Ecuador: Small hydropower and framework conditions

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Intro

Ecuador alone has more rivers per square kilometre than any other country in the world and therefore it provides a lot of potential for hydropower. However, a decade ago, Ecuador relied on oil and its by-products for energy generation. Nowadays, 93% comes from hydroelectric, a clean and renewable energy production system. The Ecuadorian 2008 Constitution promotes the use of clean and alternative energy sources, in addition to energy efficiency, while providing access to public services, preserving the environment and maintaining food and water security, among others. Ecuador's plan is to reach self-sufficiency through clean energy production and potentially export energy to neighbouring countries. The average annual generation from hydropower between 2006 and 2015 was 10,880 GWh/year, while in 2018, generation from hydropower was 20,696 GWh. It is clear that hydropower generation has gained more importance, where the total installed capacity on the Ecuadorian power system almost doubled between 2006 and 2018. A representative indicator of the hydroelectric potential of Ecuador is estimated to be very high - 0.74 GWh/year/km^2 compared to other countries like Austria, Norway (0.66) and Brazil (0.15).

Currently, there are 31 large hydro plants (>10 MW) in operation, with a total installed capacity of 4,973 MW, while for small, mini or micro hydro plants (<10 MW) a total of 41 plants in operation with a total installed capacity of about 102 MW. The cost of new hydro capacity under construction is around US$ 2,500/kW. The cost of producing a unit of electrical energy is approximately 0.048 US$/kWh in hydropower plants and 0.08 US$/kWh in other types of plants. The investment scenarios related to renewable energy projects in Ecuador are mainly concentrated in the construction and operation of hydroelectric plants, due to the great potential of the existing water resources, which depends on the beneficial natural, geographical, hydrological, and climatological conditions. Yet, there are still a number of challenges with regard to SHP adoption and a need to define a more comprehensive strategy on small hydropower project implementation and on encouraging future public-private partnerships.

1. Background

Ecuador has an area around 283,560 km^2 and a population of around 17.3 million inhabitants (August 2019 estimate). It is located on the west coast of South America, borders Colombia on the north, Peru on the east and south, and the Pacific Ocean on the west. Ecuador is characterized by three distinct regions: the coast, the highlands, and the eastern interior lowlands. The climate varies with the region, mean annual precipitation ranges between 200 mm and approximately 5,000 mm. Most of the northern coast consists of wet, tropical forest, increasingly humid environment. In the central coast area, there are two seasons: a hot rainy period, lasting from January to May; and a cooler dry season during the rest of the year, when sea breezes modify the equatorial heat. Quito, the capital city, is located at 2,850 m a.s.l., with an average temperature of 13°C and about 1,270 mm of rainfall annually. The highlands are cut by numerous deep valleys, which bring subtropical climates to within a few kilometres of the more temperate areas. Cold and wind increase as the slopes surrounding the central plateau ascends to form the paramo. The higher areas rise to peaks above 5,200 m a.s.l. that are perpetually covered with snow.
The Guayas in the center west and the Esmeraldas in the northwest form the principal river systems. The highlands are formed by two parallel ranges of the Andes and divided into 10 basins at altitudes from 2,400 to 2,900 m a.s.l., some draining East and some West. It should be noted that a large portion of Ecuador's high mountains are volcanic. The eastern interior lowlands are part of the upper Amazon Basin, beginning at the base of the Andes at about 1,200 m a.s.l. There are at least 2,000 rivers and streams in Ecuador. Ecuador alone has more rivers per square kilometre than any other country in the world and therefore it provides a lot of potential for hydropower. Most of them have headwaters in the Andes mountain range, flowing there from either westward toward the Pacific Ocean or eastward toward the Amazon River.

Until 1961, the provision of electrical energy was dominated by private companies and also by the municipalities. Only small thermal electricity generation systems were developed, installed capacity was insufficient, and therefore electricity was not a capable of promoting Ecuador's economic and technical take off. By 1964 there were 1,100 power plants in the country with generation capacity of 190,000 kW and in 1967 there were 1,218 of them (661 private and 557 public). Around 35 % of the population were supplied with electricity generated in 60 % by thermal power plants and in 40 % by hydroelectric installations. Ecuador was located at one of the last places in Latin America in terms of electrification. The change started after 1961, when the Ecuadorian Electrification Institute (INECEL) was created and the "decade of development" began throughout Latin America. Between 1971-1985, the focus was on using the river flows to generate hydroelectric power, developing two types of networks: 1) the National Interconnected System, with 4 large selected hydroelectric projects (Pisayambo, Paute, Toachi and Montúfar), and 2) the Regional Electric Systems. In 2008, in order to avoid electricity shortages that commonly occurred during 1992-2007, the Ecuadorian Government launched the so-called Change of the Energy Matrix, under which large scale hydroelectric projects were built. In 8 years, Ecuador went from consuming electricity generated in 46 % out of fossil fuels to 93 % of hydroelectric, a clean and renewable energy production system. In 2018, the access to electricity is estimated around 97.05%.

