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Cont, Walter
Barril, Diego
Agustín, Carbó

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Walter Cont, Diego Barril and Agustín Carbó*

Abstract

We explore the determinants of the electricity trade in the South American region, using a gravity approach, for the period 2009 - 2019. We find that electricity trade is related to the size of the economies involved and reflets conditions of relative scarcity, which is observed in destination prices. Also, we find that there is a relation between commerce and structural conditions in the exporting country, such as the relevance of non-conventional renewable energy or the reserve system. All these results suggest that energy exchanges are driven by demand determinants (activity and prices) as long as supply conditions (lower-cost energy sources and available capacity in exporting countries) are adequate. The paper also explores policy implications about the conditions needed for countries to engage in integration and trade: the added value for the actors and future predictability of trade.

Resumen ejecutivo

Este paper explora los determinantes del comercio de electricidad en la región de América del Sur, utilizando un enfoque gravitacional, para el período 2009 - 2019. Esta metodología permite identificar que el comercio de electricidad está relacionado con el tamaño de las economías involucradas y refleja condiciones de escasez relativa, que se observa en los precios del país de destino. Asimismo, existe una relación entre el comercio (principalmente de oportunidad) y las condiciones estructurales del país exportador, como la relevancia de las energías renovables no convencionales o el sistema de reservas. Todos estos resultados sugieren que los intercambios de energía están impulsados por determinantes de la demanda (actividad y precios) siempre que las condiciones de oferta (fuentes de energía de menor costo y capacidad disponible en los países exportadores) sean adecuadas. El documento también explora las implicaciones de política sectorial y regional, en particular, sobre las condiciones necesarias para que los países se involucren en la integración y el comercio: el valor agregado para los actores y la previsibilidad futura del comercio.

JEL Codes: Q48, F14.

Keywords: Electricity trade, South America, gravity.

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* Walter Cont (corresponding author): CAF – Banco de Desarrollo de América Latina and Universidad Nacional de La Plata. Contact information: wcont@caf.com

Diego Barril: CAF – Banco de Desarrollo de América Latina. Contact information: dbarril@caf.com

Agustín Carbó: IAE – Universidad Austral. Contact information: acarbo@austral.edu.ar

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Electricity trade in South America, an analysis based on the gravity equation

1. Introduction

Electricity integration is motivated by the advantages and multiple benefits offered by the interconnection among partner countries. Most common benefits are the possibility of achieving economies of scale in production and the consequent reduction in costs, improving the security of supply, reducing the impact of unforeseen shocks and achieving better results in terms of service quality and protection of the environment. All of this has a positive impact on consumers and firms. Integration processes can range from an interconnection of electricity systems to broad integration (single regional market), and usually involve agreements, such as bilateral or multilateral treaties, depending on the countries that are involved in the integration process.

South America has made progress in bilateral interconnections (more advanced in the Andean subregion than in the Southern Cone) and in taking advantage of common resources as the binational hydroelectric represses (in the Southern Cone). Instead, in Central America made significant advances with the conformation of a regional electric market and the investment in a 300 MW-physical network that connects six countries.

So, despite the benefits, the difference in the speed of integration between South and Central America reveals that several conditions must be met to advance in an integration process. The most relevant is that the national transmission network should be capable of supporting the exchange of power, without affecting the supply of the countries, even in contingency cases (Levy Ferre et al., 2020). This is related to the degree of specificity of the assets necessary exchange electricity (high cost, complexity, and long maturity of the investment). In fact, the nature of such assets makes a key difference between trade of electricity and trade of other goods or services. For this reason, the integration experience is done in phases, starting by bilateral trade and then, in successful cases, moving on to a regional scope.

In addition to the necessary conditions, the path of integration may face obstacles that reduce the incentives to invest in this process. One important is the understanding that each country has about energy security. The most common definition refers to the ability to preserve and manage energy resources, although there are other definitions that include concepts of robustness to different factors or resilience of electricity systems to shocks (Rodriguez Padilla, 2018). Institutional weakness or the lack of dispute resolution mechanisms in regional blocs is another barrier on the road to integration. The definition of stable and predictable rules, which provide legal security through adequate mechanisms for the resolution of disputes, has been very difficult to implement in the South American region.

