**	**50**	**44**	**In operation**
	El Dorado (Ar) - Mcal. A. López (Py)	**220/132**	**34**	**50**	**35**	**In operation**
	Aña Cuá	500	270	50		Under construction
	Formosa (Ar) – Villa Hayes (Py)	500		50		Under study
Br-Py	**Outputs from Itaipú (Binational Hydroelectric Plant)**	**750/220**	**14000**	**50/60**	**0.1**	**In operation**
	Foz de Iguazú (Br) – Acaray (Py)	220/138	50	50/60		Non-operational
Ar-Br	**Rincón Santa María. (Ar) - Garabí (Br)**	**500**	**2200**	**50/60**	**135**	**In operation**
	Paso de los Libres (Ar) – Uruguaiana (Br)	**132/230**	**50**	**50/60**	**40**	**In operation**
Ar-Uy	**Colonia Elia (Ar) - San Javier (Uy)**	**500**	**2000**	**50**	**24**	**In operation**
	Salto Grande (Ar) - Salto Grande (Oy)	**500**	**1890**	**50**	**0.1**	**In operation**
	Concep. del Uruguay (Ar) –Paysandú (Uy)	**132/150**	**100**	**50**	**70**	**In operation**
Br-Uy	**Pte. Medici (Br) - San Carlos (Uy)**	**500**	**500**	**60/50**	**400**	**In operation**
	Livramento (Br) - Rivera (Uy)	**230/150**	**70**	**60/50**	**11**	**In operation**

Source: Own elaboration with information from CIER and the countries involved

A characteristic of the integration of the Southern Cone countries is the binational hydroelectric power plants Itaipú, Yacyretá and Salto Grande, whose agreements and/or treaties establish the rules for the dispatch and allocation of energy between the parties involved.

Table 3 Southern Cone Countries - Binational Power Plants

Countries	Denomination	River	Installed Capacity (MW)	Status
Br-Py	**H.P.P. Itaipú Binational**	**Paraná**	**14,000**	**In operation**
Ar-Uy	**Salto Grande**	**Uruguay**	**1,890**	**In operation**
Ar-Br	Garabí-Panambí	Uruguay	2,200	In inventory
Ar-Py	**Yacyretá**	**Paraná**	**3,200**	**In operation**
	Aña Cuá	Paraná	270	Under construction
	Corpus Christi (Pindó-í)	Paraná	2,800	In inventory
	Itatí - Itá Corá	Paraná	1,600	In inventory
Bo-Br	Binational hydro	Madera/Mamoré		Under study

Source: Own elaboration with information from CIER and the countries involved

6. Electricity exchanges between countries in the region.

The exchanges in the region show fluctuations that have different origins, in some cases marked by a changing hydrology, with behaviors that deviate from historical behavior; and on the other hand, the heat waves that have occurred in some countries and that have led to a growth in demand that is above the historical average. Another factor to take into account is the greater incorporation of non-conventional renewable energies that replace production with hydrocarbons. In the case of the Southern Cone, flows may have been impacted by the emergence of new regulations introduced by Brazil's Portaria Normativa MME No. 49/2022, which facilitates the export of turbineable discharges and electricity from non-hydroelectric renewable surpluses.

The realities at the subregional level are diverse and very different, each with its own characteristics and nuances. It is therefore necessary to individualize each subregion for the analysis.

6.1. Andean Region

At the Andean Region level, the only countries that have operational interconnection links are Colombia, Ecuador and Peru. The first two maintain almost permanent exchanges, while exchanges between Ecuador and Peru are sporadic.

Exchanges between Colombia and Venezuela have shown no activity in the last years.

The interconnection lines and towers on the Colombian side of the former Cuestecita interconnection (La Guajira-CO) - Cuatricentenario (Zulia-VE) entered into a reconstruction plan due to the renewable projects being executed in the department of La Guajira.

6.1.1. Colombia - Ecuador exchanges

Exchanges between Ecuador and Colombia are governed by the rules of the International Electricity Transactions – IET and consist of short-term hourly transactions that are activated at the price signal. The IET are governed by specific regulations issued by the CAN (Andean Community), of a supranational nature and therefore mandatory for member countries.

Exchanges occur based on coordinated economic dispatch, where the operators of each country (XM in Colombia and CENACE in Ecuador) consider the supply and demand equivalent of the other in the border nodes. Import or export decisions are made based on the availability of exportable surpluses and the comparison of marginal prices at border nodes. The maximum values to export or import are given by the maximum operational capacity of the link that is somewhat less than 500 MW of nominal capacity.

The historical record allows us to identify three very marked periods: A first that begins from the start of transactions in 2003 and extends until 2015 in which Ecuador is clearly an importer; a second period 2016-2021 in which Ecuador puts in operation an important hydroelectric capacity and becomes an exporter; and finally a third period, which begins in 2022 and deepens in 2023 and 2024 in which the situation reverses, Ecuador experiences very severe drought conditions that affect the production of its main hydroelectric plants, having to resort, among other alternatives, to a greater import of energy from Colombia.

In 2023, Ecuador imported 1297 GWh, equivalent to 4.3% of its demand, while exports reached 530 GWh, which represents 0.7% of Colombia's demand.

Colombia has also been facing serious drought conditions with a decrease in the levels of its reservoirs that, according to alerts from the system operator, could affect the operation of the electricity system towards the end of 2024 and therefore has had to restrict energy exports to Ecuador which, for its part and in the absence of sufficient installed backup capacity, has reached rationing conditions.

Figure 2 Historical IET Ecuador - Colombia (GWh), 2003 – 2023
Source: Own elaboration with data from CENACE, Ecuador

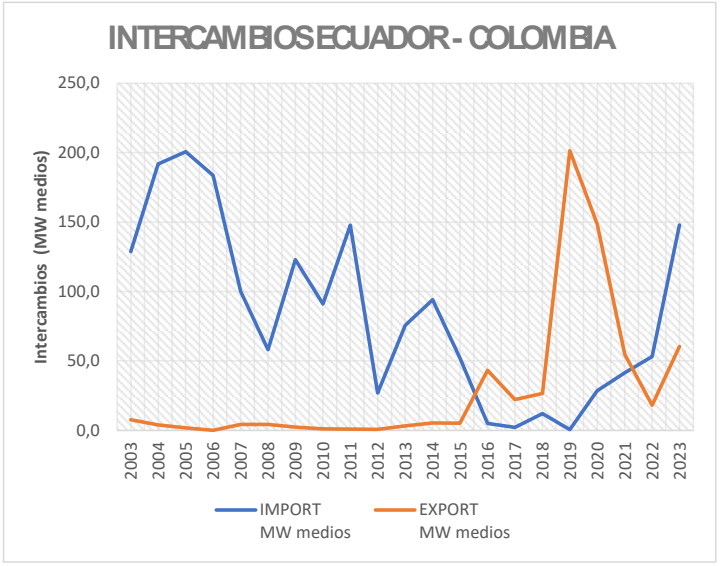


Figure 3 Historical IET Ecuador – Colombia (annual average MW)
Source: Own elaboration with data from CENACE, Ecuador

Until 2023, the interconnection between Colombia and Ecuador shows an average utilization of 25% of its operational capacity, with a maximum of 46% reached in 2023, which coincides with the period of extreme drought referred to above.

Table 4 Andan Region: Interconnection Usage Factor

Interconexión	Capacidad	2022	2023
Colombia - Ecuador	500	15,8%	46,3%
Ecuador - Perú	100	4,2%	4,7%

Source: Own elaboration with data from CENACE, Ecuador

The statistics with monthly details of the exchanges show a markedly seasonal behavior, with greater intensity between September and March.

