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Strategies of Expansion for Electric Power Systems Based on Hydroelectric Plants in the Context of Climate Change: Case of Analysis of Colombia

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ABSTRACT

The phenomena of climatic variability such as El Niño affect the expansion planning of electricity supply systems with hydroelectric power plants due to the uncertainty presented in the variables of rainfall patterns, temperature, wind, solar radiation changes, among others. The El Niño affects the electricity generation in Colombia, Venezuela and northwestern Brazil due to severe droughts that reduce water flows in rivers and water volume in dams. While in Peru, Paraguay, Bolivia, Uruguay, Argentina and southern Brazil, causes heavy rains that lead to an increase in reservoirs. Recent findings provide sufficient evidence on how climate change modifies the patterns of duration, frequency and intensity of El Niño and therefore will introduce additional uncertainties to the expansion planning of electricity generation systems in countries that uses predominantly hydroelectric power. The vulnerability of electricity supply systems with a significant participation of hydroelectric power plants in Colombia, Brazil, Ecuador, Peru, Panama, Canada, Norway, Costa Rica and New Zealand is associated with fluctuations in the availability of water resources. This document aims to analyze the current plans for the expansion of electric power generation systems by the aforementioned countries in the context of climate change in medium and long term. Additionally, this document provides a detailed analysis of the situation of electricity supply systems in Colombia.

Keywords: El Niño Phenomenon; Vulnerability; Colombia; Water Resource; Development Planning
JEL Classifications: L94, O20, Q4

1. INTRODUCTION

In recent decades, hydroelectric power plants were built to take advantage of abundant water resources to generate electricity. However, the fluctuations in the availability of water resources has impacted the electric power generation in terms of reliability for both for plant generations with dam and run of the river plants. Electricity supply systems involving hydroelectric power plants are prone to prolonged variations in precipitation and temperature patterns. Due to the problems described above, the generation system expansion planning must seek the appropriate way to expand the generation systems according to technical and economic considerations to meet the electricity demand at medium and long term.

It should be noted that the greatest complexity of planning the electrical system in the long term is the uncertainty that exists in two ways. Those ways are from the demand side and from the supply side, seen in terms of the inclusion of new capacity to the system. The inclusion of new capacity to the system is framed in the time horizon (short or long) and in the cost vs. operation paradox. When looking for a short-term solution, options such as the inclusion of generators with gas turbines are a good alternative of low capital cost and high performance. However, when the long-term operation of the system is analyzed, units with higher capital costs and with low operating costs, are taken into account into the power supply system.

In the planning of the expansion of the long-term system there are great uncertainties regarding the electricity demand, improvements in technological performance, availability and cost of fuel, financial conditions and other important factors. All forecasts of these parameters have a high degree of difficulty that is the reason why it is very important to carry out sensitivity analyzes to evaluate the effects of uncertainties on the parameters. Another additional difficulty lies in the large number of equations and variables to optimize, a common strategy usually involves, to solve the generation and the transmission expansion as two problems, recently, an integrated approach has been proposed. The planning with analytical tools has been developed from different approaches to include innovation (Miremadi and Saboohi, 2018). Even some authors have proposed the development of green energy policies to improve economic growth (Daryono et al., 2019). Planning under uncertainty is critical in order to find alternatives to electricity supply (Sharifi et al., 2019).

Another problem of special interest arises from the stochastic nature of supply and demand electricity. The electricity supply may be affected at any time randomly by breakdowns of generating equipment or, on a longer time scale, by the availability of water for hydroelectric generation. Thus, the supply of hydroelectric power is a difficult problem that must be faced at the hour to do the planning the expansion of generating systems.

El Niño-Southern Oscillation (ENSO) boosts rainfall variability (Power et al., 1999), (Ropelewski et al., 1989), (Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation (CSIRO), 2011), (Jajcay et al., 2018) and it is the dominant climate phenomenon that produces extreme weather conditions around the world (Cai et al., 2015). El Niño episodes are associated in a complex way by the Pacific Ocean dynamics and the interchange of heat with the atmosphere. Those coupled interactions result in ocean temperature variations in the equatorial Pacific region (Neelin et al., 1998). Regular interchanges between air pressure in the atmosphere and the sea-surface temperature cause the ENSO phenomenon. In Colombia and in the northern part of the equatorial line, El Niño is characterized by above average temperatures and low rainfall patterns, while La Niña episodes exhibit periods of below average temperatures and high precipitation patterns. The ENSO will continue to be a major source of climatic variability in the region (Alley et al., 2007), (Collins et al., 2010).