In this context, this paper studies the experience of integration and trade of electricity in South America, from the aspects referred to the volumes of energy traded between countries and their determinants, following a standard methodology in international trade. Using a gravity model, the econometric approach shows that the determinants of trade in South America are in line to those shown by literature on trade. Among them, the equation identifies the impulse of the demand (captured by the size of the economy and the price of electric energy of the importer country), the negative effect of distance and the structural conditions derived from the energy policies of the exporter countries (captured by the system reserves and the supply of renewable sources).

Then, the paper focuses on challenges that South American countries face to deepen the integration process. The study points out that even though electricity integration has significant benefits, the volumes traded through interconnections represent a 0.5 percent of consumption in South America (once the exchanges from binational hydroelectric represses are removed). There is evidence of an underuse of the existent infrastructure, and important obstacles, such as the concept of energy security and the absence of robust institutional frameworks, are present in many countries.

This paper contributes to the literature of international trade, in this case, focused on electricity. There is a long strand of literature that studies international trade of goods, services, people and knowledge, focusing on determinants of trade or the impact of trade policies (tariffs or trade agreements).[1] Some papers focus on cross-border electricity trade. For example, Antweiler (2016) studies intra and inter regional electricity between US and Canada. Costa-Campi et al. (2018) study the trade of energy inputs. A paper close to ours is Batalla, Paniagua and Trujillo (2019), who study trade creation and trade diversion throughout the integration experience in Europe. There are also papers dedicated to study specific cases in South America, such as the integration experience of Argentina and Chile in natural gas (Navajas, 2008) and electricity (Navajas, 2016), and also the experience between Argentina and Brasil (Natale and Navajas, 2016).

The paper organizes as follows. Section 2 presents the steps taken towards electricity integration in South America, while Section 3 describes the patterns of trade. Section 4 presents the econometric model based on the gravity equation and explores the main results. Finally, Section 5 concludes.

2. South America experience on energy integration

Regional electricity exchanges, from simplest bilateral interconnections to the most sophisticated schemes that aim for a single market, require a bare minimum of coordination among the countries involved. The greater the coordination, the lower the transaction costs, and the more predictable the electricity systems (both for the systems themselves and for the players involved), and the greater the benefits for societies. There have been initiatives on bilateral interconnection or integration (not only in electricity but also in natural gas) within the framework of broader regional integration initiatives (which in turn evolved from commercial arrangements to broad-scope unions).

In the case of South America, interconnection agreements have been bilateral in nature. Mercosur established a Memorandum of Understanding on electricity exchanges and integration (1998) that agrees principles of minimum symmetries regarding non-discrimination between agents from

[1] See Bergstrand (1985, 1990), Helpman and Krugman (1985), Anderson and van Wincoop (2003), Eaton and Kortum (2002), Helmpan, Melitz and Rubinstein (2008), Melitz and Ottaviano (2008) and Novy (2013). See also Moncarz, Flores, Villano and Vaillant (2020).

different countries, free contracting, regulations in electricity markets that allow ensuring supply, etc. Then, progress made in subsequent interconnections was through bilateral agreements under public and private initiatives (as in the natural gas sector). In several cases, results were disappointing due to regulatory instability and a weak contract design (Navajas, 2008, Navajas, 2016, and Natale and Navajas, 2016).

Former experiences on trade are based on the joint exploitation of water resources, through hydroelectric plants. This was the case of Brasil and Paraguay (Itaipú), Argentina and Paraguay (Yacyretá), and Argentina and Uruguay (Salto Grande). But the rules that apply to electricity generated in dams are case-specific. First, the investment project is a process that faces many challenges (see the review by Buchansky, 2013). Second, the allocation and payment rules usually set a preferred status on the larger country (specifically in the Yacyretá and Itaipú cases).

More recently, in December 2018, representatives of the electricity sector from Argentina, Chile and Uruguay, along with representatives from IADB, OLADE, CAF, and CIER, signed a protocol to perform a study of electrical interconnections in the Southern Cone (the SIESUR initiative). Such initiative is currently in the stage of identifying and solving the main barriers that limit the use of the existing infrastructure and, on the other hand, searching for opportunities and challenges to coordinated regional planning.

The Andean countries have been more advanced compared to their Southern neighbors. Bolivia, Ecuador, Colombia and Perú conform the Andean Community of Nations (CAN), established in 1969 with the Agreement of Cartagena (which initially included Chile and Venezuela, but they retired their member status after several years).