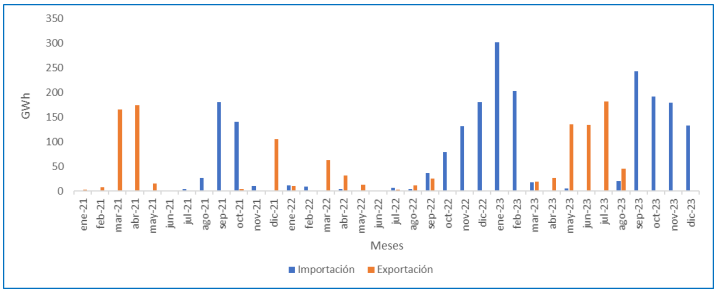
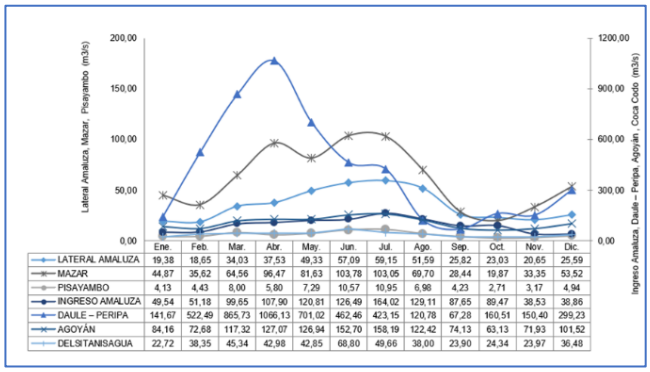


Figure 4 IET Ecuador – Colombia 2021 – 2023 monthly (GWh)

Source: Own elaboration with data from CENACE, Ecuador

The increase in Colombia's export to Ecuador coincides with the period of drought, absence of rainfall, and reduction of tributary flows from the main hydroelectric generation plants in Ecuador, which under normal conditions can supply more than 90% of the demand.



	Ene.	Feb.	Mar.	Abr.	May.	Jun.	Jul.	Ago.	Sep.	Oct.	Nov.	Dic.
LATERAL AMALUZA	19,38	18,65	34,03	37,53	49,33	57,09	59,15	51,59	25,82	23,03	20,65	25,59
MAZAR	44,87	35,62	64,56	96,47	81,63	103,78	103,05	69,70	28,44	19,87	33,35	53,52
PISAYAMBO	4,13	4,43	8,00	5,80	7,29	10,57	10,95	6,98	4,23	2,71	3,17	4,94
INGRESO AMALUZA	49,54	51,18	99,65	107,90	120,81	126,49	164,02	129,11	87,65	89,47	38,53	38,86
DAULE – PERIPA	141,67	522,49	865,73	1066,13	701,02	462,46	423,15	120,78	67,28	160,51	150,40	299,23
AGOYÁN	84,16	72,68	117,32	127,07	126,94	152,70	158,19	122,42	74,13	63,13	71,93	101,52
DELSITANISAGUA	22,72	38,35	45,34	42,98	42,85	68,80	49,66	38,00	23,90	24,34	23,97	36,48

Figure 5 Average flows to the S.N.I. reservoirs (m3/s)
Source: CENACE, Ecuador

On the Colombian side, the largest water contributions occur in October and November, which marks a behavior of seasonal complementarity that is very beneficial for the two countries.

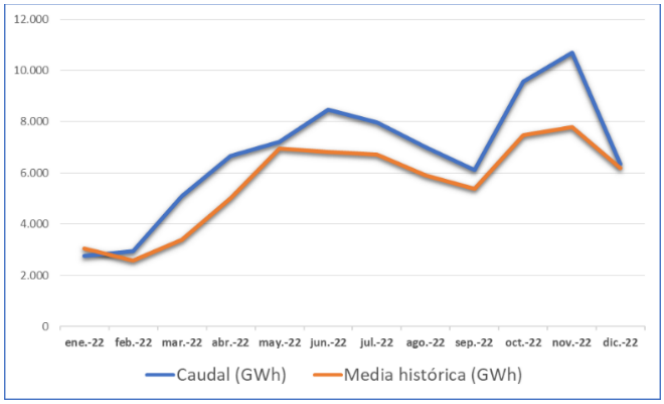


Figure 6 Colombia, monthly water contributions 2022 (GWh)
Source: XM, Colombia

This hydrological complementarity and the high dependence on hydrological conditions in Ecuador explain the correspondence that can be observed between Ecuador's hydroelectric production and imports that intensify between September and March.

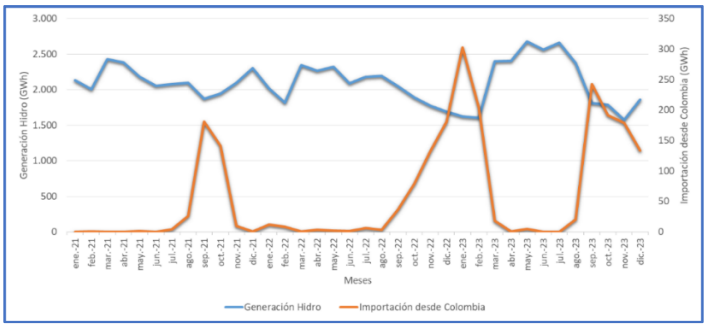


Figure 7 Ecuador: Hydroelectric generation vs. Imports (GWh)
Source: Energy Regulation and Control Agency, Ecuador

Import and export prices are variable and mainly depend on the origin of exportable energy (hydro, unconventional renewables, or fossil fuels).

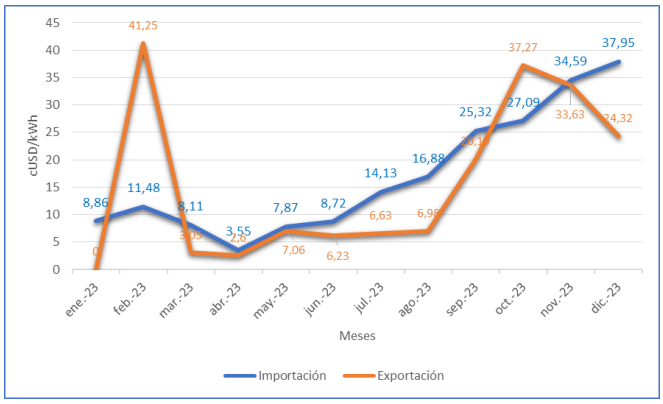


Figure 8 Ecuador: Import and Export Prices 2023 (US¢/kWh)
Source: CENACE, Ecuador

6.1.2. Ecuador - Peru Exchanges

Exchanges between Ecuador and Peru have been sporadic and are due to emergency situations that have occurred indiscriminately in the two countries. The presence of a weak interconnection and the impossibility of a synchronous operation of the two systems constitutes a limitation. This situation could be reversed with the operation of a new interconnection at the 500 kV level programmed for 2027.

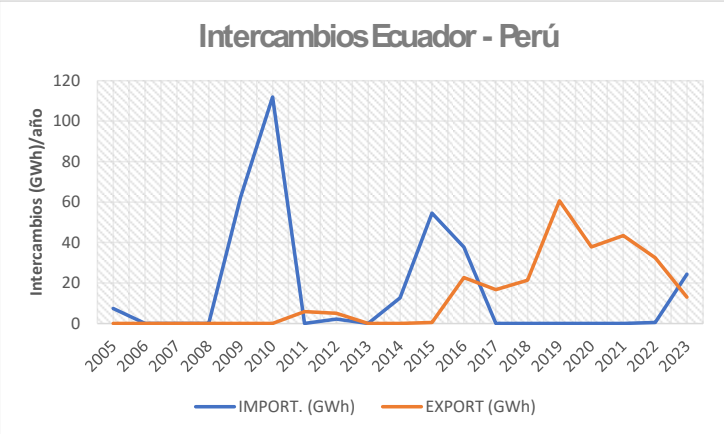


Figure 9 Historical IET Ecuador - Peru (GWh), 2005 – 2023
Source: Own elaboration with data from CENACE

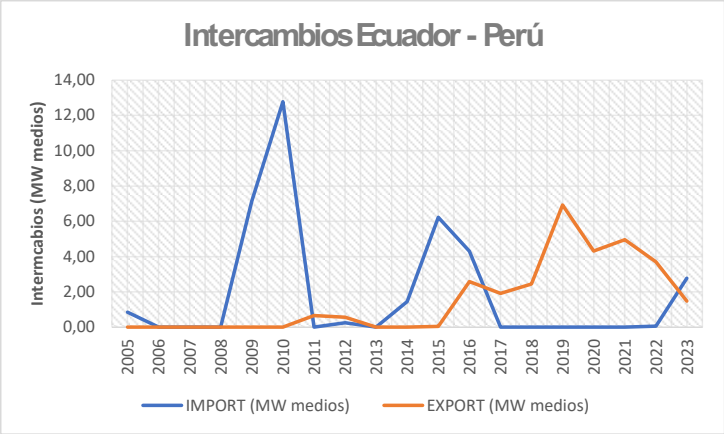


Figure 10 Historical IET Ecuador - Peru (annual average MW), 2005 – 2023
Source: Own elaboration with data from CENACE

The statistical information at the monthly detail level does not show a clear trend, but it is evident that the largest exports from Ecuador to Peru have occurred between April and August, which coincide with the rainy period in the inter-Andean region of Ecuador.