1.1 Power sector overview

A decade ago, Ecuador mostly relied on oil and its by-products for energy generation. Nowadays the hydropower generation has gained more importance since the Ecuadorian government committed to obtain a cleaner energy system through the development of hydropower plants, biomass, wind power and other renewable source projects. The total installed capacity on the Ecuadorian power system almost doubled between 2006 and 2018. During this period, the country invested close to $US 6 billion in eight flagship projects with a total installed capacity of 2,832 MW. Two large-scale projects make up most of this new capacity and both were inaugurated in 2016: Coca Coda Sinclair (1,500 MW), a run-of-river facility located in the Coca River (Napo basin) and Sopladora (487 MW), an additional phase to the Paute Integral reservoir (DAM) hydropower system in the Paute River (Santiago basin). The remaining six projects are already in advanced construction stages and they were planned to be fully operational by 2020 (Carvajal et al., 2019).

The country total effective installed capacity from all sources is 8,662 MW (2018), comprising: hydropower (5,066 MW); thermal plants with fossil fuels (3,395 MW); thermal biomass plants (144.3 MW); thermal biogas (7.3 MW), solar PV (27.6 MW); and wind power installations (21.2 MW) (Fig. 1).

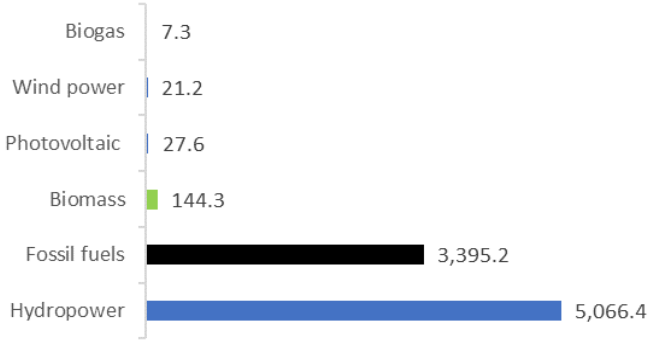

Fig. 1. Ecuador - Effective installed capacities of the Ecuadorian power system in MW (ARCONEL, 2018)

In September 2018, three ministries - responsible for hydrocarbons, electricity and renewable energy, and mines, respectively - were merged into the new Ministry of Energy and Non-Renewable Natural Resources (MERNNR). In January 2015, a new law governing the electrical sector was approved by the National Assembly called the Organic Law for the Public Service of Electricity. According to this legislation, ARCONEL (Agencia de Regulation y Control de Electricidad) is the regulatory body for the electricity sector. The National Operator of Electricity (Operador Nacional de Electricidad) CENACE is responsible for administration of the national interconnected grid and the state-owned company, Electrical Corporation of Ecuador (Corporation Electrica del Ecuador) CELEC groups together the main electricity companies.

The representative indicator of the hydroelectric potential of Ecuador is estimated to be very high - 0.74 GWh/year/km^2 compared to other countries like Austria, Norway (0.66) and Brazil (0.15). The installed hydro capacity was around 5,282 MW and hydro generation 20,671 GWh by 2018 (MEER, 2017).

1.2 Renewable electricity policy

The Ecuadorian 2008 Constitution explicitly states that the government will promote the use of clean and alternative energy sources, in addition to energy efficiency, while providing access to public services, preserving the environment and maintaining food and water security, among others. Ecuador's plan is to reach self-sufficiency through clean energy production and potentially export energy to neighbouring countries.

The regulatory framework for electricity is the Electric Law of 2015, which explicitly states the objective of promoting renewable energy sources. It points out that National Electricity Council (CONELEC) will issue the regulations for the operation of generation plants using renewable sources. As a result, CONELEC periodically issues regulations (normally every two or three years) for renewable energy plants installed on or after the date of the new regulations, as well as other regulations that cover all renewable plants (including those previously installed).