After of several attempts of establishing a regulatory frame (bilateral agreements were implemented through temporary regimes, allowing surplus short-term trade originated in coordinated dispatches), in 2017 they created the Andean Market of Regional Energy of Short Term (*Mercado Andino de Energía Regional de Corto Plazo*). This is a market where a regional coordinator would organize the transactions of national electricity surpluses by using the national interconnected grids, to be rewarded with a tariff defined in each country and allocating congestion rents of an international link evenly between the exporter and importer markets. However, regulations have not been defined yet (2021).

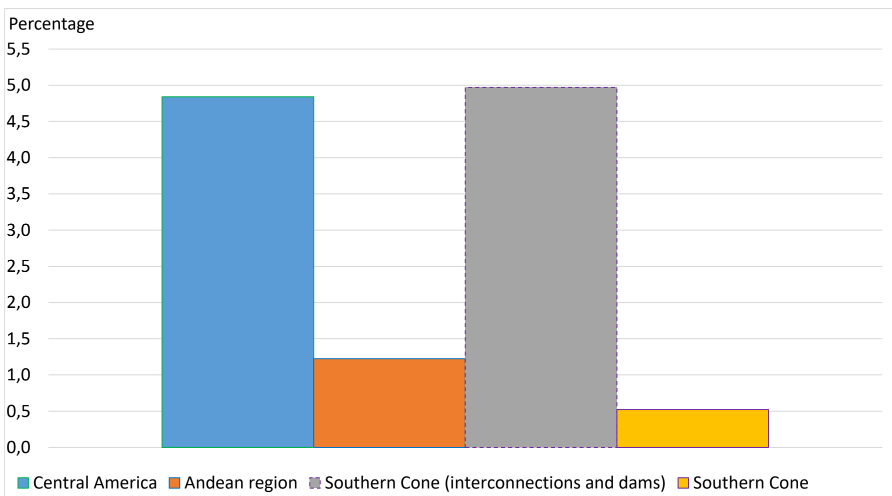
This evolution in regulation is part of a regional agenda, which includes the Andean Electric Interconnection System (*Sistema de Interconexión Eléctrica Andina - SINEA*) initiative, promoted since 2011 to connect the electricity markets of the CAN and Chile. The project took the form of bilateral interconnections since it does not establish a subjection of the respective national authorities to a supranational body. In fact, interconnection is a residual tool in the national energy policy of each country, having a lower order of priority compared to the domestic capacity and energy security. Therefore, this initiative is focused on short run trade and does not consider long run agreements, for the time being. More ambitious integrations could arise if short run spot interactions are successful and will need regulations at a regional level and the appropriate interconnection infrastructure. Nevertheless, advances in this direction will be possible as far as countries are willing to make them.

3. Electricity trade in South America

The experiences of electricity integration and trade in South America can be characterized into two groups: joint exploitation of water resources (bilateral dams projects) and interconnections that allow bilateral or multilateral exchanges of electricity.

Electricity flows between countries ranged between 6 percent and 10 percent of total consumption of the Southern cone when considering the exploitation of mutual water resources (binational hydroelectric dams). This is basically Paraguay-Argentina through Yacyretá and Paraguay-Brasil through Itaipú. Trade through interconnections represents 0.5 percent of electricity consumption, lower that the trade in the Central America region of 4.8 percent (Figure 1 summarizes aggregate trade in 2019; details for the period 2009-2019 can be found in CAF 2021, forthcoming).

Figure 1. Electricity import as a percentage of consumption: selected years.

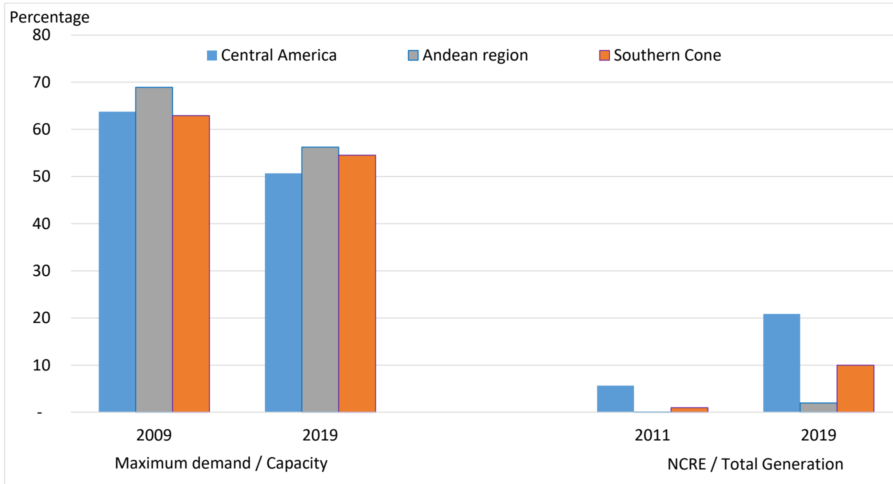


Notes: The values correspond to the percentage of imported electricity over total consumption.
Source: Own elaboration based on information from national statistical offices, (EIA, 2020; Eurostat, 2020).