Figure x Monthly IET Ecuador - Peru (GWh), 2021 – 2023

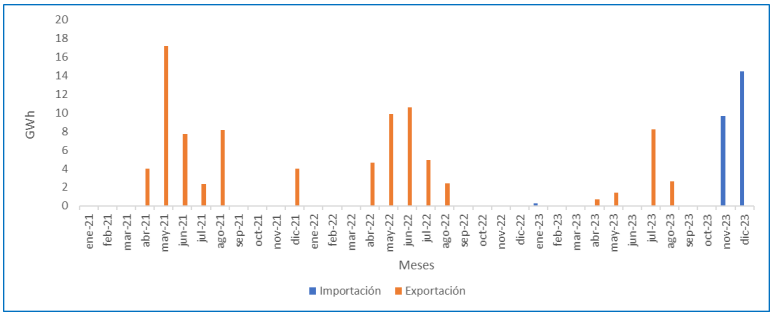


Figure 11 Monthly IET Ecuador - Peru (GWh), 2021 – 2023
Source: Own elaboration with data from CENACE, Ecuador

6.2. Southern Cone Countries

At the level of the Southern Cone countries, exchanges are permanent, using the important existing interconnection infrastructure, apart from the transactions arising from the agreements related to the binational power plants Itaipu, Yacyretá and Salto Grande.

With the sole exception of Paraguay, which is consolidating its position as a net exporter of electricity, exchanges between the other Southern Cone countries have allowed all of them to act as exporters or importers, either to meet their domestic demand or to take advantage of more favorable price conditions.

On the infrastructure use side, the interconnection utilization factor shows an increase in 2023 compared to the previous year, with the exception of the interconnection between Argentina and Uruguay.

6.2.1. Argentina-Brazil Exchanges

The history of electricity exchanges between Argentina and Brazil since 2007 can be separated into three periods:

1. 2007-2011: Exchanges of the order of 200 MW-averages per year, which represent a usage factor of 9% of the capacity of the Garabí converter.
2. 2012-2019: Very low exchanges, close to zero.
3. 2020-2023: increasing exchanges, reaching 900 MW-averages per year in 2023 and a converter usage factor of 45%.

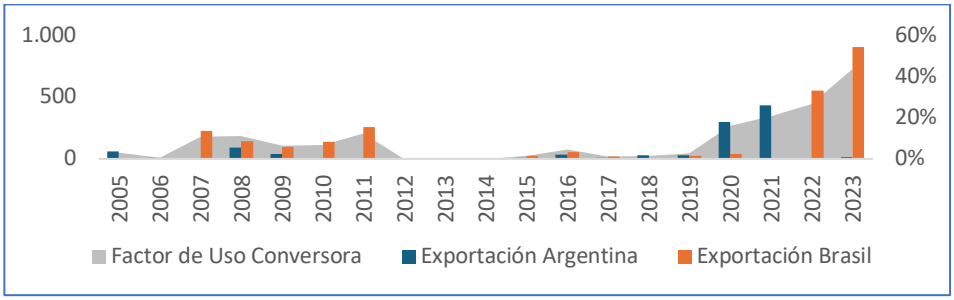


Figure 12 Argentina-Brazil Exchanges. 2005-2023 (MW-annual averages and % converting capacity of Garabí).
Source: Own elaboration based on CAMMESA's data

The following shows the series of monthly net exchanges and the % of occupation of the reservoirs of the Southeast-Central-West subsystem of Brazil, which allows a better appreciation of some aspects of the exchanges of the period under analysis.

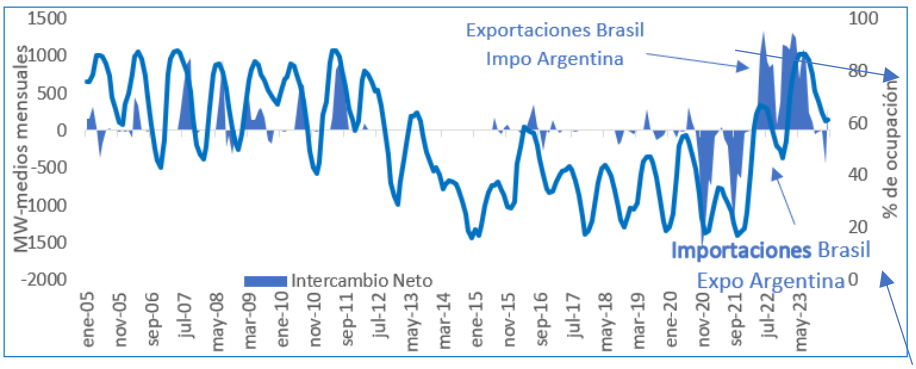


Figure 13 Argentina-Brazil 2005-2023 Net Exchanges (MW-Monthly Averages) and SE-CO Subsystem Stored Energy (%)
Source: Own elaboration based on CAMMESA's and ONS' data

During the period 2007-2011 Argentina resorted to electricity imports from Brazil during the winter months. The rapid growth in demand registered during that period in the SADI, and the sharp decline in natural gas production turned Argentina into an importer of natural gas, LNG and its substitutes such as gasoil and fuel oil during the winter.

During this stage, the Southeast-Central-West Subsystem registered high levels of hydraulicity, a situation that is reflected in the % of energy stored in its reservoir system, which allowed Brazil to export electricity to Argentina when required, thus ensuring supply and reducing Argentine operating costs.

Since 2012, there has been a sharp drop in the energy stored in the SE-CO Subsystem, a situation that extends until 2022. Throughout this stage, Brazil's energy exports to Argentina are low or non-existent, apart from some particular situations in which emergency exchanges were carried out to cover demand peaks or specific deficits of primary resources in the Argentinian system.

In 2020 and 2021 Brazil faced a historic drought that brought dammed energy to minimum levels. Argentina during that stage had enough installed thermal capacity to cover its demand, had recovered natural gas production levels, and was able to export relevant volumes of energy to Brazil during the summer periods.

In 2022 and 2023 the hydrological situation in Brazil began to improve significantly, in a context in which a series of phenomena that affected the Argentinian electricity market combined: 1) from mid-2021 to mid-2022 there was a historical low of the Paraná River that affected Yaciretá's generation; 2) except for the winter months of 2022 the contributions in Salto Grande remained very low

between 2020 and the beginning of 2023; 3) the contributions to the Comahue power plants remained very low between 2021 and mid-2023; 4) liquid fuel and LNG prices rose significantly in 2022 as a result of the start of the war between Russia and Ukraine; and 5) very intense and long-lasting heat waves were recorded in Argentina during February and March 2023, which pushed the system's capacity to the limit. In this context, Argentina was able to take energy from Brazil in a very sustained way throughout the period from May 2022 to October 2023.

It should be noted that Argentina's average import volumes for this period were close to the technical maximums, since although the converter allows exchanges for 2,200 MW, the Yaciretá-AMBA corridor does not accept volumes higher than 1,500 MW on average. Taking this into consideration, Argentina's imports in 2023 reached a 60% use of the direct interconnection infrastructure with Brazil.

A complementary way to analyze the evolution of exchanges is through the relationship between the differential of Marginal Operating Costs (MOC) of the systems and net energy exchanges.