The ENSO is an alternating phenomenon with two phases, the warm phase: El Niño and the cold phase: La Niña. ENSO phases occur every 2-7 years on average (Jajcay et al., 2018), and their impacts tend to be completely different. The occurrence of the ENSO is globally determined by the Oceanic Niño Index (ONI) that measures the temperature difference of the Equatorial Pacific Ocean. If ONI is $\geq 0.5°$ during 5 or more consecutive months, it means that it is an El Niño Phenomenon. On the contrary, if it is $\leq -0.5°$ for 5 or more consecutive months, it means that it is a La Niña Phenomenon (National Oceanic and Atmospheric Administration (NOAA), 2018).

The nature of the ENSO has varied significantly over time; in this regard, historical data shows a trend towards longer and stronger El Niño phenomena (Trenberth et al., 2001), (IPCC, 2007), (Cai et al., 2018). The uncertainty associated with predictions about the intensity, duration, and occurrence of the climatic phenomenon is high, because it corresponds to a complex climate system (Timmermann et al., 2018). For example, the prediction about El Niño in 2005 was far from the duration and intensity experienced during that year (Trenberth et al., 2001).

In this way, climate change affects the reliability of electricity supply systems in countries that depends on water resources to generate electricity according to economic and security requirements. Therefore, the planning of electric power supply systems should include strategies to adapt their operation to climatic circumstances related to water availability. This paper is a review of state of art with respect to strategies of electricity expansion systems based on hydroelectric resources in the context of climate change. This review focuses on countries that generate more than fifty percent (50%) of energy with hydroelectric power plants. In addition, the Colombian electrical power system is described in terms of hydroelectric power supply and vulnerability to climate change. The need to carry out future work regarding resilience to climate change for electricity supply systems is shown.

2. METHODOLOGY

In the expansion of electric power supply systems, it is strongly important to consider the uncertainties that the system it has currently presents and what could it have in the future. Within these uncertainties it is important to consider those that may increase the vulnerability of electric power supply systems.

The vulnerability of electricity supply systems is related to the possibility of changes in climatic variations that have impacts on the electric power supply reliability. According to the IPCC (Intergovernmental Panel on Climate Change), vulnerability is stated as being: "Propensity or predisposition to be negatively affected. Vulnerability comprises a variety of concepts and elements that include sensitivity or susceptibility to harm and lack of responsiveness and adaptation" (Alley et al., 2007). Therefore, the vulnerability of electricity supply systems is focused on the sensitivity or susceptibility of the system to produce electricity given the variability of water resources by the climate change.

This review was carried out using the following methodology: (1) selection of studies from several countries that have a priority hydroelectric power generation mix and are vulnerable to climate change; (2) review of expansion strategies for power systems in countries that have power generation portfolio with significant use of hydroelectric power plants; and (3) description and analysis of the expansion strategies of the electric power generation sector in Colombia.

The power generation mix in each country is made up of technologies that take advantage of different primary energy resources according to their availability and associated costs. In the context of energy transition, during the last years, renewable resources (RS) such as wind farms and photovoltaic power plants are part of the power generation mix (International Energy Agency (IEA), 2018b). For this analysis, ten countries have been characterized by the usage of hydroelectric power plants in the power generation mix. The countries are Costa Rica, Colombia, Brazil, Venezuela, Ecuador, Peru, Panama, Canada, Norway, and New Zealand. The power generation portfolio of these countries are presented in Table 1 with information from (International Energy Agency (IEA), 2017b), (International Energy Agency (IEA), 2017c), (International Energy Agency (IEA), 2017g), (International Energy Agency (IEA), 2017h), (International Energy Agency (IEA), 2016), (International Energy Agency (IEA), 2018a), (International Energy Agency (IEA), 2020), (International Energy Agency (IEA), 2017a), (International Energy Agency (IEA), 2017f), (International Energy Agency (IEA), 2017e).