This volume of trade is consistent with the fact that South America has invested in generation capacity to attend demand in the last 10 years (Figure 2). In fact, many countries have made progress is in the incorporation of non-conventional renewable energies (NCRE) in the energy matrix, notably Uruguay.

We build a dataset on electricity flows by origin and destination between 2009 and 2019 (CAF, 2021), based on information published by ministries, statistics agencies, regulators, and market operators of South American countries. Available information allows us to differentiate trade between interconnections and dams. We focus on the first source of trade -interconnections- as trade flows from binational dams follow specific contract rules.

Figure 2. Inverse of reserve ratio and share of NCRE in energy generation: selected years

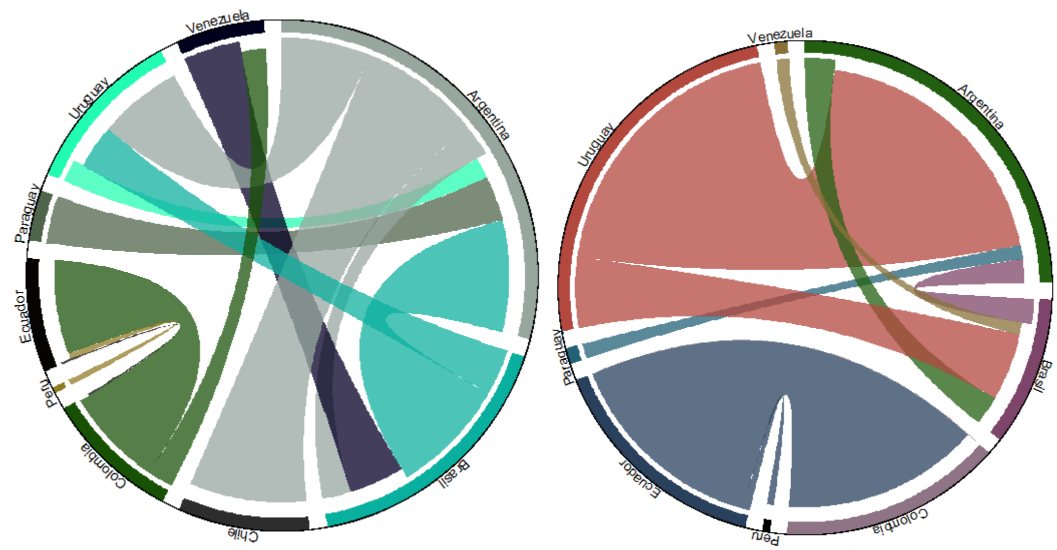


Notes: Installed capacity is measured in nominal power. Therefore, the effective reserve ratio is less than the represented in the Figure. Non-conventional renewable energy includes wind and solar sources, biomass, biogas, and small hydroelectric generators with a capacity of less than 50 MW
Source: Own elaboration based on information from national statistical offices.

Figure 3 summarizes the electricity flows between the countries of South America for two selected years: 2009 and 2019. Details for the complete period can be found in CAF (2021, forthcoming). In 2009, Chile was only an importer (so it was in the previous years), and Paraguay was an exporter. The rest of the countries – Argentina, Uruguay and Brazil – imported and exported during that year. In the Andean subregion, Colombia exported electricity to Ecuador and Venezuela, while Peru exported a small volume to Ecuador. The situation in 2019 presents some changes. Total electricity exchanges through interconnections decreased to 5,6 TWh, from 7,3 TWh in 2009. In the southern subregion, Uruguay became an exclusive exporter of electricity. On the other hand, Brazil and Argentina established themselves as the major net importers of the subregion, while Uruguay and Paraguay consolidated as net exporters. In the Andean subregion, Colombia lost its leading role as an exporter: the exports of electricity to Venezuela stopped in 2017. Also, the country reduced sales and increased imports from Ecuador. Peru remained an importer of electricity, but always in small quantities. Finally, Figure 3 shows the split of the system of South America into two subsystems, due to the disconnection between Venezuela and Colombia. On the one side, Colombia, Ecuador and Peru, and on the other side, Argentina, Uruguay, Paraguay, Brazil (the connection between Brasil and Venezuela).