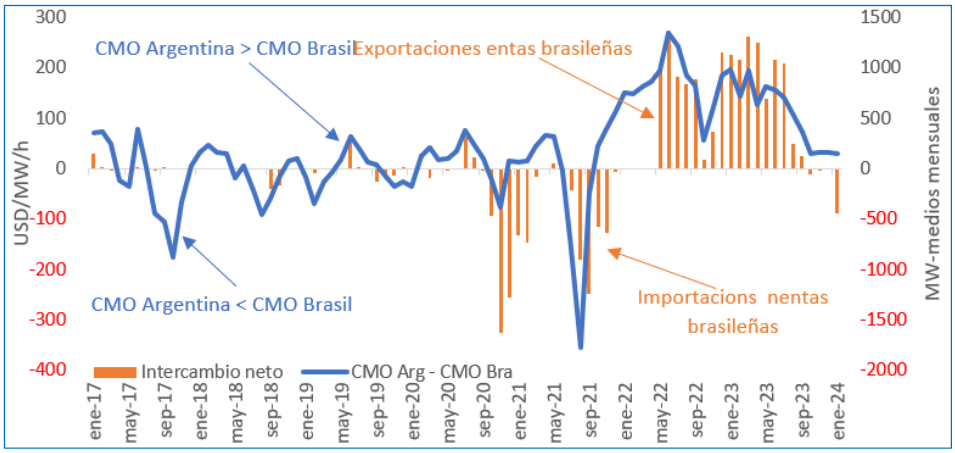


Figure Argentina-Brazil Net 14 Exchanges 2017-2023 (MW-Monthly Averages) and MOC Spread (USD)

Source: Own elaboration based on CAMMESA's and ONS' data

Between 2017 and 2019 in line with the low availability of primary resources in both countries (low hydraulicity in Brazil and scarcity of hydrocarbons in Argentina) price differentials are seasonal, and generate punctual exchanges consistent with such differentials.

Since 2020 the energy exchanges correlate very well with the Marginal Cost differentials between the systems of Argentina and Brazil. During 2020 and 2021 in the summer periods, when Argentina was marginal with gas and Brazil had a hydroelectric shortage, the marginal cost differential was significant (Brazil more

expensive than Argentina) and Argentina's exports to Brazil grew significantly. In 2022, with the improvement of Brazil's hydrological situation and the rising cost of the Argentinian system, the cost differential is reversed and Brazil exports significant volumes of energy to Argentina. When the Marginal Cost differential is reduced, trades return to low levels.

The memorandums signed in 2011 and 2014 defined the exchange as a scheme of assistance from the Brazilian system to the Argentinian system, which could be without return ("commercial") or with interruptible return. In the memorandum of understanding signed in 2016 and ratified in 2019 and 2022, exchange schemes conceived in both directions were established, and 3 forms of exchange were defined: 1) Without interruptible return, from thermal generation not required by the country of origin or non-usable turbineable hydroelectric discharge ("commercial"); 2) With return, under emergency conditions, interruptible; 3) With interruptible return for the use of hydroelectric or renewable energy discharge.

Until 2015, the predominant scheme is that of compensated exchanges. Since 2020, when the increase in energy exchanges is registered, the predominant scheme is "commercial". Operationally, each of the countries offers weekly energy blocks to the other country with their respective volumes and prices. The offers are interruptible, and the required volumes are confirmed with the daily schedule. Argentina exports exclusively thermal generation, and Brazil has mostly exported thermal generation. Since October 2022, with the availability of turbineable hydroelectric surpluses (discharge), the possibility of their export under the "commercial" format was enabled (up to that moment, the exchanges on discharge energy were carried out under the "compensated exchange" modality).

The performance of exchanges under this format has shown to be adequate to activate energy flows to levels close to the technical maximums when there are significant differences in the MOCs of each of the countries, as long as primary resources are available.

In stages with low availability of primary resources on both sides of the border (2007-2019), price differentials (which sometimes reflected specific tensions in one of the systems) enabled specific exchanges. This reflects that in situations of need or emergency, countries have been assisted even without having relevant surpluses.

6.2.2. Uruguay-Argentina and Uruguay-Brazil Exchanges

The exchange between Argentina and Uruguay, countries with highly integrated electrical systems, went through two stages:

1. Between 2005 and 2013, exchanges went back and forth, with a decreasing trend, going from a 10% use of infrastructure between 2005 and 2007, to 6% between 2008 and 2010, to 2% between 2011 and 2013.
2. Between 2014 and 2023, Uruguay became a net exporter throughout the period, and there was an increase in the average use of interconnection infrastructure.

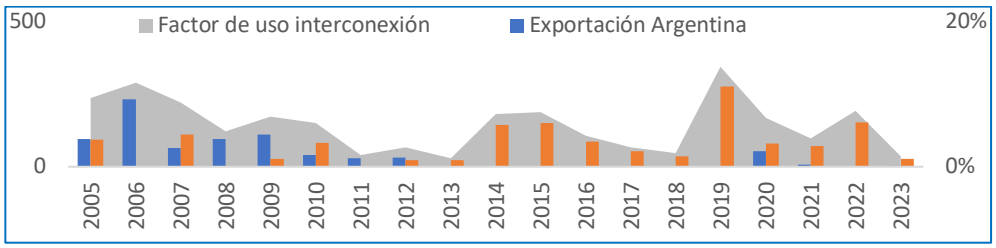


Figure 15 Argentina-Uruguay Exchanges 2005-2023 (MW-annual averages and % of interconnection use)
Source: Own elaboration based on CAMMESA's data

Exchanges of surpluses from Salto Grande have been limited in recent years, with an average 50/50 distribution between Argentina and Uruguay.

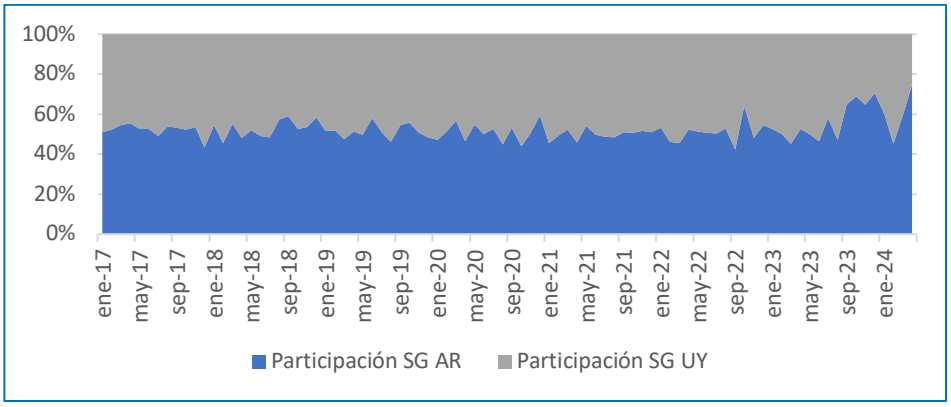


Figure 16 Distribution of Salto Grande generation between Argentina and Uruguay (%).
Source: Own elaboration based on CAMMESA's and ADME's data

The largest deviation in the distribution of Salto Grande's generation is observed at the end of 2023 and the beginning of 2024, with an increase in Argentina's participation.

In the case of exchanges between Brazil and Uruguay, two stages are identified. The first until 2016, when there was only one interconnection for 70 MW, which operated mainly in the sense of exports from Brazil to Uruguay, and which until 2012 had an average use of 33% with exchanges for very limited volumes (less than 25 MW average). And a second stage since 2017, when the operation of the 500 MW converter is enabled, at which point the volumes of energy exchanged

grow and Uruguay becomes a net exporter most of the time (with the exception of 2023, a year with a water crisis in Uruguay).