3. RESULTS AND DISCUSSION

3.1. Strategies of Electricity Expansion Systems in Latin American Countries

Some countries in Latin America have been developing and designing strategies to diversify their electricity supply matrix. Costa Rica's electricity supply system is highly dependence on water resources (75%, in 2015) (International Energy Agency (IEA), 2015). The most recent energy policies proposals in Costa Rica are focused on diversifying the generation matrix through the increase of geothermal generation and electrical interconnection with other countries, to guarantee reliability in the supply of electric power (Plan Nacional de Energía 2015-2030 VII, 2015), (Secretaria Nacional de Energía, 2015b), (Instituto Costarricense de Electricidad (ICE), 2017), (Nacional, n.d.).

Costa Rica's propose to have support power generation of a thermal or geothermal type to provide firmness to the system. According to the recommendations of the generation expansion plan (Instituto Costarricense de Electricidad (ICE), 2016a), a total of 1,324 MW will be added to 2030, of which 80% will come from hydroelectric plants, 7.5% from wind power, 12% from geothermal and 5% of solar to continue satisfying adequately the demand of electrical energy of the country, without taking into account electrical interconnections. Additionally, it is important to consider that during this process of expansion towards cleaner energy generation, the use of backup thermal energy is proposed.

Table 1: Countries with predominantly hydroelectric power generation matrices

Country	Thermal (%)	Hydraulic (%)	Renewable energy (%)
Costa Rica	1	75	24
Panama	35	61	5
Venezuela	36	64	0
Colombia	32	65	3
Ecuador	47	51	2
Peru	47	49	4
Brazil	26	62	12
Canada	36	57	7
Norway	2	96	2
New Zealand	20	56	25

The electricity supply system of Brazil is vulnerable to water variations caused by the ENSO (Colón, 2016). In drought seasons, the level of reservoirs is reduced in the northeast which produces the increase in production in thermal power stations with liquid oil, gas, and coal fuels increasing the emission of greenhouse gases (Instituto Costarricense de Electricidad (ICE), 2016a). The expected reduction of water flows in the rivers: Rio San Francisco, Rio Amazonas, and Rio Tapajos shows the vulnerability in the rivers of the north of Brazil. The reduction in the water flow in those rivers has been reported in several studies. For instance, San Francisco River will impact the generation of hydroelectric energy (De Jong et al., 2018) according to the IPCC scenarios. Itaipu, the second hydroelectric plant with the largest installed capacity, is located to the south of Brazil, and it supplies electricity to Brazil and Paraguay (Itaipu Binacional, 2018). However, El Niño phenomenon triggers in the region the rain precipitations increase; for example, The 2016 El Niño led to the discharge of water through the landfill in order to maintain the level of the river upstream (Sociedad, 2016).

In Brazil in order to reduce the vulnerability associated with the reduction of the water captured by the hydroelectric plants for the generation of electrical energy, the energy policies are looking for alternative energy sources with the programs alternative energy sources incentives program (PROINFA) and the 10-year energy expansion plan (PDE), with investments on alternative sources such as wind and nuclear generation to diversify the electric energy (Da Silva and Vasconcelos, 2011), (Andrade et al., 2012), (Samprogna et al., 2015).

For its part, wind energy will go from 3.72% in 2015 to 8% in 2024, due to the expansion of 20 GW in the period. Solar energy will also enter. Despite these attempts, the matrix will still be based on hydraulic power (Dubrovsky et al., 2019).

Energy policies in Ecuador are focused on the diversification of its electricity supply system and the reduction of GHG emissions (Centro Ecuatoriano de Derecho Ambiental (CEDA), 2011). According to the expansion plan of the supply system of electric energy in Ecuador, hydroelectric power is expected to cover more than ninety percent (90%) of the electricity supply in the coming years (Ponce-Jara et al., 2018). One of rivers that has been considerated for the expansion of the hydroelectrical system is the Jubones River, but is expected he climate change impact in the Jubones River basin could induce that during the dry season a hydroelectric generation reduction of up to 13% is expected (Hasan and Wyseure, 2018). The development of new studies is proposed, in which the role of El Niño in the region is analyzed as well as its changes in frequency, intensity, and duration. Knowledge of these changes will make it possible to better define the critical points of vulnerability to which hydroelectric energy and other renewable energy sources are critically exposed. Therefore, it is considered important for Ecuador to review the precise location of new hydroelectric plants so as not to build them in places that will be affected by the El Niño phenomenon (Hasan and Wyseure, 2018), (Carvajal et al., 2019), (Carvajal et al., 2017).