Between 2000 to 2015, Ecuador had a feed-in tariff system to support renewable electricity deployment, which evolved over time in terms of duration, rates and technologies included. It is one of the very few Latin American countries that implemented a feed-in tariff (FIT) scheme for renewable energy (Vargas et al., 2018). In 2014, Resolution CONELEC 014/14 maintained the feed-in tariff only for biomass and biogas, with differentiated rates for the first time, and for hydropower smaller than 30 MW.

Small-scale electricity producers (with capacity smaller than 1 MW) do not require a permit for operation (Decree 1581 of 1999). However, in order to benefit from the feed-in tariffs, they need to be registered with the CONELEC. In 2013, Regulation CONELEC 002/13 introduced two payments; a registration guarantee of US$ 7,000 for projects smaller than 500 kW and US$ 15,000 for projects larger than 500 kW; and an execution guarantee of one per cent of the total project cost (Norton Rose Fulbright, 2017).

The Electrification Master Plan 2013-2022 developed by CONELEC jointly with other relevant entities plans for 25 hydropower projects totalling 4.2 GW of new capacity by 2022, as well as an additional 217 MW of solar, wind and other non-conventional renewables (IRENA, 2015).

1.3 Hydropower sector and potential

Ecuador has a gross theoretical hydropower potential of 90,970 MW, equivalent to 638,000 GWh/year (H&D, 2019), while the technically and economically feasible hydro potential figures are 189,300 GWh/year and 156,700 GWh/year, respectively (Fig. 2). CONELEC (2012) and IDB (2013) indicated different estimations for theoretical and economically feasible hydropower potential, which are 77,000 and 21,520 MW, respectively. So far, about 19.7 % of the technically feasible potential has been developed and by August 2019, Ecuador's total hydro capacity was 5,041 MW. The average annual generation from hydropower between 2006 and 2015 was 10,880 GWh/year, about 45 % of total generation. In 2018, generation from hydropower was 20,696 GWh (70.2 %), a notable increase compared with the years mentioned above.

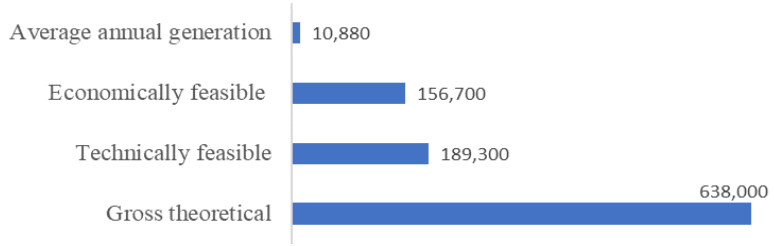

Fig. 2. Hydropower potential in GWh/year in Ecuador - 2006-2015 average annual generation (data from H&D 2019)

Based on the Government's assessment of hydropower potential (GW), Ecuador has six major river basins geographically distributed in two main regions; Pacific and Amazon (Fig. 3) (Carvajal et al., 2019). There are 31 large hydro plants (>10 MW) in operation, with a total installed capacity of 4,973 MW, while for small, mini or micro hydro plants (<10 MW) a total of 41 plants in operation with a total installed capacity of about 102 MW.

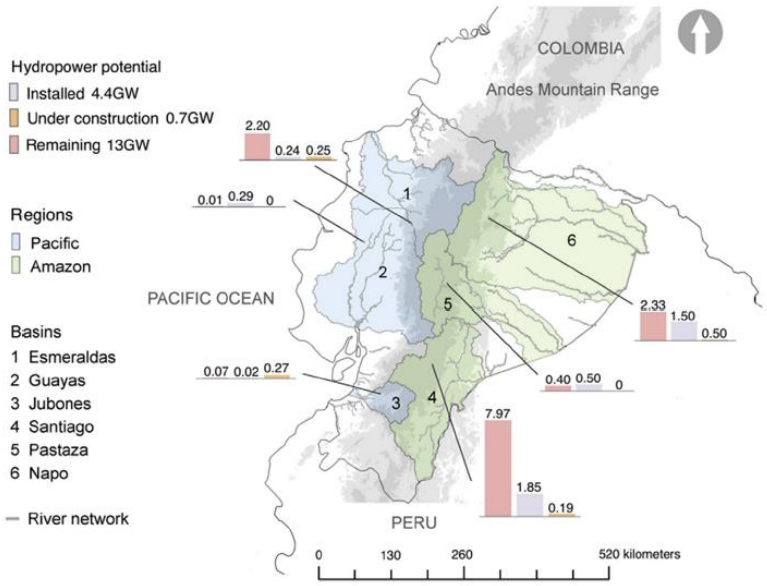

Fig. 3. Ecuador's six major river basins and geographical distribution of hydropower potential (based on MEER, 2017)