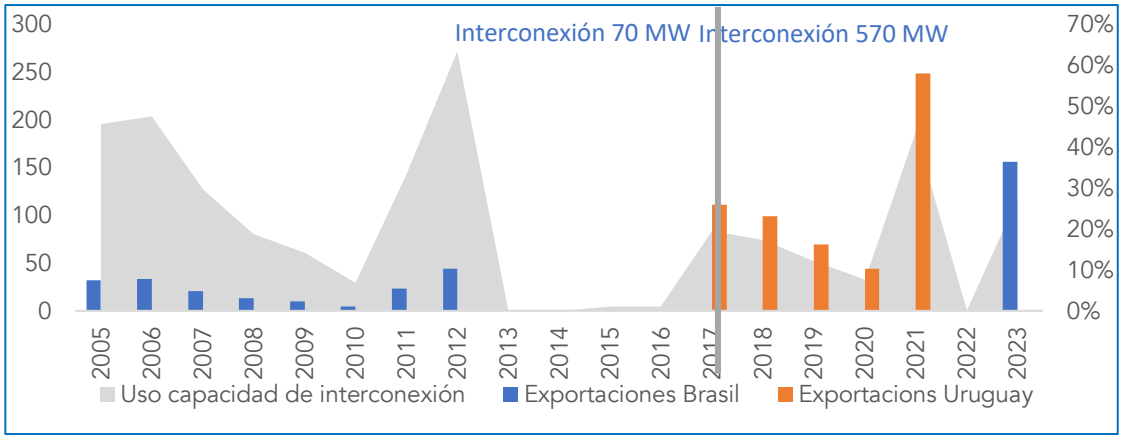


Figure 17 Brazil-Uruguay Electricity Exchanges 2005-2023 (MW-annual averages and % of interconnection use

Source: Own elaboration based on ONS' data

It can be seen in the following figure that in the first stage (2005-2013) the exchanges respond to the hydrological conditions of the Uruguayan system. In the years of greater hydroelectric availability, Uruguay is an exporter, and in those of lesser availability, it is an importer. Argentine exports have been declining since 2010, in accordance with the lower availability of gas and reserve power in its system, forcing a greater thermal dispatch in Uruguay (diesel).

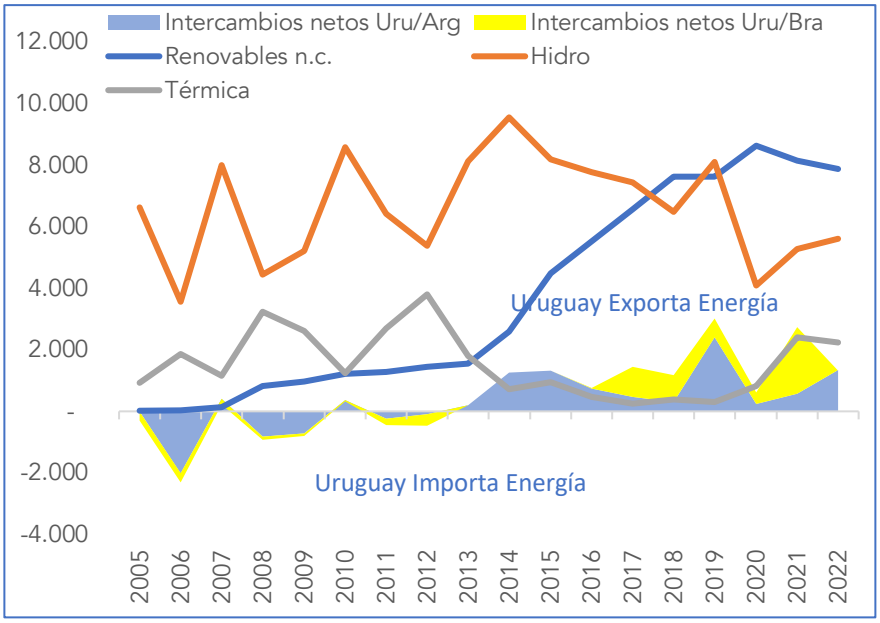


Figure 18 Uruguay/Argentina/Brazil Net Exchanges and Uruguay Generation by Source (GWh) 2005-2022
Source: Own elaboration based on CAMMESA's, ADME's and ONS' data

As of 2014, in line with the progressive increase in its renewable generation mainly of wind origin, Uruguay is a net exporter. Fluctuations in hydroelectric availability have an impact on the volume of surpluses that from 2016, as a result of the qualification of the Melo converter with 500 MW of capacity, can be exported to the Argentine market or to the Brazilian market.

Analyzing the evolution of recent exchanges with a monthly frequency, it is possible to better appreciate the existing correlation between the hydraulic capacity of the Uruguayan system and exports to Argentina and Brazil. Likewise, the reversal of exchange flows in periods of reduced hydroelectric generation in Uruguay.

If you want to look at the behavior of exchanges based on Marginal Operating Costs, you see a correlation, although not linear, between differential costs and energy flows. When the MOC is higher in Argentina, Uruguay exports and when it is higher in Uruguay, the opposite happens.

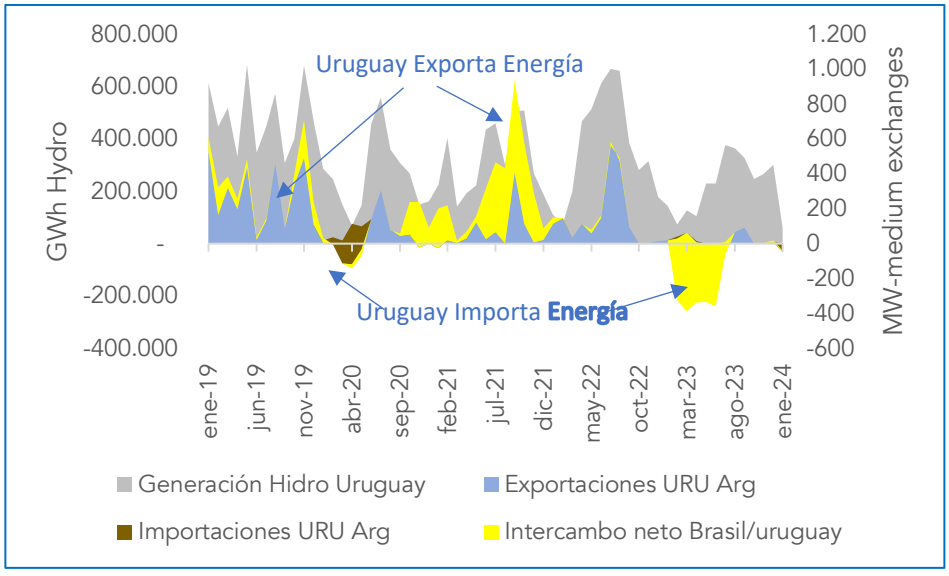


Figure 19 Uruguay/Argentina/Brazil Exchanges 2019-2024 (MW-monthly averages) and Uruguay's hydroelectric generation (GWh)
Source: Own elaboration based on CAMMESA's, ADME's and ONS' data

For exchanges between Uruguay and Brazil, a correlation is observed between the marginal cost differential and energy flows. When costs are higher in Brazil, Uruguay exports and when the cost equation is reversed, Uruguay becomes an

importer. This behavior does not necessarily constitute a rule, due to the incidence of the hydrological conditions of the two countries. During dry period 2020/2021 Brazil imported energy to preserve its reservoirs, although marginal cost differentials were negative.

