LONG-TERM PLANNING AND CHARACTERIZATION OF LATIN AMERICAN ELECTRICAL SYSTEMS BASED ON THEIR RESOURCES

Lorena Di Chiara, +59899294106, lorenadichiara@gmail.com
Gonzalo Casaravilla, Member, +59899725662, gcp@fing.edu.uy
Ruben Chaer, Member, +59899671944, rchaer@fing.edu.uy

Overview

Power system planning is a fundamental activity for the energy sector. It allows anticipating potential challenges, such as supplying a growing energy demand, achieving energy policy goals, meeting environmental commitments, among others. The assets of electrical power systems have long lifetime, which according to the type of technology ranges from 20 to 50 years and a construction time between 1 to 2 years for Non-Conventional Renewable Energy (NCRE), 2 to 3 years for combined cycles and 7 to 10 years for large hydroelectric plants and nuclear energy. Transmission lines, according to the complexity of the geographical area, may have very long construction times or not be viable due to economical and/or environmental issues.

Long-term planning studies typically have time horizons from 15 to 30 years. The result of these studies are a set of optimal investments that meet certain requirements, including the type of technology to be installed and when they should be installed.

Given the complexity of these studies, specific models are required to determine the energy demand forecast (demand models) and the expansion of the power system taking into account this demand (offer models).

In 2018, the Interamerican Development Bank carried out a study about energy planning institutions and energy planning models knowns in Latin American and Caribbean Countries (LAC) [1]. Some countries in LAC do not have energy planning institution or capacities. Several energy planning models are known with different level of diffusion and acceptance.

In 2019, the hydroelectric generation in Latin American region represented approximately 50% of the total electricity demand [2]. It is observed that most Latin American countries rain flows are influenced by the climatologic phenomenon known as El Niño / La Niña. These climatological phenomena present pseudo-cycles with periods from 5 to 8 years. In extreme situations, these might cause severe droughts and / or floods.

Traditionally, one of the most common questions in long-term energy planning, especially in systems with medium and high share of hydroelectric capacity, is the risk of electricity curtailment that a country is willing to take in the face of an extreme very low probability drought. This concept is defined as Non Service Energy (NSE) and is assigned a NSE Cost that should be included in the energy planning study.

In addition, nowadays, due to improvements in efficiency and cost drop of wind and solar photovoltaic (PV) capacity, these technologies are a competitive alternative. The variability in short term (hours, days) should be taken into account in energy planning processes. In medium and long term (months to years), the variation of energy produced by these technologies is very low.

In systems with hydroelectric plants with storage capacity, short-term fluctuations of Non-Conventional Renewable Energy (NCRE) can be mitigated by increasing hydroelectric generation when the production drops or by storing water when they are generating in abundance. In this study, generation expansions will be performed considering NCRE (wind and solar PV) and traditional thermal generation (open turbines and combined cycles) as candidate plants.

Considering the characteristics of Latin American countries and cost of NCRE, it is necessary to choose a model that adequately represent the dynamics and variability of these power systems, such as, hydrological flows, wind and solar resources, and demand. One of the most suitable model to use in power systems planning with high share of hydroelectric and NCRE integration is SimSEE [3] (Simulation of Electric Power Systems).

In this work, a long-term energy planning study is carried out to define the optimal combination of investments in generation for different integration of hydroelectric and storage capacity (reservoir), considering variability of flows, wind and solar PV capacity factor[1] (FC), fossil fuel costs, installation costs, operation and maintenance costs of different technologies and NSE costs, similar to those in Latin American countries.

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[1] The Capacity Factor (FC) is defined as the ratio between energy production and energy that would be generated at full capacity installed in a given frame time.

Methods

Due to different characteristics of natural resources, mainly wind, flow and solar irradiation, in order to simplify this study, Latin America is divided into the following 3 regions: Southern Cone (Argentina, Uruguay and Rio Grande do Sul), Andean Region (Chile, Bolivia, Peru, Ecuador and Colombia) and Central America (Panama, Costa Rica, Nicaragua, El Salvador, Honduras and Guatemala).

In Latin American countries, a survey of hydroelectric installed capacity, historical hydrological flows and generation, electricity demand, installation costs of different technologies, wind and solar resources, availability and price of fossil fuels was obtained using public and available information.

