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A Brazilian perspective of power systems integration using OSeMOSYS SAMBA – South America Model Base – and the bargaining power of neighbouring countries: A cooperative games approach

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ABSTRACT

This paper intends to contribute to a better understanding of both advantages and drawbacks of power systems interconnection processes between Brazil and its South American neighbours. Based on data available in national and international reports, three scenarios for the power supply sector expansion were modelled in OSeMOSYS. The Brazilian perspective of power integration considers funding strategic hydro projects in Argentina, Bolivia, Guyana and Peru. An alternative to the power integration process considers higher penetration of distributed photovoltaics and biogas power plants as well as lower hydro capacity expansion in Brazil. Features related to costs, carbon emissions, hydro reservoirs, technological performance, electricity demand, population growth, time zones and reserve margin were considered. The comparison of different scenarios provides insights regarding the contribution of renewable energy generation and sheds light on cross-border trade perspectives between Brazil and other countries in South America. Using a cooperative games approach, the bargaining power of each country (player) was calculated by applying the Shapley value concept. Argentina, Brazil, Paraguay, Peru and Guyana have the largest bargaining power, either as exporter or importer.

1. Introduction

South American countries have diverse and abundant energy resources ranging from oil, natural gas, coal and biomass to considerable potentials of other renewable sources, such as large hydro, wind and solar. These resources are not evenly distributed. This asymmetry is precisely what underlines the potential for developing important energy exchanges within the continent, mainly through hydro-wind power synergies. Studies about modelling power integration in South America exist in the literature (Sauma et al., 2011; Ochoa et al., 2013), but focus on a particular group of countries in the Andean region.

In 2014, electricity generation from renewable sources in South America represented 64% of the total, which is significantly higher than the global average of 21% (CIER, 2015). However, due to structural reforms in the electricity sectors in the 1990s the continent is becoming increasingly dependent on thermal generation (Arango and Larsen, 2010). This is particularly true in Brazil, the largest producer (59%) and consumer (59%) of electricity in the continent, where there has been a steady increase in installed thermal power capacity since 2003 (EPE, 2014a; CIER, 2015).

The operation of the Brazilian electricity system prioritizes the (lower cost) generation of hydro plants with reservoirs. However, the backup generation provided by the water stored in reservoirs will be relatively lower than nowadays, because new hydro in Brazil are essentially of the run-of-the river type, which means less flexibility for hydroelectric generation. The objective of such expansion policy is to meet current society environmental concerns caused by hydro plants in the Amazon region, where the largest remaining hydro potential is located. Actually, the storage capacity of existing reservoirs are being used to its limits, thus impairing the flexibility they provide (EPE, 2014b, 2014c). In addition, the long-term planning of the Brazilian electricity sector carried out by the state owned company Empresa de Pesquisa Energética (EPE) is reluctant to increase the number of conventional thermal plants — such as Natural Gas Combined Cycle (NGCC) — to supply the base of the power demand, a move that could circumvent the decline in the flexibility of reservoirs.

Despite the decrease in flexibility, the storage capacity of Brazilian reservoirs was sufficient, in 2012, to supply about 4.5 months of the national consumption monthly average (EPE, 2013). A storage capacity

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Table 1
South America population and electricity consumption in 2013.
Source: Own elaboration, based on PRB (2013) and CIER (2013).

Country	Population	Electricity consumption[a] (TWh)	Electricity consumption/ population (kWh per Capita)
Argentina	41.3	113.0	2735
Bolivia	11.0	6.3	574
Brazil	195.5	464.1	2374
Chile	17.6	66.8	3795
Colombia	48.0	54.5	1134
Ecuador	15.8	20.9	1324
Guyana	0.8	0.5	569
Paraguay	6.8	9.0	1324
Peru	30.5	35.8	1174
Uruguay	3.4	8.6	2516
Venezuela	29.7	91.1	3067

[a] Gross production + imports exports transmission/distribution losses.

of this magnitude allows for the integration of electricity generation from other renewable sources with higher levels of intermittency, such as thermal biomass, wind and solar power.

The electricity demand is expected to increase steadily across South America during the next decades, as its low per capita consumption (1.871 kWh per year) is about one third of the average value for countries such as Portugal, Spain and Italy, which centres around 5.500 kWh per year (World Bank, 2015). Besides, there are significant disparities among countries, with per capita annual consumption ranging from 569 kWh in Guyana to 3.795 kWh in Chile as shown in Table 1 (CIER, 2013).