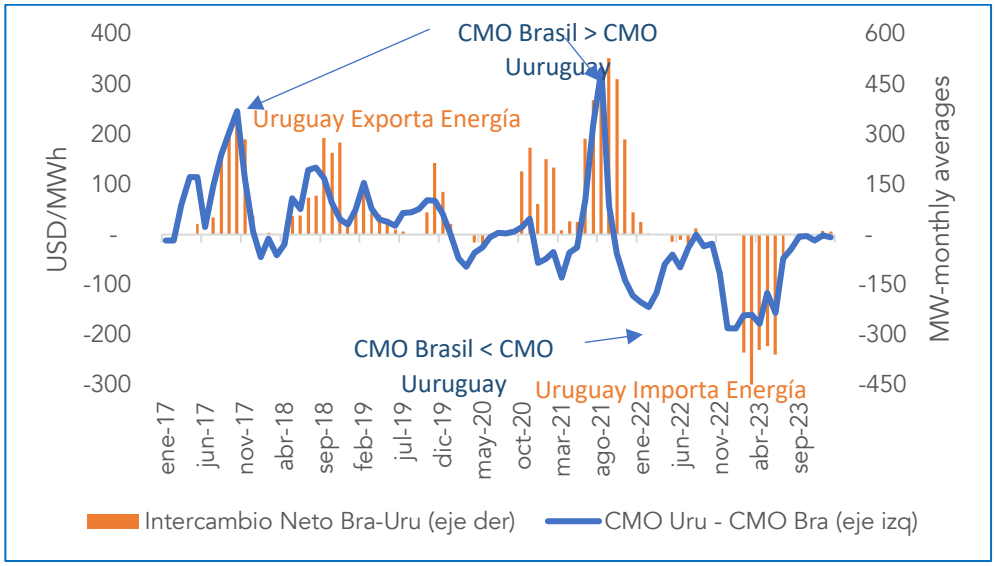


Figure 20 Argentina-Brazil Net Exchanges 2017-2023 (MW-Monthly Averages) and MOC differential (USD/MWh)

Source: Own elaboration based on ONS' and ADME's data

In 2023, a year in which Uruguay endured severe drought conditions, the hydrological situation forced Ute to put its entire thermoelectric plant into operation and resort to Brazilian net imports to guarantee supply. On certain days in 2023, imports covered 30% of demand.

The benefits of importing from Brazil were not only on the energy side, but also on prices. Brazil's export of turbinable surpluses allowed Uruguay to obtain lower prices through imports than those represented by putting its combined cycles into operation. For example, it was the case that energy from Brazil was paid at 60 USD/MWh, while the operation of the Punta del Tigre combined cycle reached 193.5 USD/MWh.

At the same time, at certain times of the day, Uruguay also exported thermal energy to Argentina, which endured a heat wave with high demand peaks in February and March 2023.

6.2.3. Argentina-Paraguay exchanges

The main interconnection between Argentina and Paraguay is the Yaciretá binational power plant. The treaty establishes that the energy generated by the plant corresponds in equal parts to each of the countries, and in the event that one of them (Paraguay) does not take its 50%, the difference will be at the disposal of the other country, which will have to pay the established cost to EBY. Until 2021, when the interconnection of Yaciretá with Asunción was enabled, Paraguay's capacity to take energy was limited to 400 MW. From that moment on, the Paraguayan system is in a position to absorb a more significant proportion of the energy generated by Yaciretá.

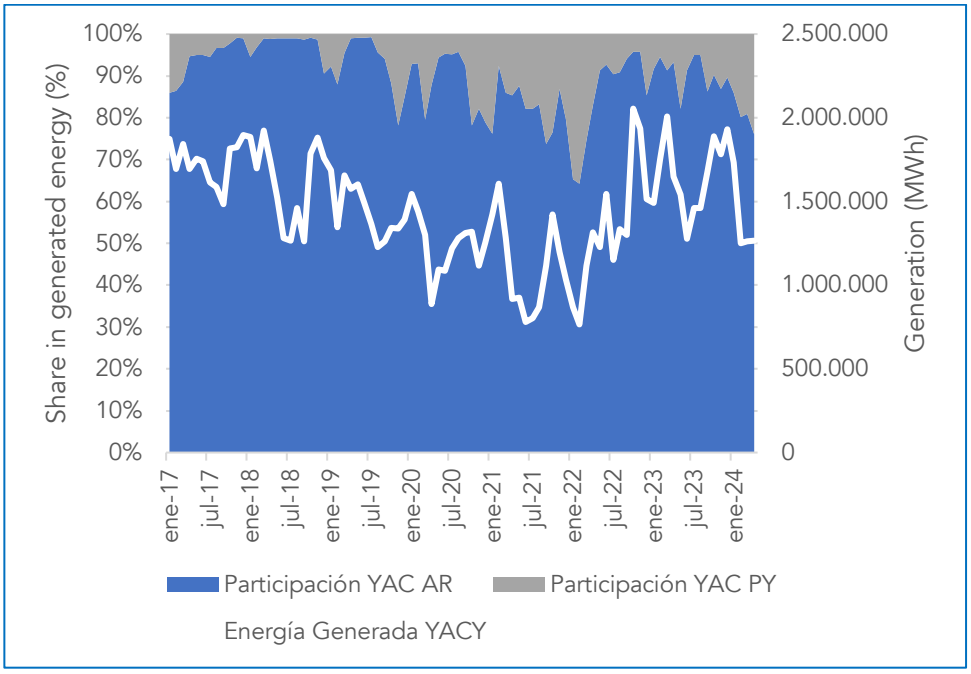


Figure 21 Share of energy generated by Yaciretá and total generation 2017-2024 (% and MWh)
Source: Own elaboration based on CAMMESA's data

Argentina consumes most of the power plant's generation, with a 90% share for the 2017-2024 period. Paraguay has increased its share since mid-2019, a phenomenon that is partly explained by the plant's lower total generation.

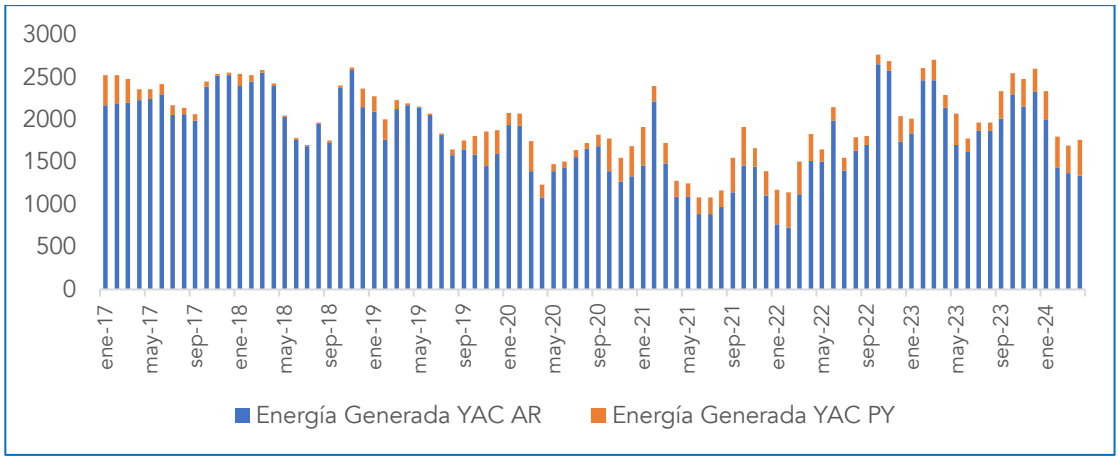


Figure 22 Yaciretá energy destined for Paraguay and Argentina 2017-2024 (MW-average monthly).
Source: Own elaboration based on CAMMESA's data

When looking at the evolution of Yaciretá's average monthly energy required by Paraguay, an increase is observed since mid-2019. However, the periods in which demand is above 400 MW-medium are very specific. The consistent economic growth that the Paraguayan economy has been experiencing is an incremental requirement for Yaciretá's surpluses in the coming years.

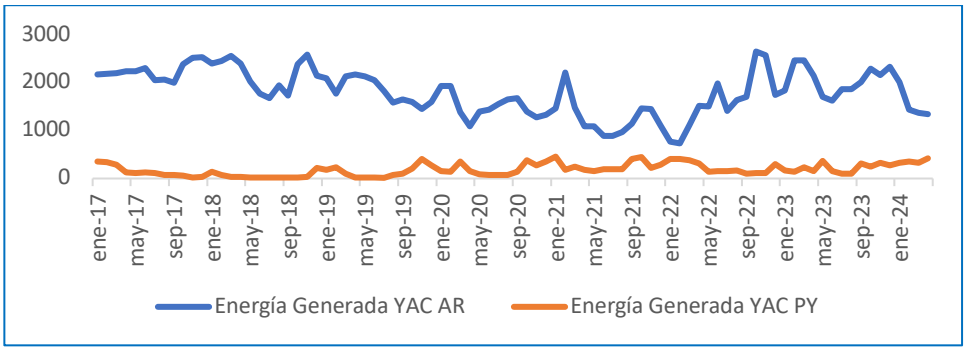


Figure 23 Yaciretá Energy Demanded by Argentina and Paraguay 2017-2024 (MW-Monthly Average)
Source: Own elaboration based on CAMMESA's data

Additionally, there are two active interconnections for 110 MW, which have significantly reduced their use from 2011 onwards as a result of the development of Argentina's transmission system in the northeast of the country and its impact on supply costs and operational security in the region.