Figure 3. Electricity trade in South America by origin and destination

2009 2019



4. A gravity approach to electricity trade in South America

The gravity approach has as a background from applied international trade literature to study structural determinants of bilateral trade and the impact of trade policies (tariffs or trade agreements) on international flows of goods, services, people or knowledge. As mentioned in the introduction, a few applications have been done regarding electricity trade (Antweiler,2016, Costa-Campi et al., 2018, and Batalla, Paniagua and Trujillo,2019).

The information on trade by origin-destination built for South America makes it possible to carry out a quantitative exercise that helps identify the determinants that enable or generate resistance to electricity trade in the region. The following equation is specified:

$$x_{ijt} = exp\big(\beta_0 + \beta_1 \ln(GDP_{it}) + \beta_2 \ln\big(GDP_{jt}\big) + \beta_3 Dist_{ij} + \beta_4 \ln(p_{it}) + \beta_5 \ln\big(p_{jt}\big) + \beta_6 H_{it} + \beta_7 H_{jt} + \beta_8 NCRE_{it} + \beta_9 NCRE_{jt} + \beta_{10} Res_{it} + \beta_{11} Res_{jt} + \gamma\ Control + \delta_t\big) \times \varepsilon_{ijt}$$

According to which, the flow of energy through interconnections between the country of origin i and the country of destination j in a year t (x_{ijt}), measured in annual GWh, depends on the size of the economies (GDP) and the distance between electrical systems and consumption centers (considered as usual determinants of trade).[2] A second group of structural determinants result from the energy policy adopted in the countries involved (specifically, the hydroelectric component -H- and that of non-conventional renewal energies -$NCRE$- in generation, as well as the reserve margin

[2] Anderson (1979).

- Res- of the respective electrical sectors). To the extent that the greater participation of these sources of energy imply lower costs, a flow to neighboring countries is expected, transferring not only efficiencies, but also environmental benefits. Third, the equation incorporates the spot prices in the countries of origin and destination (p_{it} and p_{jt}, respectively).

In studies of international trade of goods and services, these effects are subsumed in dummy variables of the μ_{ij}, ψ_{it}, y n_{jt} type.[3] On the other hand, the evidence from this sector in South America suggests that there are no additional determinants of (or frictions to) bilateral electricity trade (such as the existence of trade alliances, external tariffs, trade policies, favored nation clauses, etc.). For this same reason, the internal electricity trade is not incorporated. In this sector, there is a clear prioritization of the domestic market under the energy security objective explained in the first section and the exchanges between countries play a secondary role. One way to capture this prioritization is by including the relationship between maximum demand and production capacity as a proxy for the internal conditions of a country to perform exchanges with its neighbors. Finally, a δ_t is included to capture the fixed effect per year, and ε_{ijt} is a classical error term. Table 1 summarizes the relevant variables and sources of information. Table 2 shows the summary statistics.

Table 1. Summary of variables used in the regression of electric South America

Variable	Definition	Source
Commercial flow of electricity	Quantities in GWh	National Statistics
Gross Domestic Product	GDP of the corresponding country in MM of constant USD 2010	World Bank
Distance	Distance between interconnection and consumption centers (capitals)	Own estimates
Price	Spot price in USD/MWh	Own estimates
NCRE/Total Generation	The country's percentage of generation with an non-conventional renewable sources (mostly wind and solar photovoltaic)	Own estimates
Hydro/Total generation	The country's generation with a hydro source	Own estimates
Reserves	Reserves level of the country's electricity system	Own estimates
Restrictions	Dichotomous variable that functions as a control (1= absence of trade due to institutional or political restrictions)	Own estimates
Yacyretá	Paraguay-Argentina exports through the Yacyretá binational dam in thousands of GWh (which affects trade through interconnections between Paraguay and Argentina)	Own estimates
Rainfall	Total annual rainfall and/ or snowmelt (mm)	Own estimates

[3] In this study, we chose to estimate explicit relationships instead of using fixed origin-year, destination-year (suggested by Baldwin and Taglioni, 2006). Otherwise, the structural and national policy effects are absorbed in the *dummies*.