The definition of small hydropower plant (SHP) in Ecuador is up to 10 MW (WSHPDR, 2019). In practice, installations of slightly higher capacity are classified sometimes as small ones. The main features of Ecuadorian small hydro sector are presented in Table 1. Note that small hydropower potential as given in Table 1 (296.6 MW) is underestimated taking into account the fact that total hydropower potential is high (economically feasible is 25,550 MW). A preliminary assessment done by the HYPOSO project roughly estimates a SHP potential at least 5 to 10 times bigger than given in the report of WSHPDR (2019).

Table 1: Ecuador - Small hydro (<10 MW) characteristics according to different sources

References	Potential, MW	Installed capacity, MW	Number of operating SHPs	Comments
WSHPDR, 2019	296.6	98.2	37	Data at the end of 2016
H&D, 2019		~120	31	Capacity limit for SHP is unknown
HYPOSO, 2020		102	41	

2. SHP policy and market analysis

It is difficult to clearly separate small and large hydro policy and other relevant issues of the electric sector as there is no specific legalisation related to the sizes of hydropower plants in the country. A contact list of the main stakeholders involved within the hydropower sector were identified (HYPOSO D3.1, 2019).

2.1 SHP policy

Key legal documents making up the legal framework to which hydropower must comply are: Legal Legislation of Ecuador, Organic Law on Public Service of Electric Energy, Organic Law on Popular and Solidarity Economy, Environmental Organic Code, Organic Law on Water Resources, Uses and Water Development, among others.

The main permits/rights granted to use SHP in Ecuador are: 1) Authorization for Hydroelectric development issued by the MERNNR, which takes approximately 6 months to get; 2) Productive Water Use Authorization for Power Generation, issued by the National Water Secretary (SENAGUA), which takes 1 year to get and it is valid for 10 years; 3) Environmental Licence for projects, works and activities that produce medium to high impact and environmental risks, issued by the Ministry of Environment (MAE) and it is valid during the project´s life; 4) Construction License for installations on 1st and 2nd category, issued by the MERNNR and it is valid during

construction work and 5) Operation and Maintenance license. Hydropower plants smaller than 1 MW do not need environmental licence, only an environmental plan.

For more detail on these legal documents that regulate the renewable energy and hydropower as well as the regulations for granting concessions and permits please refer to the HYPOSO deliverables (HYPOSO D3.2, 2020). The small hydropower is integrated within the whole energy and hydropower sector.

2.2 Industrial and economic overview

There are at least 11 companies in the country in some degree acting in SHP consultancy, design and construction operation & maintenance, just to mention: Sedemi, ASTEC, Ingeconsul, ICA, Macroconsult, PANAVIAL, CVA, Constructora Villacreces Andrade S.A., Acotecnic, EPMAPS, Geincosolution, Hidrosierra. Hydraulic machinery manufacture is not well developed (only one contact identified so far). Some preliminary economic estimates for hydropower are presented in Table 2.

Table 1: Ecuador - Key economic estimates for hydropower

Year: 2015-2019 (average)	**Small Hydro (<10 MW)**		**Medium Hydro (10 - 50 MW)**	**Large Hydro (>50 MW)**
	Low head (<20 m)	Medium and high head*		
Average Investment Cost (€/kW)	3,017	2,907	2,068	1,481
Average O&M Cost (as % of total investment cost)	3	3	2.50	2
Average lifetime of the mechanical equipment (number of years)	25	25	20	20
Average Civil Works Cost (as a % of total investment cost)	40	50	68	64
Internal Rate of Return (Average in %)	20	20	16	26

* head in the range of 20 to 100 m and above 100 m, respectively

The cost of new hydro capacity under construction is around US$ 2,500/kW. The cost of producing a unit of electrical energy is approximately 0.048 US$/kWh in hydropower plants and 0.08 US$/kWh in other types of plants (H&D, 2019). The Ecuadorian Government implemented a feed-in tariff (FIT) scheme for renewable energy (Vargas et al. 2018) that was approved in 2013 and since then it has been awarded for a period of 15 years. For small hydropower of up to 10 MW, the FIT rate is 0.0781 US$/kWh. Since 2011, it was mandatory for FIT-sponsored renewable energy projects to contribute a part of income per each kWh generated to social and community projects (0.0189 US$/kWh for hydropower < 30 MW).