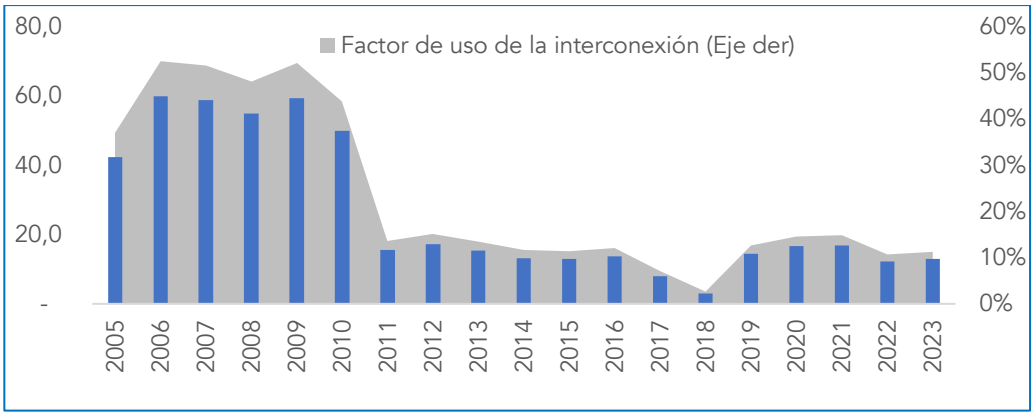


Figure 24 Paraguay-Argentina Exchanges without Yaciretá 2005-2023 (MW-annual averages and in % of interconnection use).

Source: Own elaboration based on CAMMESA's data

6.2.4. Brazil-Paraguay exchanges

Exchanges between Brazil and Paraguay occur through the transfer of energy generated by Itaipu by Paraguay in favor of Brazil, within the framework of the treaty of origin.

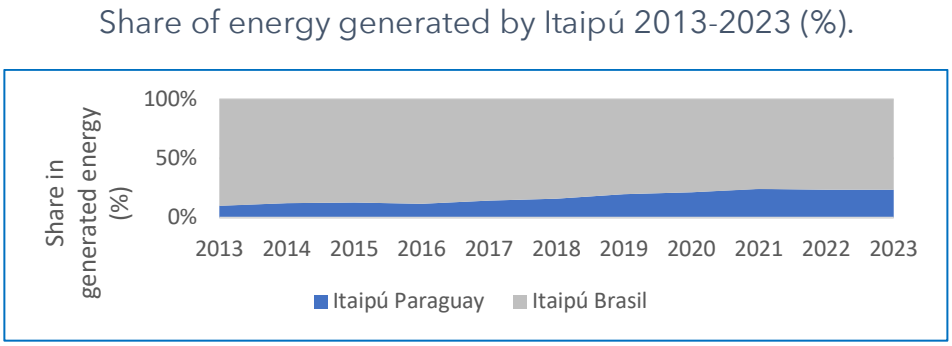


Figure 25 Share of energy generated by Itaipú 2013-2023 (%)

Source: Own elaboration based on Itaipú's data.

In line with what has been pointed out in the case of Yaciretá, there is a growing participation of Paraguay in the total energy generated by the Itaipu power plant, which, as confirmed in the next graph, responds to a trend increase in Paraguay's energy consumption.

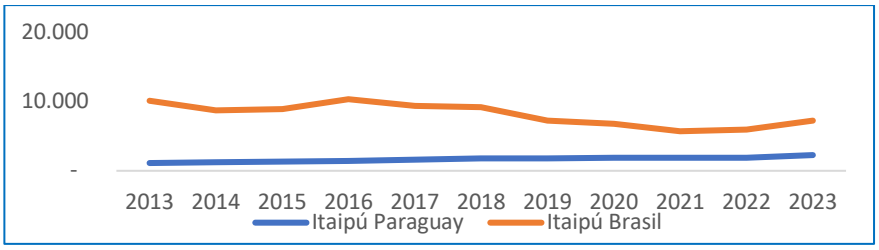
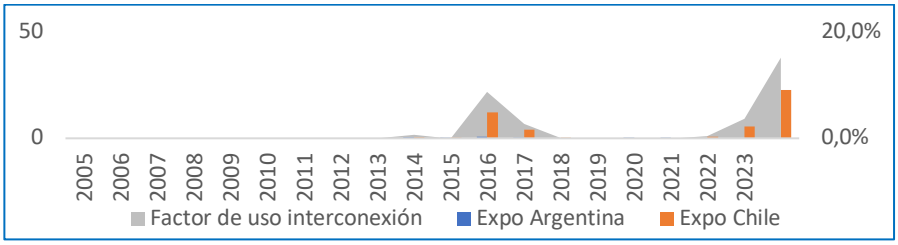


Figure 26 Share of energy generated by Itaipú 2013-2023 (%)

Source: Own elaboration based on Itaipú's data.

6.2.5. Exchanges Chile -Argentina

Chile-Argentina electricity exchanges. 2005-2023. In MW-annual averages and in % of interconnection use.

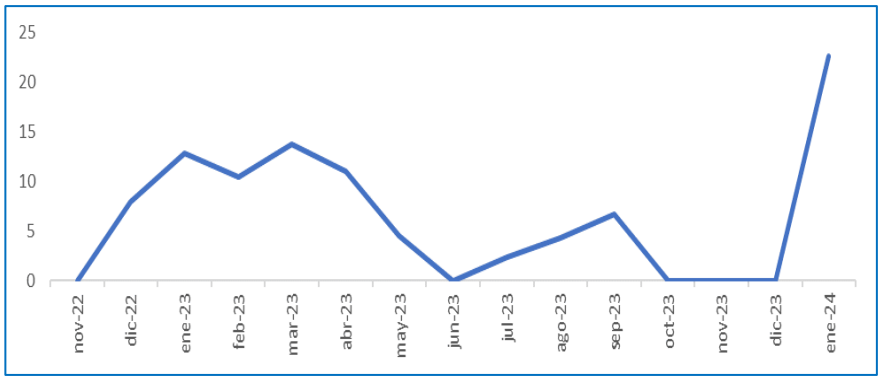


Source: Own elaboration based on CAMMESA

Exchanges between Argentina and Chile were reactivated from September 2022, when the International Power Exchange Agreement was signed between AES Andes S.A. and CAMMESA through the Andes-Cobos interconnection line with a transfer limit of up to 200 MW from Argentina to Chile and up to 80 MW in the opposite direction. Currently, the line is disconnected from the SEN (Chile) and connects radially to a photovoltaic solar park located whose dispatch is not required for the supply of Chile's demand, with the SADI (Argentina).

The volumes of energy exported by Chile are insignificant, and having origin in photovoltaic surpluses are higher in summer, and very low in winter.

Energy exports from Chile to Argentina. 2022-2024. In MW-monthly averages.



Source: Own elaboration based on CAMMESA's data

Exchange restrictions, with the line limited to work synchronously due to stability problems in the systems, and with limitations to increase exports from Chile in isolation from the SIN due to the incorporation of solar generation on Argentina's side that saturate the line during the day, only allow a deeper integration based on the existing infrastructure on the margin.

Exports of photovoltaic surpluses could grow to a maximum of 150 MW (today the maximum hourly capacity is 80 MW), although there are no incentives for new solar generation to be installed in Chile for export to Argentina. The option of exporting thermal energy from Argentina overnight to replace diesel generation in Chile was explored, but it involves maneuvers that are not justified by the volume and expected benefits of the exchange.