Given the proposed functional form, the estimated coefficients can be interpreted as elasticities (when the explanatory variable is in logarithms) or semi-elasticities (when the explanatory variable is presented in levels). The omission of exchanges through binational dams is because the mechanism used for trade (a binational dam) and the specific contracts, have a different logic than that applied to transactions over grids. The equation is estimated by Pseudo-Poisson Maximum Likelihood (PPML), following the methodology that renders robust estimates to heteroscedasticity in error terms (Santos-Silva and Tenreyro, 2006, 2011) and is adequate for samples a few years in duration (Baltagi et al., 2014).

Table 2. Statistic summary of variables used in the regression of electric South America

Variable	Observaciones	Promedio	Desv. Estándar	Mínimo	Máximo
x_{ijt}	158	272,6	440,7	0	2407,4
ln(GDP Origin)	158	5,435	1,297	3,198	7,793
ln(GDP Destination)	158	5,726	1,301	3,621	7,793
ln(Price Origin)	147	4,012	0,630	2,027	5,505
ln(Price Destination)	147	4,034	0,656	2,027	5,505
NCRE-Origin	158	0,043	0,096	0	0,474
NCRE-Destination	158	0,047	0,095	0	0,474
Hidro-Origin	158	0,611	0,212	0,265	0,999
Hidro-Destination	158	0,563	0,197	0,265	0,916
Reserve-Origin	147	0,381	0,089	0,230	0,606
Reserve-Destination	147	0,386	0,092	0,230	0,606
Yacyretá	158	0,559	2,061	0	9,258
Rainfall-Destination	158	0,723	0,344	0	1,411

Table 3 shows the results of the gravity model. In line with the literature, there is a significant relationship between the size of economies and trade. In particular, the size of the destination country seems to be more important than the size of the origin country. The income elasticity is in line with the magnitudes found in the case of goods (expected value of 1) and with the results obtained by Batalla et al. (2019) for the European electricity system (the GDP elasticity of the destination country was estimated at 1.3).

Secondly, as there are mostly opportunity exchanges or swaps between countries, the observed flows are a result of the conditions of relative scarcity, captured mainly by the spot prices at the destination country. Shocks to the cost of spot trade do not seem significant, as is a reaction from exports when destination prices rise. Our preferred equation is (4), including several drivers associated with sector policy. But equation (1), which is run considering price and income effects, captures a price elasticity of -0.5 in the origin country.

Thirdly, the resistance effect is captured by the distance between the export point and the consumption center of the destination country. As expected, less volumes are traded when they involve longer distances.[4]

Table 3. Results of the gravity regression

Variables	(1)	(2)	(3)	(4)
ln(GDP-O)	0.174**	0.293**	0.271***	0.338***
	(0.0739)	(0.128)	(0.101)	(0.109)
ln(GDP-D)	1.036***	0.759***	1.014***	0.922***
	(0.197)	(0.249)	(0.287)	(0.253)
Distance	-2.516***	-1.390**	-2.299***	-1.978***
	(0.539)	(0.623)	(0.416)	(0.623)
ln(Price-O)	-0.511**	-0.0522	-0.165	-0.00121
	(0.219)	(0.279)	(0.232)	(0.261)
ln(Price-D)	1.437***	1.355***	1.414***	1.352***
	(0.450)	(0.396)	(0.428)	(0.372)
ERNC-O		4.799**		2.623**
		(1.932)		(1.227)
ERNC-D		0.853		1.008
		(3.743)		(3.101)
Hydro-O		1.606		0.374
		(1.414)		(1.506)
Hydro-D		-0.0120		-0.334
		(0.631)		(0.999)
Res-O			8.564***	6.631***
			(3.216)	(2.059)
Res-D			2.682	3.438
			(1.909)	(3.021)
Restrictions	-4.596***	-4.657***	-4.463***	-4.565***
	-1.099	(0.970)	-1.016	(0.933)
Yacyretá	-0.0397	-0.0340	0.0273	0.0501
	(0.0393)	(0.0938)	(0.0525)	(0.0967)
Rainfall-D	-0.752	-1.337	-1.096	-1.358*
	(0.668)	(0.947)	(0.855)	(0.813)
Constant	-2.880	-5.044	-8.820*	-8.815**
	(3.258)	(3.068)	(4.555)	(3.922)
Observations	136	136	136	136
Fixed effects by year	Yes	Yes	Yes	Yes

Fourthly, bilateral exchanges seem to be guided by a mix of structural conditions in the respective electricity sectors (resulting from each country's energy policies). Particularly, a significant relationship is identified for electricity exports from countries with relative greater investments in non-conventional renewable energy. Such investments favor the optimization of resources and environment sustainability among the countries involved in the exchange. One remarkable case

[4] The advances in the trade literature, of including country-pair fixed effect (ij) together with country-time fixed effect (it, jt), cannot be applied here. In such case, all identified effects would be absorbed by dummies.