Last summer in 2019, the government started launching auctions for renewable energy projects, including small hydro installations, through which it intended to allocate around 500 MW of power generation capacity. Developers will be granted a 25-year PPA (Power Purchase Agreement), while the sole off-taker of the generated energy will be state-owned utility Corporacion Electrica de Ecuador, S.A. (CELEC).

3. SHP financing opportunities

The investment scenarios related to renewable energy projects in Ecuador are mainly concentrated in the construction and operation of hydroelectric plants, due to the great potential of the existing water resources, which depends on the beneficial natural, geographical, hydrological, and climatological conditions.

Many organizations currently finance or have financed small hydropower projects. Those organizations are national and foreign banks etc, to be mentioned just a few of them:

- Governmental entities: BIESS, MERNN;
- Local Government: EPMAPS, GAD´s (Gobiernos Autonomos descentralizados), Municipalities in each province;
- Private investment: Grupo Noboa, Caminosca (currently out of the market), Grupo Supermaxi;
- Regional Institutions: Corporación Iberoamericana de Inversiones (CII), Corporación Andina de Fomento (CAF);
- All type of foreign companies: Banco Nacional de Desarrollo Económico y Social de Brazil, Société Générale de France, Deutsche Bank, Chinese Bank (Eximbank), Agencia Francesa de Desarrollo (AFD);
- National investors: Fondo Ecuatoriano de Inversión en los Sectores Estratégicos e Hidrocarburífero (FEISEH), Constructora Nacional;
- Others: cooperation agreements,

4. Environment

The provision of basic services such as water and electricity are responsibility of the Government, through the public companies; however, it is possible for private companies to invest in renewable energy projects. The institution responsible for the water management is the National Secretariat of Water (Secretaría Nacional de Agua, SENAGUA). The Ecuadorian Constitution put special emphasis on the environmental protection in all fields of development, but in particular the ones related to water resources development. Environmental legislation relating to hydro projects is outlined in the Estudios de Impacto Ambiental Preliminar y Definitivo (Preliminary and Final Studies on Environmental Impact).

The participation of local people in new power projects is actively encouraged, in fact State policy dictates that communities and neighbouring towns may participate in, and benefit from new projects. However, some community opposition remains, particularly regarding private and large hydro projects. The Ministry of Energy and Non-Renewable Natural Resources (MERNNR) is working with ARCONEL to raise awareness of the importance of dams and hydro plants, and the benefits they can bring to communities and the country as a whole.

5. Barriers to SHP development

While the Ecuadorian Ministry of Electricity and Renewable Energy is making considerable efforts to ensure higher reliability and resilience of the energy sector, there are still a number of challenges with regard to SHP adoption, as outlined below (WSHPDR, 2019):

- Lack of detailed data regarding to economic and technical potential of SHP affects investment decisions and policies in the sector;
- Lack of technical capabilities and knowledge to ensure effective integration of small hydropower technology into the power system;
- Dependency on large hydropower makes larger projects a priority for the Government and limits the interest in small hydropower investment;
- Lack of reliable information for the private sector and for international investors due to most data available being based on theoretical predictions, increases uncertainty in the planning process.

There is a need to define a more comprehensive strategy on small hydropower project implementation and on encouraging future public-private partnerships. Progress regarding environmental awareness, social acceptance, and cultural justice, is still needed to ensure the rural electrification sustainability efforts in small indigenous communities in the Amazon basin (Feron et al., 2016).

6. Future prospects

As of 2019, the following SHP projects were under construction or prepared to go ahead on construction soon (HP&D, 2019).

Under construction are:

- Mazar Dudas San Antonio (7.2 MW), CELEC EP - Hidroazogues, public funds, expected to begin operation in 2020.

- San Jose de Minas (6 MW), Hidroelectrica San Jose de Minas SA, private funds, expected to begin operation in 2020.
- Chorrillos (4 MW), Hidrozamora EP, public funds, expected to begin operation in 2022.

Next to go ahead for construction are:

- Maravilla (9 MW), Hidroequinoccio EP, public funds, expected to begin operation in 2021.
- Chalpi Grande (7.6 MW), EPMAPS EP, public funds, expected to begin operation in 2021.
- Mazar Dudas Dudas (7.4 MW), CELEC EP - Hidroazogues, public funds, expected to begin operation in 2021.
- El Laurel (1 MW), CBS Energy SA, private funds, expected to begin operation in 2021.
- Ulba (1 MW), Hidroulba SA, private funds, expected to begin operation in 2021.
- Others: Soldados (7.20 MW), Chorrillos (4 MW), expected to begin operation in 2022

Around 40 SHP projects with a total capacity of 225 MW already completed the final design stages and are ready to go ahead for construction (Fig. 4). A number of pilot projects for pico hydro have been carried out. The experience acquired in applying this technology will be used in the future helping thus rural communities in gaining access to electricity.