Since in recent years the integration of wind a solar generation has been very dynamic, it is very difficult to quantify the capacity factor based only on historical data. For this reason, it is decided to complement the historical data with public data available of wind and solar Atlases from World Bank.

A summary of hydrological, wind and solar resources data used in this study are shown in Sections Hydrological resource modelling, Wind resource modelling and Solar resource modelling, respectively.

The electricity demand in each region is modelled from hourly data adjusted to an annual demand of 10.000 GWh and peak demand around 1.900 MW. All results can be extrapolated according to the demand of each region or country. For each region, 12 scenarios of hydroelectric capacity with storage are considered. The installed hydroelectric capacities are: 60%, 40% and 20% of peak demand, and storage capacity are: few hours, 1 week, 12 weeks (3 months) or 52 weeks (1 year).

Considering the availability of sufficient native natural gas, use of liquefied natural gas and use of oil for operation of thermal plants respectively, the following three fuel cost scenarios are considered: Low Prices, Medium Prices and High Prices. In Southern Cone countries fossil fuel prices are medium or high, in Andean Region countries are low and medium, and in Central America are medium and high.

Candidate generation expansion plants are combined cycles, turbines, wind and solar PV generation. Turbines have a higher variable cost than combined cycles at nominal operation, but they are more flexible since they can operate for very short-time periods, while combined cycles must be on / off for some hours (at least 1 day in this study). The installation of a new hydroelectric plant or the expansion of the reservoir is not analysed.

Wind and solar PV capacity investments are modelled based on cost projections published by the International Renewable Energy Agency (IRENA) [4][5] and Lazard [6]. Investment costs of turbines and combined cycles thermal plants are modelled based on real projects in Latin American countries. A detailed technical and economic information is shown in Section Candidate plants modelling.

Optimizations of the generation expansions are performed using SimSEE and the Generation Investment Planning module (PIG-OddFace) [7]. A daily time step (24 hours) with 4 time divisions is used (1, 4, 13, 6 hours). The first division is the peak demand with 1-hour duration, the last division corresponds to the lowest 6-hour demand. The electrical system is modelled with a single node where the electricity demand and generators are connected. Hydrological flow, wind and solar generation are modelled using a stochastic model known as CEGH [8].

All costs / prices considered in this study are expressed in 2020 constant dollars. A discount rate of 10% is assumed and taxes are not considered.

Hydrological resource modelling

To model the variability in each region, due to characteristics of the hydrological resource, it is required several years of annual flow data and/or hydroelectric production and the monthly evolution data throughout the year.

The annual variability by region, is modelled by public historical production and installed capacity during 2005 to 2015 (See Table 1). This information is available on SIELAC – OLADE website.

The hydroelectric evolution throughout the year is modelled using 3 years monthly generation in El Salvador (Central America), 10 years monthly generation in Colombia (Andean Region), and 80 years of historical flow in Uruguay (Southern Cone) (See Fig. 1.).

Year	Central America	Southern Cone (without Brazil)	Andean Region
2005	50	57	57
2006	50	58	60
2007	51	54	62
2008	56	54	65
2009	52	55	62
2010	56	52	57
2011	49	51	63
2012	50	50	62
2013	48	53	60
2014	45	51	57
2015	45	55	54

Table 1: Capacity Factor (%).

Source: Own elaboration, data from SIELAC-OLADE

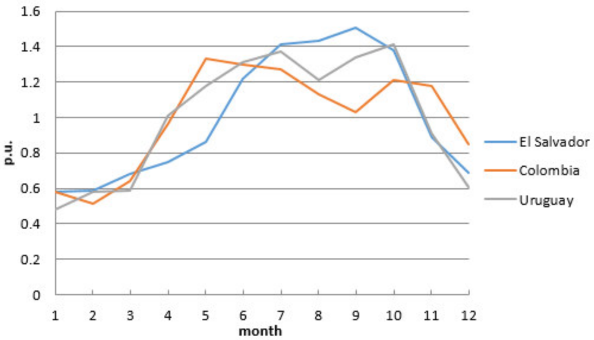


Fig. 1:Average monthly evolution per unit.