The energy policies in Peru are seeking for an energy development to diversify the electricity supply system to comply with the Paris Agreement, and to satisfy the growing demand for energy. The percentage of participation of thermal power plants reduced by 15.2% between 2006 and 2016. On the other hand, hydroelectric generation decreased by 17.8% between 2006 and 2016 (Ministerio de Energía y Minas, 2016). The gas-fired thermoelectric plants accounted for 45% of the energy generated in the country in 2015. The Peruvian proposal for the transformation of its electricity supply system is based on the usage of gas in combined cycle plants, increasing of generation with unconventional renewable energies (NCRE), and increasing the share of hydroelectric generation (Ministerio de Energía y Minas, 2016), (Aita, 2006).

In Peru, the installation and start-up of various generation projects are expected by 2020, almost 20% of these are hydroelectric, about 13% are from non-conventional renewable energy (solar, wind and biomass) and approximately 67% are from thermal power plants, mostly natural gas, which are a good option according to the IEA's suggestions (Dubrovsky et al., 2019).

In Panama, the El Niño phenomenon produces a decrease in rainfall with variations associated with the orography of the place and the intensity of the phenomenon (Empresa de Transmisión Eléctrica S.A., n.d.). The electricity supply system in Panama is vulnerable to variation in hydro resources due to its high contribution of hydroelectric power generation plants (Table 1). The proposals for the transformation of the electric power generation matrix(Programa de las Naciones Unidas para el Desarrollo (PNUD), 2015), (Secretaria Nacional de Energía, 2015a), which consist in promoting the generation of electricity with NCRE and reducing the share of hydroelectric energy, are aligned with the national objective for 2050. This objective consists in generating 51.8% of the energy from non-conventional renewable sources, 15.1% from hydroelectric, and 33.1% from thermal energy ((Programa de las Naciones Unidas para el Desarrollo (PNUD), 2015) .It is considered that the generation of thermal energy is necessary to give firmness to the generation system due to the volatility of supply presented by non-conventional renewable energies (Programa de las Naciones Unidas para el Desarrollo (PNUD), 2015).

3.2. Strategies of Electricity Expansion Systems from Countries Utside Latin America

Canada has a predominantly hydroelectric power generation matrix (Table 1). Climate variations in Canada are triggered by the ENSO and interdecadal oscillations of the Pacific (Government of Canada, 2015). Initiatives in Canada are aimed at transforming the electricity supply system (National Energy Board of Canada, 2018), increasing the share of NCREs as is promoted by the Paris Agreement, and increase the generation of nuclear energy despite the discussion that has been generated due to the precedent of the accident in Japan.

Countries that have predominantly hydric matrices such as Norway (97% in the electricity supply system) have reported about the importance to consider the climate vulnerability of electricity generation systems in the system expansion planning. In those studies, proposed considering the current and future availability of water resources in a context of climate change in order to build an appropriated expansion plan. Several studies inform of the importance of considering climate change scenarios and their impact on local watersheds (Chilkoti et al., 2017), (The Research Council of Norway, 2013), (IEA, 2016). However, the studies conclude that hydroelectric dams with reservoirs can mitigate the effect of climatic variations through multiannual planning of reservoirs, the interconnected electrical system of Nordic is connected with neighboring countries, providing reliability and flexibility in the supply of electricity (Ollila, 2017). Currently, the Norway energy policies are seeking for the inclusion of NCRE (International Energy Agency (IEA), 2019) and energy storage (Chilkoti et al., 2017).