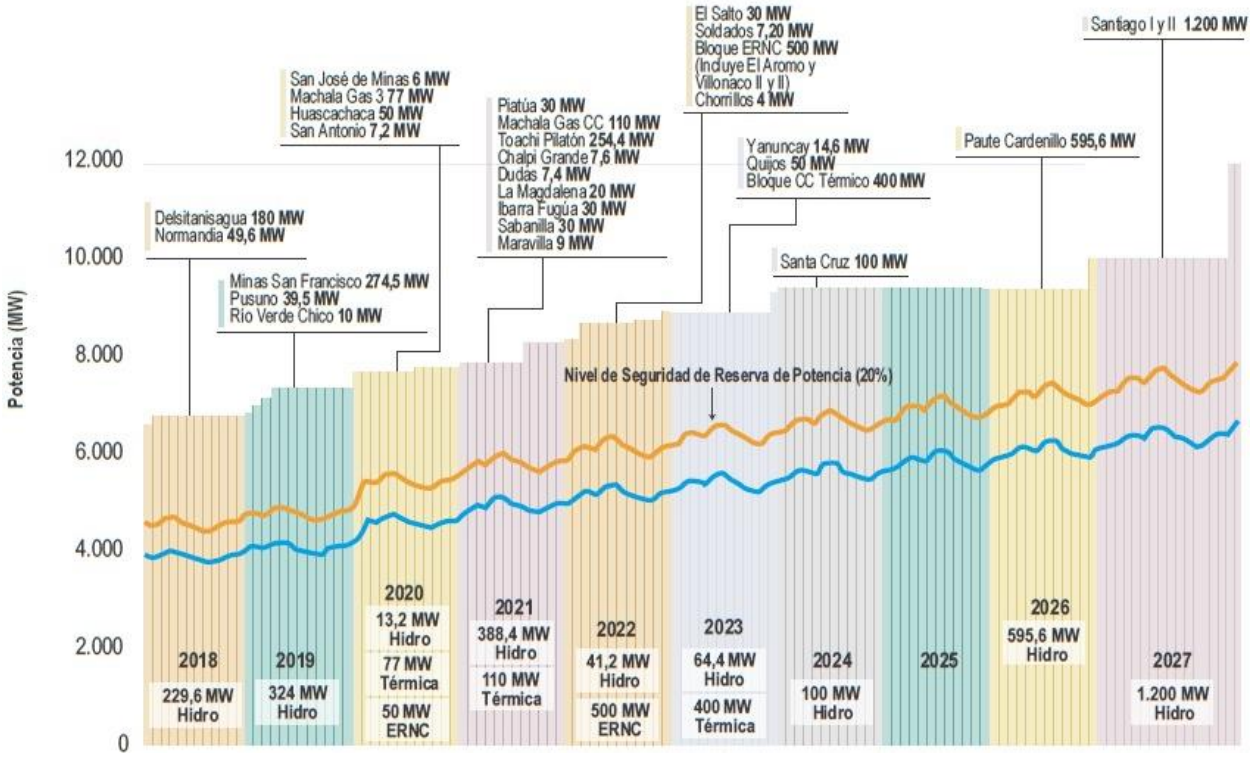

Fig. 4: Ecuador - Sequence of projects that will be implemented until 2027 (MERNN, 2019)

7. Acknowledgement

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Patricia Haro graduated as Civil Engineer (2007) and later obtained a MSc in Water Resources Engineering (2010) at the Escuela Politécnica Nacional (EPN), Ecuador. From 2008 to 2014, she worked for the Ministry of Electricity and Renewable Energy (MEER) and supervised hydroelectric projects as: Sopladora (487 MW), Manduriacu (65 MW), Minas – San Francisco (270 MW). In 2019, she obtained her PhD at Universidad Politécnica de Cartagena (UPCT), Spain. At the moment, she is working as a full-time assistant professor at EPN in Quito – Ecuador, giving lectures related to hydraulic structures as bottom rack derivation systems and energy dissipators and coordinating the MSc programme in Hydraulic Engineering.

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