Source: Own elaboration, data from XM - Colombia, UT - El Salvador and 80 years historical flow data - Uruguay.

It is observed in the analysed period that in Central American region the annual FC varies between 45% to 56%, in Southern Cone between 50% to 58% and in Andean Region between 55% to 65%. Considering similarities in the annual FC in the period and regions, the same annual FC is assumed in the three regions with an annual average value of 55% and extreme values of 40% and 70% to cover possible climatologic variations.

Given the similarities in the annual evolution of the average flow of Colombia and Uruguay, the same modelling is used in Southern Cone and Andean Region. In Central America a model with more pronounced variations between dry a wet season is used.

Wind resource modelling

Wind resource in each region is modelled from Global Wind Atlas data of wind resource at 100 meters in height in sites of good resource along each region. The data is validated with real generation information and data from La Red del Futuro [9] study.

Fig. 2 shows an image of Latin American annual wind resource. The following annual FC are assumed:

- Southern Cone: 42%
- Andean Region: 32.5%
- Central America: 37.5%

Fig. 3 and Fig. 4 shows the monthly and hourly FC of each region. It is observed the evolution in Southern Cone and Andean Region are smoother than in Central America, where there are two seasons, one of high wind and other of low wind.

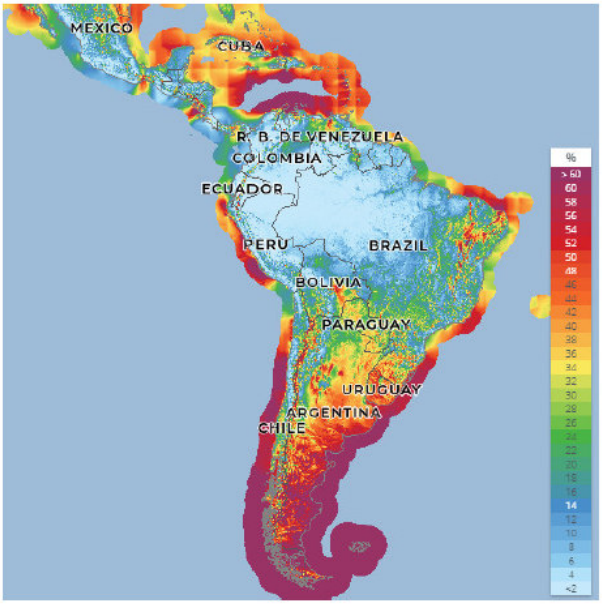
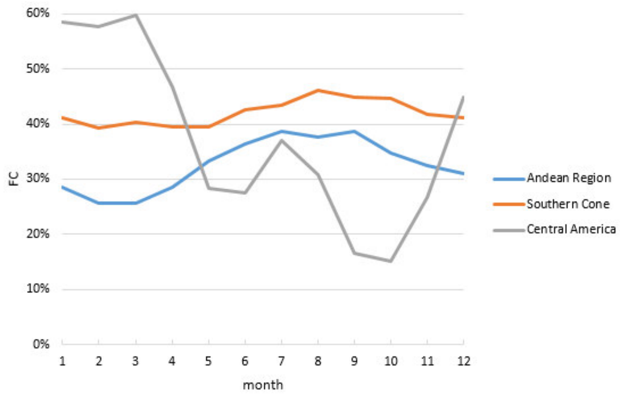


Fig. 2: Global Wind Atlas.



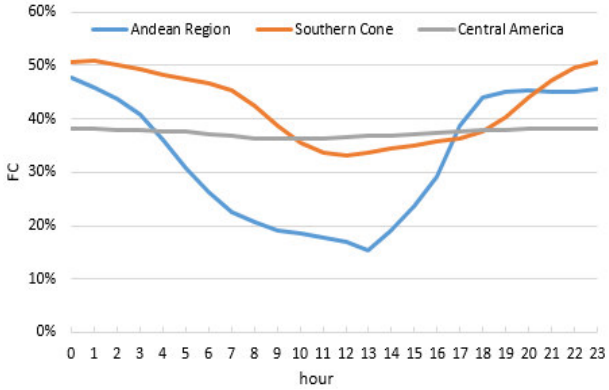


Fig. 3: Average monthly FC wind generation by region.

Fig. 4: Average hourly FC wind generation by region.