The Brazilian government has shown interest in funding and developing joint-venture projects in the electricity sectors of neighbouring countries, particularly hydropower plants and grid interconnectors (MME, 2006). However, short-term macroeconomic and political conditions in Brazil (Sciaudone, 2015) are as yet not favourable to funding hydro dams abroad and may postpone the assessment of such projects. Another impact of the economic crisis in Brazil was the weakening of electricity demand since 2015 (a decrease of 2.1% and 0.9%, respectively, in 2015 and 2016) (EPE, 2017). Despite short-term conditions, Brazil might still lead the process of power systems integration in the region that goes beyond occasional electricity surplus exchanges. Environmental and feasibility studies are being carried out for the construction of hydropower plants and transmission lines with Argentina, Uruguay, Venezuela, Bolivia, Peru and Guyana.

Taking into consideration all transmission lines – whether or not associated to binational hydroelectric plants – there were 23 international interconnections in operation in 2013 (CIER, 2015). The expansion of international grid connections may foster an increase in renewable generation, with important synergistic gains due to the seasonal variability of renewable sources and the differences in the shape of load curves throughout the region. Nevertheless, the long-term consequences of Brazilian plans for cross-border exchanges remain unclear from a broader perspective. One example of the changing conditions in the region is the transmission lines, non-associated to hydro projects, built between Brazil-Argentina and Brazil-Venezuela, which were intended for importation to Brazil of low cost electricity surplus. This actually happened in the first years of operation, but from 2010 onwards the situation reversed and Brazil became an important exporter as well (Rodrigues, 2012).

To take into account such possible variations, three scenarios were developed for the expansion of the South American power supply sector, with a focus on the long-term (2013–2058).

- *Reference Trade SAMBA (RTS)*: based on national expansion plans projected by governments (short, medium and long-term) with the existing 23 international power interconnections (Table 2);

Table 2
Total installed capacity of international transmission lines in South America.
Source: Based on CIER (2015).

Interconnections	Total installed capacity (MW)
Argentina – Chile	633
Argentina – Brazil South	2200
Argentina – Paraguay	3000
Argentina – Uruguay	3376
Brazil North – Venezuela	200
Brazil Southeast – Paraguay	6100
Brazil South – Uruguay	570
Colombia – Ecuador	363
Colombia – Venezuela	380
Ecuador – Peru	100

Table 3
Strategic large hydro projects for Brazilian government.
Source: Based on EPE (2014b, 2014c).

Strategic hydropower projects	Interconnections	Total installed capacity (MW)
Inambari Dam and Peruvian Amazon Dam Complex	Peru – Brazil Southeast	7200
Middle Mazzaruni and Upper Mazzaruni Dams	Guyana – Brazil North	4500
Garabi and Panambi Dams	Argentina – Brazil South	2200
Cachuela Esperanza Dam	Bolivia – Brazil Southeast	800

- *Integration Trade SAMBA (ITS)*: based on the reference scenario with the addition of strategic large hydro projects and associated transmission lines now under evaluation by the Brazilian government (Table 3, EPE, 2014b, 2014c).
- *Alternative Trade SAMBA (ATS)*: based on the reference scenario with the addition of distributed photovoltaic in Brazil, lower hydro expansion capacity and reduced investment costs of biogas (from second generation) power plants.

Although the scenarios consider upper limits on carbon dioxide emissions for the power sector, a comparison between them provides insights on how renewable energy generation is affected by the power systems integration. Additionally, using a cooperative games approach with the application of the Shapley value concept, the bargaining power of each country (player) was calculated for all SAMBA scenarios. This allows an analysis of how an asymmetrical bargaining power — and distortions of a country's payoffs vis-à-vis its Shapley value — impacts the continent's trade perspectives.

Several studies have shown how the Shapley value concept applied to the energy sector might help in devising schemes for the fair distribution of the benefits attained from cooperation behaviour among agents (Pierru, 2007; Naveiro et al., 2009; Medina, 2012; Banez-Chicharro et al., 2017). Nevertheless, to our knowledge there are no studies which have applied the Shapley value to the fair distribution of benefits of power system integration processes. This paper intends to help filling this gap by proposing a methodology that provides important information to support policy makers in international negotiations.

In order to achieve this objective, Section 2 presents the proposed methodology and the tools used to implement it, while Section 3 presents the available power generation resources of South America. Sections 4 and 5 introduce and discuss the basic premises used and the results obtained for SAMBA scenarios. In the Section 6 a cooperative game theory approach is used to identify the importance of all interconnections. Conclusions of this study as well as future research are provided in Section 7.