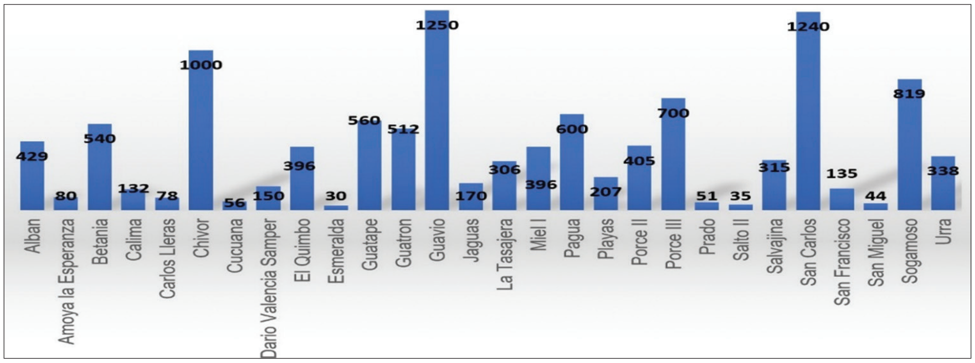
The electric power generation in New Zealand is predominantly water-dependent (Table 1). The climatic variations in 2015 were supported by gas and coal thermal power plants and with geothermal power plants (International Energy Agency (IEA), 2017d). New Zealand seeks to transform its power generation matrix by increasing the percentage share of geothermal energy as well as other NCRE (International Energy Agency (IEA), 2019, (New Zeland Government, 2016).

3.3. Colombian Hydroelectric Generation System

Colombia's electricity supply system has covered, in recent decades, between 60% and 80% of the country's demand with production from hydroelectric power plants. The hydroelectric generation capacity in December 2017 was 10974 MW (XM Compañía de expertos en mercados S.A. E.S.P., 2019a), while the generation was 53553 GWh corresponding to 80% of total demand of the National Interconnected System (SIN). The SIN has 28 hydroelectric plants, 23 reservoirs, and 39 associated rivers (XM Compañía de expertos en mercados S.A. E.S.P., 2019a). In six plants has more than the 50% of the hydroelectric capacity of the system, those are as follows: Guavio 1250 MW, San Carlos 1240 MW, Chivor 1000 MW, Sogamoso 819 MW, Pagua (Paraíso-Guacas) 600 MW y Guatapé 560 MW (XM Compañía de expertos en mercados S.A. E.S.P., 2019b), and some others as can be seen in Figure 1.

The electricity supply system of Colombia is susceptible to changes in the availability of water resources (Unidad de Plaeación Minero Energética (UPME); Ministerio de Minas y Energía, 2015). In recent years the impacts caused by El Niño phenomenon have been observed, given that periods of prolonged drought produce a decrease in the flow of rivers and therefore in the useful volume of water to produce electricity (Pabón, 2012). The impacts of the El Niño phenomenon in the geographic areas where the hydroelectric power plants are located have been studied and pointed out in various documents (Departamento Nacional de Planeación (DNP), 1997), (Compañía de expertos en mercado (XM), 2018), (Paredes and Ramirez, 2017), (Paz et al., n.d.), considering the reduction of hydroelectric generation.

Figure 1: Net effective capacity of hydroelectric plants (MW) Modified by the authors from (XM), 2018)



Due to the effects triggered by El Niño in hydroelectric generation Colombia has sought to modernize and expand the generation park to meet demand efficiently in critical water supply conditions through the definition of a market product known as firm energy. As of 2006, a reliability charge was created, which, according to Resolution 071 of 2006, is defined as "a remuneration scheme that makes it possible to invest in the necessary electric generation resources to effectively guarantee the attention of the demand for energy in critical supply conditions through long-term signals and the stabilization of generator revenues" (Comisión de Regulación de Energía y Gas (CREG), 2006). In other words, the reliability charge is a remuneration that is paid for the future availability to the generation plants in order to guarantee the delivery of the energy committed to the SIN upon assignment through the auction mechanism of Firm Energy Obligations (OEF) (Ospina and Mosquera, 2016).

Despite the OEF market mechanism described above in order to facilitate investment in electricity generation resources to meet the demand under the critical conditions of supply of the SIN, the power generation mix in Colombia remains vulnerable to critical supply conditions as was evident at 2015-2016 when a strong El Niño, among other contingencies, affects the supply of electricity from hydroelectric plants with an increase in the price of energy in the stock market (Ospina and Mosquera,2016).