Uruguay. In this country, NCRE share in the energy matrix exceeded 40 percent in recent years.[5,6] There is also a significant relationship between exporting country's reserve system and trade. All these results suggest that energy exchanges are driven by demand determinants (activity and prices) as long as supply conditions (lower-cost energy sources and available capacity in exporting countries) are adequate.

Lastly, some control variables were introduced into the regression equations. The variable "restrictions" controls cases of absence of flows that do not respond to market situations, but rather to institutional issues.[7] The "Yacyretá" is used because in some years flows through interconnections from Paraguay to Argentina are correlated with lower levels of generation in the Yacyretá dam. A variable that controls by rainfall in the destination country is included, with a negative effect on the volumes traded (rainfall in the country of origin has no additional effect to the captured by the hydro mix).

Given the nature of electricity trade during the period of analysis, there are no elements that facilitate or hinder the ability to trade electricity, although they fail to capture an ideal measure of proximity based on explicit agreements between pairs of countries to exchange energy (for example, from a primarily hydro system to one primarily thermal).[8,9]

5. Conclusions and policy implications

We explore the determinants of the electricity trade in the South American region, using a gravity approach. To achieve this objective, we a dataset on electricity flows by origin and destination between 2009 and 2019.

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[5] The effect of counting with hydroelectric generation is not significant, but the signs of the specific estimates are as expected (positive for origin countries with higher levels of hydroelectricity and negative for those with lower levels of hydroelectricity).

[6] Hydroelectric and other renewable sources depend on random factors (rainfall in the case of hydro, the time of day and solar light in the case of photovoltaic sources and wind in the case of wind energy) and the energy exchanges can help mitigate the associated risks (considered to be more extreme and more frequent in the future) and improve reliability in electrical systems. For example, the extreme event of El Niño in 2016 required increasing exports from Ecuador to Colombia to satisfy electricity needs in the later country under low hydrological conditions.

[7] Specifically, this variable includes the cases of Argentina-Brazil in both directions between 2012 and 2014 (renegotiations), Brazil-Uruguay in both directions between 2013 and 2015 (modification of the Uruguayan generation matrix, testing period to later export), Argentina-Chile from 2010 (energy crisis in Argentina) and Colombia-Venezuela from 2015 (political crisis).

[8] Billette de Villemeur and Pineay (2016) analyzed this case within a context of superficial integration (with different regulations in the interconnected regions) between the provinces of Quebec and Ontario, Canada. In their study, the authors point out that a superficial integration may end up in a worse situation (in terms of welfare, including environmental considerations) than a broad integration (unifying market rules in both regions) or isolated systems.

[9] Considering a period that includes the second half of the 1990s and the first decade of the XXI Century could allow the introduction of bilateral differential agreements (notably, Argentina and Chile, and Argentina and Brasil), but the identified effects would interact with the Argentine crisis eventually.

We find that electricity trade is related to the size of the economies involved and reflets conditions of relative scarcity, which is observed in destination prices. Also, we find that there is a relation between commerce and structural conditions in the exporting country, such as the relevance of non-conventional renewable energy or the reserve system. All these results suggest that energy exchanges are driven by demand determinants (activity and prices) as long as supply conditions (lower-cost energy sources and available capacity in exporting countries) are adequate.

There is consensus on the benefits of integrating electricity systems. A necessary condition to the increase of electricity trade is that countries gain confidence in the availability of the good in an expanded market. This institutional framework should be built from two properties that commercial exchanges must satisfy: the added value for the actors (so that they are interested in participating voluntarily) and future predictability (the necessary volumes will be found in the market, at a market price, at the time required). The experience of Central America reveals that a gradual path of integration is possible, although is still facing challenges to deepen its commerce (CAF, 2021 forthcoming).

The methodology used in this document will gain potential if regional agenda on electricity integration (the SINEA, SIESUR and ARCONORTE initiatives) advances in the following years. Identifying the results of an increasing trade should be the key to promote further integration.

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