Source: Own elaboration, data from Global Wind Atlas.

Solar resource modelling

The solar resource modelling in each region is carried out mainly using data from Global Solar Atlas. Fig. 6 shows the average Horizontal Solar Irradiation (GHI) in Latin America. It is observed that, except in Atacama Desert region, the average yearly GHI is from 1800 to 2300 kWh/m^2.

The Global Solar Atlas also has a tool for calculating the energy produced by different kind of solar PV technologies. In this study, solar PV plants are assumed ground mounted.

The following annual FC are assumed:

- Southern Cone[2]: 20%
- Andean Region: 25% (Atacama region) and 20%
- Central America: 21.5%

Fig. 5 shows the average monthly FC of solar PV by region.

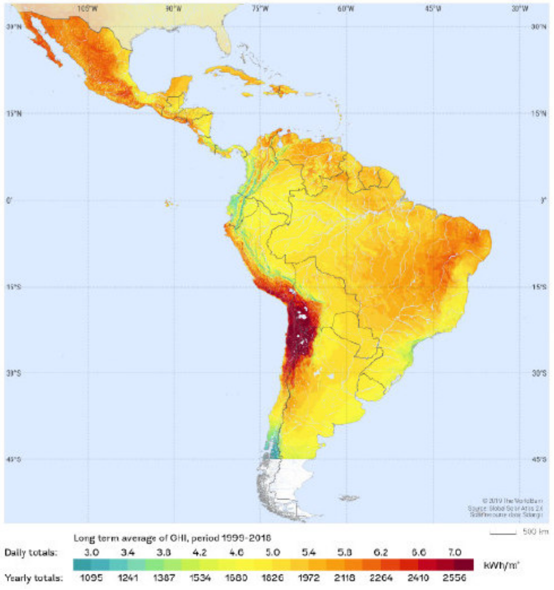


Fig. 6: Global Solar Atlas.

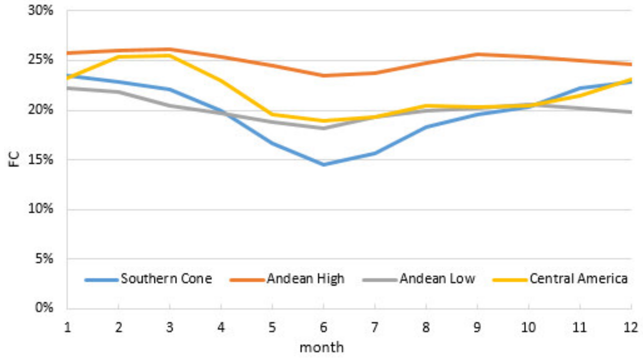


Fig. 5: Average monthly FC solar PV by region.

Source: Own elaboration, data from Global Solar Atlas.

Candidate plants modelling

Table 2 shows the basic information used for modelling the candidate plants in SimSEE – PIG model and Table 3 shows the thermal plants variable costs by fossil fuel prices.

	Wind onshore	**PV**	**Turbine**	**Combined Cycle**
Capacity (MW)	50	50	60	120
Lifetime (years)	20	20	25	25
Investment cost (USD/kW installed)	1400	800	1000	1200
Availability Factor (%)	1	1	0.85	0.85

Table 2: Candidate plants information.

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[2] Due to the distance from high consumption areas, the region of Argentina close to Atacama Desert is not considered.

Fossil Fuel Price	Variable cost Turbine (USD/MWh)	Variable cost Combined Cycle (USD/MWh)	
		Technical minimum	Nominal
Low Price	31	32	25
Medium Price	57	59	43
High Price	88	90	60

Table 3: Thermal plants variable cost.

Results

The optimal NCRE share in different scenarios is shown in Fig. 7:Right. In systems with medium and high fossil fuels prices, the share of NCRE is very high, especially in systems of 20% hydroelectric capacity. In systems with the same hydroelectric and storage capacity, the increase in fossil fuel prices increases the share of NCRE. In systems with the same hydroelectric capacity, the integration of NCRE is higher when the storage capacity increases.

In Andean Region countries with native natural gas (low fuel prices, 3 USD/MBTU) despite the excellent solar resource, the optimal generation integration is only thermal. A sensitivity analysis is carried out increasing low fossil fuel price by 1USD/MBTU and in this situation, NCRE begin being competitive options.