This vulnerability was studied in 2013 and presented in a report dedicated to determining the vulnerability and adaptation options of the Colombian energy sector to climate change (Unión temporal ACOM-OPTIM, 2013). The report organizes the Colombia's reservoirs in 11 aggregated reservoirs (Caribe, Antioquia 1, Antioquia 2, Caldas, Cauca, Tolima, Pacífico, Bogotá, Huila, Oriente 1, and Oriente 2) according to geographical criteria of proximity between the individual reservoirs, the companies that own and operate the hydroelectric plants, and the generation capacities of each system.

Each of the added reservoirs is composed of one or more reservoirs: Caribe-Urra1; Antioquia 1-Playas, El Peñol, Punchina, San Lorenzo, Porvenir and 2 power plants at the edge of the water; Antioquia 2- interbasins Nechi, Pajarito and Dolores, Miraflores, Troneras, Riogrande, Porce II and Porce III; Caldas- Miel, Manso River and Guarinó interbasins; Cauca-Camedadua and San Francisco; Tolima- Prado and 3 plants at the edge of water; Pacifico-Calima, Bajo Anchicaya and Alto Anchicaya; Bogotá- Muña, Tomine, Sisga, Neusa, Bogotá River (3), Chuza, Bogotá River interbasin; Huila-Betania and Quimbo; Oriente 1- Sogamoso; and Oriente 2- Esmeralda and Guavio. The study concludes that climate change could limit the effective capacity of generation in all aggregated reservoirs. Additionally, it was concluded that the aggregate reservoirs with greater vulnerability to climate change are Pacífico, Cauca, Antioquia 1 and Antioquia 2, while those with medium vulnerability are Caribe, Oriente 1, Bogotá and Tolima. The least vulnerable are Caldas and Huila.

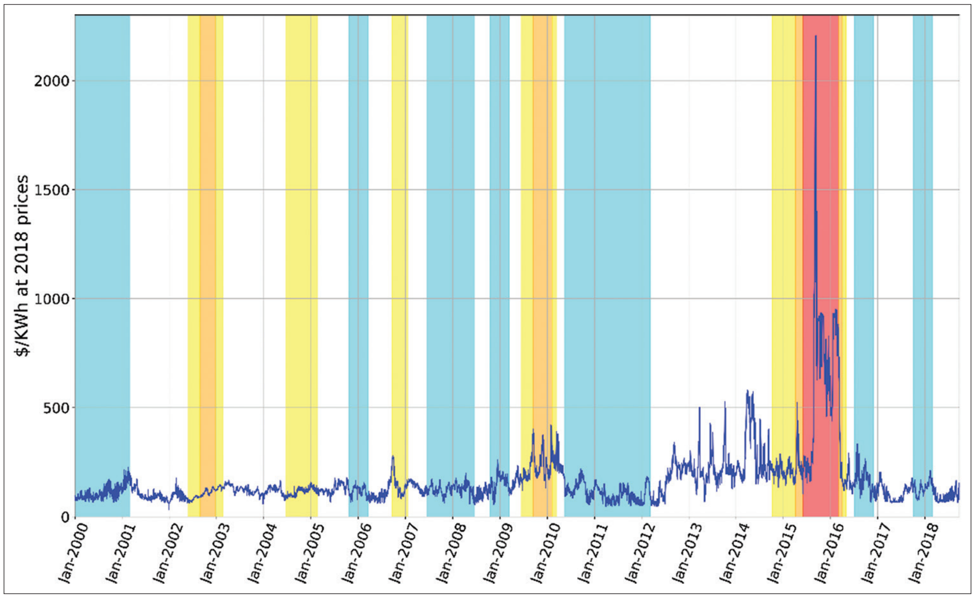
Despite the institutional and market mitigation measures implemented in previous years, the phenomenon that occurred in 2015 along with other unrelated events highlighted the vulnerability of the system to provide electricity in a reliable and economical manner. In particular, during 2015, some reservoirs in the country experienced an accelerated decline in useful volume. It should be emphasized that the reliability of a power generation system is the probability that it will adequately achieve a specific purpose for a specific period of time under specified environmental conditions (Billinton and Allan, 1996). The evaluation of reliability in an electrical power system takes into account adequacy and safety. Adequacy refers to the existence of sufficient facilities within the system to meet the consumer's load demand, while safety is the system's ability to respond to disturbances (Irandoust, 2018). Thus, the Colombian electricity system is reliable insofar as it has enough generation facilities to satisfy the national demand and react in a timely manner to the disturbances, complying with quality standards. The security of electricity supply in Colombia has been maintained so far, however, it is uncertain to what extent, since as shown in Figure 2, there is an increase in the price of the stock exchange.