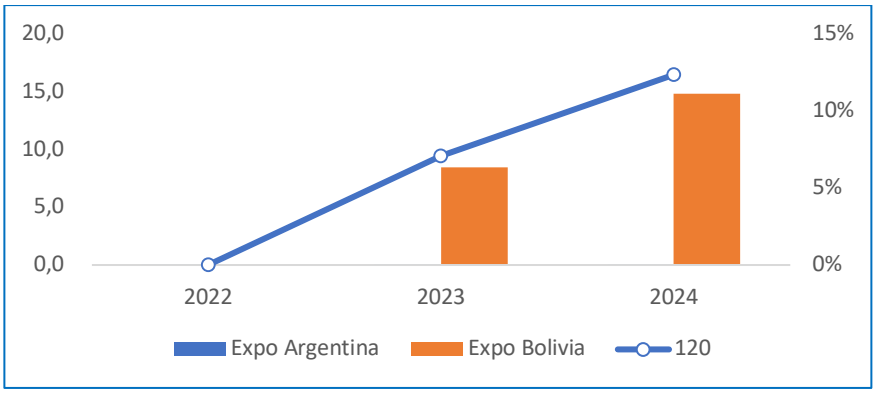
In the last instances of discussion between the countries to evaluate alternatives to deepen integration, it was concluded that the development of new interconnection infrastructure would be necessary for these purposes.

6.2.6. Argentina-Bolivia exchanges

Exchanges between Argentina and Bolivia are recent. They started once the 132 KV interconnection linking Tartagal and Yacuiba was put into operation. The volume of energy exported by Bolivia is limited for the time being.

Bolivia-Argentina electricity exchanges. 2022-2024. In MW-annual averages and in % of interconnection use[4].

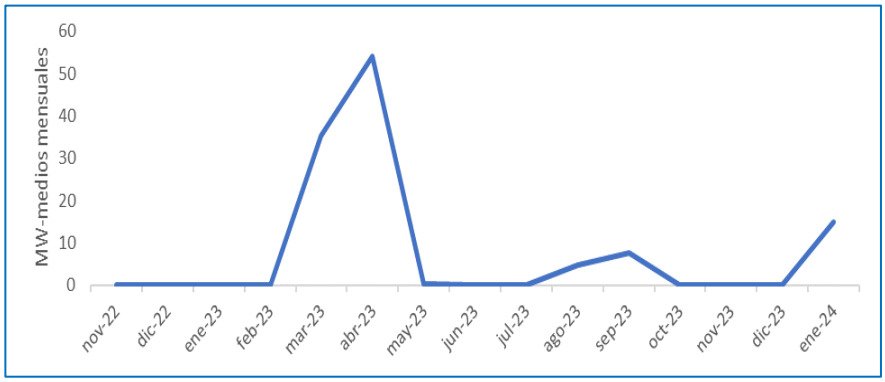
[4] For 2024, the MW-averages for the month of January are considered.



Source: Own elaboration based on CAMMESA's data

The monthly values show that exports are contingent and do not show an upward trend.

Bolivia-Argentina electricity exchanges. 2022-2024. In MW-monthly averages.



Source: Own elaboration based on CAMMESA's data

6.3. Exchange Summary:


INTERCAMBIOS 2023 (GWh)
olade
VENEZUELA
GUYANA
COLOMBIA
530
1.297
ECUADOR
13
24
PERU
BRAZIL
BOLIVIA
14
22.203
48
8.100
5.776
78
15
20
1.384
229

7. Relevant results

The collection of information and subsequent analysis that has been carried out for the preparation of this document allow us to extract some relevant information that is summarized below:

- Exchanges in South America occur at the bilateral level. There is no regional or sub-regional electricity market. The first experience in this regard will occur when the Regional Andean Electricity Market (MAER) between Colombia, Ecuador and Peru is put into operation.

- In 2023, international electricity exchanges between South American countries reached 39,755 GWh, with a 28% increase compared to 31,045 GWh that were exchanged in 2022.

- 95.3% of that energy was exchanged at the level of countries of the Southern Cone, and only 4.7% between countries of the Andean Region.

- At the general level of South America, in 2023 electricity exchanges represented only 3.7% of demand, but if we analyze the situation at the individual level by country, we find cases such as Uruguay that supplied 11.1% of its demand with imports mainly from Brazil and to a lesser extent from Argentina; or the case of Argentina, which supplied 10% of its demand with imports from Brazil, Uruguay and Paraguay and to a lesser extent from Bolivia and Chile; and also Ecuador, which covered 4.4% of its domestic demand with imports mainly from Colombia.

- In 2023, the utilization factor of international links increased compared to 2022. In the Southern Cone, the average utilization reached 35.5% compared to 28.4% in 2022. The Garabí converter station of the interconnection between Argentina and Brazil reached a 45% use factor and in general Argentine imports reached 60% use of the direct interconnection infrastructure with Brazil. In the Andean Region, this average reached 39.4%, up from 13.9% in 2022. The link with the highest use was Colombia-Ecuador, with 46.3%.

- A significant increase in exchanges is projected at the level of the Andean countries with the operation of the new 500 kV electricity interconnection between Ecuador and Peru from 2027.

- Regarding infrastructure in South America, there are 1,679 kilometers of lines in international interconnections.
- At the level of inventory, studies and projects to be executed, 4,775 km of international interconnection lines between South American countries have been identified.

- Of these, 975 km (20%) correspond to interconnection line projects between Argentina and Chile. It is expected that in the short term, there will be news about the execution of some of these interconnection projects.

8. Conclusions:

The recent evolution of exchanges between the countries of the region makes it possible to identify some facts that deserve to be highlighted:

- The *use of interconnections was increased*, along with the occurrence of extreme climatic phenomena, and the greater availability of primary resources: recovery of reservoirs in Brazil, incorporation of wind generation in Uruguay, and recovery of the availability of natural gas for thermal generation in Argentina.

- The *energy flows* in the region, where the participation of hydroelectric generation is very significant, in recent years respond to a large extent to the *seasonal complementarity* of the hydroelectric supply (Ecuador/Colombia), *and to the occurrence of dry years* in some of the relevant basins of the countries (Argentina/Brazil/Uruguay, Ecuador/Colombia).

- The occurrence of *periods of joint hydrological scarcity*, such as that recently recorded in Colombia and Ecuador, or as observed in 2020/21 in the Paraná basin, or in a good part of the 2020/23 period in the Uruguay River basin, brings to light the problems associated with extreme climate phenomena to which the countries of the region are exposed with its effects on: increased generation costs, higher emissions, and even rationing.

- Countries with higher levels of physical integration, even when their use in normal periods has been low, have been able to better cushion or avoid the most critical effects. These cases *suggests the need to deepen the analysis of the impact of extreme weather on electrical systems and the possible coverage that regional integration projects could provide via new infrastructure*.

- The increase in the *availability of natural gas in the Neuquén basin*, which will continue to grow in the coming years with the expansion of the transportation infrastructure and the *upstream* investments that are being made, suggests that Argentina could play a role as a *regional thermal backup for intermittent generation, as well as acting as a supply guarantee in the event of extreme hydrological events in neighboring countries*. This horizon would require the development of new interconnection infrastructure with countries such as Brazil and Chile, where there are also gas pipelines or pipeline projects that could fulfill the same role. Further studies remain to be carried out in order to have more clarity regarding the most convenient alternative in each case.

- The trend towards the electrification of consumption historically linked to fossil fuels and the commitments made in terms of decarbonisation and climate change mitigation, highlight that in the short term the integration agenda has been more focused on more immediate solution problems such as the best use of existing infrastructure

- However, large binational hydropower projects such as Corpus Christi for Paraguay and Argentina, or Garabí/Pananmbí for Argentina and Brazil, or the use of the Madeira River for Brazil and Bolivia, or Inambarí for Peru/Brazil, as well as the Tufiño-Chiles-Cerro Negro binational geothermal project for Colombia/Ecuador, remain very competitive and convenient alternatives in the path of decarbonization, cost reduction and regional energy security.

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Latin American Energy Organization (OLADE)

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