In systems with medium and high fossil fuel prices and little storage capacity, the daily evolution of wind and PV generation in relation to the demand, has a more important role than in systems with greater storage capacity.

Considering the same assumptions of fossil fuel prices, technologies costs and hydroelectric capacity, the optimum generation expansion varies according to the region considered. Fig. 7:Left shows in Southern Cone, due to the excellent wind resource and fossil fuel prices, wind energy is an excellent option. In Andean Region, in countries like Peru and Bolivia, despite the high solar resource, low fossil fuel price is a barrier for the deployment of NCRE.

In Central America countries, due to the characteristics of the resources, the optimal generation results show similarities in the share of solar PV and wind generation.

Two sensitivity analysis are considered, one in Southern Cone using a 10% lower technology cost for solar PV, and other in Andean Region, in countries with high solar resource and medium fossil fuel price, using 10% lower technology cost for wind generation. In Southern Cone, the share of solar PV increases but wind generation is still predominant and in Andean region the share of wind generation increases but solar PV is still predominant.

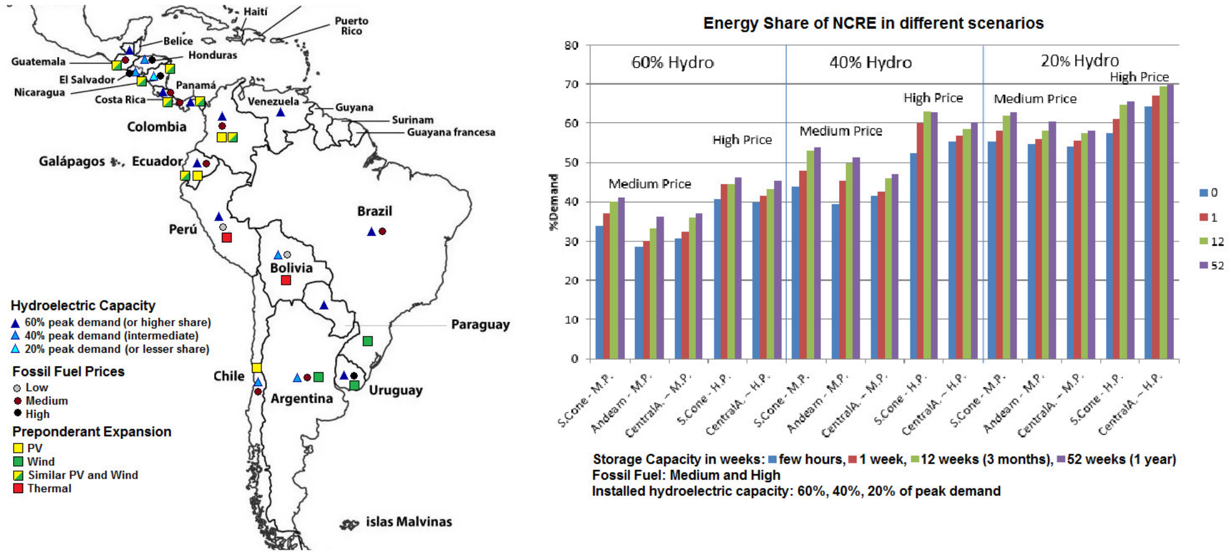

Fig. 7: Left.: Preponderant technologies – optimal expansions; Right: Energy Share of NRCE in different scenarios.

Conclusions

Nowadays, except in scenarios with very low fossil fuel prices, wind and solar PV technologies are very competitive generation expansion alternatives and reduce the system costs.

The share of solar PV and wind energy generation vary along Latin American countries, and depend mainly on fossil fuel prices, hydroelectric capacity, storage capacity, hydrological, solar and wind resources.

In Southern Cone, wind energy is the predominant generation expansion option. On the other hand, in countries like Chile, due to the excellent irradiation, solar PV is an excellent option. In Central America countries, the share of wind and PV capacity are similar.

It is important to take into account that this is an energy study, and for a complete validation of the NCRE integration, especially in systems with 20% hydroelectric capacity, it is necessary to perform a flexibility and stability study.

References

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