The stripes shown in Figure 2 depict the episodes of La Niña (light blue), moderate Niño (yellow), intense Niño (orange), and very Intense Niño (red). Figure 2 shows that when El Niño is very intense, as it happened between January 2015 and 2016, the prices of energy in the stock market increased to a value close to $1,900; that is, the price of energy in the stock market had increases of up to 87.5% in the period.

3.4. Contrast of the Colombian Case against the Situation of the Other Countries

From the previous analysis, it is evident that, of the countries with participation of hydroelectric power plants in the

Figure 2: Stock price 2000 - 2018



production of electrical energy superior to 60% and exposed to the effects of climatic variability of the phenomenon El Niño, Colombia and Costa Rica present similarities. In such a way, it is important to take into account the climatic variability in the considerations of expansion of the hydroelectric generation systems in the medium and long term of these countries. It is necessary to diversify the energy matrix, in such a way that other natural resources are used to generate electricity in order to take care of the short-term mitigation of the El Niño effects mentioned above.

In the reviewed works, the proposals for strengthening interconnections with other countries stand out, as in the case of Costa Rica (Instituto Costarricense de Electricidad (ICE), 2016b). On the other hand, Brazil and Canada consider the expansion of production with nuclear power plants as an alternative (Ministry of Mines and Energy of Brazil, 2007) and (National Energy Board of Canada, 2018), respectively. The coincidences and the search for other alternatives to diversify the electric power matrix are also highlighted. The increase in the inclusion of unconventional renewable energies is a measure proposed by 70% of the countries analyzed in Table 1 (Brazil, Colombia, Peru, Panama, Canada, New Zealand and Norway), and it is a measure consistent with the purpose of the energy transition and the objectives of the Paris Agreement (International Energy Agency (IEA), n.d.).

It should be noted that the case of the electricity generation sector in Colombia is particular because it is predominantly hydraulic, because of the impacts of El Niño phenomenon in the country, and because of its geographic location in the northwestern region of South America. Regarding its location, it should be noted that Colombia is located between a southern latitude of 4º 13’ 30”, and a northern latitude of 12º 27’46”, and from 66º 50’54 “to 79º 0’23” of the Greenwich meridian (Red Cultural del Banco de la República en Colombia, 2017). It has a coastline on the Pacific and Atlantic Oceans, and from these it receives strong climatic influences. Lastly, it is crossed by the Andean mountain range that originates a great diversity of climates and ecosystems (Pabón, 2012).

The analysis of the electric power generation matrix transformation proposals is opportune because it offers visions and alternatives that can be considered, taking into account the situation of electric power in Colombia. Thus, it can be inferred that mainly the proposals are focused on increasing the generation of electric power with conventional and non-conventional renewable sources.

4. CONCLUSIONS

Colombia has had a reliable electric power generation system. This is due to the fact that in the period 2000-2018 it has had an adequate electric power generation park that has been able to supply electricity in a safe manner. However, it has seen a significant increase in the prices of the stock market in critical periods of supply of water resources. Due to this, the diversification of the energy generation matrix through the inclusion of ERNC is of greater importance because these are technologies that currently have competitive prices in the market and which in turn help to reduce GHG emissions, and thus the compliance with the Paris Agreement.

The inclusion of complementary and competitively priced power generation technologies is important due to the limitation of the effective generation capacity of hydroelectric power plants throughout the national territory. Additionally, it is interesting to analyze how the multiannual programming of the reservoirs it is a manner to control the droughts.

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