Hydropower Solutions

HYPOSO

Hydropower solutions for developing and emerging countries

Framework analysis and research needs in Ecuador (part of HYPOSO D3.2)

by Veronica Minaya, EPN, Ecuador

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Ecuador

1 Key facts

Population	17.3 million	August 2019 estimate
Area	283,561 km^2	
Access to electricity	97.05 %	2018
Installed hydro capacity	5,282 MW	2018
Hydro capacity under construction	324 MW	2019
Share of generation from hydropower	62.58 %	2018
Hydro generation	20,671 GWh	2018
Economically feasible hydro generation potential	156,700 GWh	1997
Small hydropower potential	297 MW	1997
Small hydropower installed capacity	120 MW	2019

Ecuador is located on the west coast of South America and is crossed by the equator. It has a length of 714 km north–south and a width of 658 km east-west. Ecuador borders Colombia on the north, Peru on the east and south, and the Pacific Ocean on the west.

1.1 Climate

The climate varies with the region, most of the northern coast consists of wet, tropical forest, increasingly humid environment. In the Guayaquil 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. The climate of the central plateau is governed mainly by the altitude. The capital, Quito, located at 2,850 m a.s.l., enjoys perpetual spring, 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, or highland meadow. The higher areas rise to peaks above 5,200 m a.s.l. that are perpetually covered with snow.

1.2 Topography

Ecuador is characterized by three distinct regions: the coast; the highlands, or Sierra; and the eastern interior lowlands, or Oriente. The coast, except for a hilly area west of Guayaquil, is a low alluvial plain, comprising about one-quarter of the country territory. It extends from sea level to the base of the Cordillera Real of the Andes, at an elevation of about 460 m a.s.l. The Guayas in the center west and the Esmeraldas in the northwest form the principal river systems.

The highlands constitute another quarter of the country. This region is formed by two parallel ranges of the Andes, from 110 to 290 km wide, and the intervening narrow central plateau, nearly 640 km long. This inter-Andean plateau is 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 Oriente, forming part of the upper Amazon Basin, begins at the base of the Andes at about 1,200 m a.s.l..

1.3 Water resources

Mean annual precipitation ranges between 200 mm and approximately 5,000 mm, depending on the region.

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. Narrow in the highlands, the majority of the rivers broaden as they reach the lower elevations of the Coast and Oriente.

A representative indicator of the hydroelectric potential of a country is the density of hydropower potential or relative potential, defined as the technical hydropower potential (or sometime gross theoretical) per area unit (square of kilometre) of the country. For Ecuador it is estimated to be very high - 0.74 GWh/(year·km^2). To compare, for Austria and Norway this specific indicator is around 0.66, for Brazil - 0.15 GWh/(year·km^2).

2 Power sector overview

One decade ago, Ecuador 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 will 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) (Figure 1).

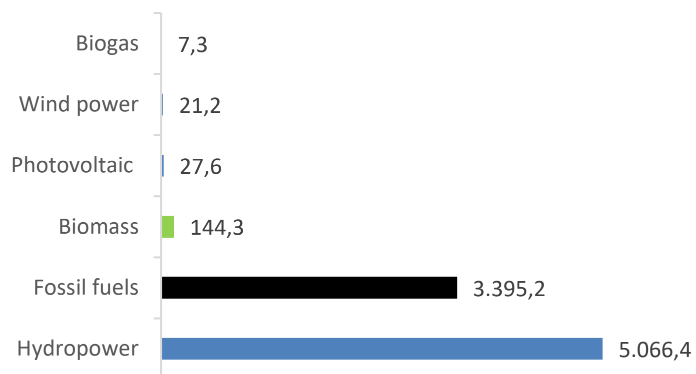

Figure 1: Ecuador - Effective installed capacities of the Ecuadorian power system in MW (ARCONEL, 2018)

On 1 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. The law is called the Organic Law for the Public Service of Electricity. According to this legislation, ARCONEL (*Agenda 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. A state-owned company, *Corporation Electrica del Ecuador*, CELEC (Electrical Corporation of Ecuador), groups together the main electricity companies.

3 Renewable electricity policy

Ecuador's 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).

In the 2000–2015 period, Ecuador had a feed-in tariff system to support renewable electricity deployment. 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). The feed-in tariff evolved over time in terms of duration, rates and technologies included. 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).

4 Hydropower sector and potential

Ecuador has a gross theoretical hydropower potential of 90,970 MW, equivalent to 638,000 GWh/year (H&D, 2019). The economically feasible installed capacity is 25,550 MW. CONELEC (2012) and IDB (2013) indicate a bit different estimates of theoretical and economically feasible hydropower potential – 77,000 and 21,520 MW, respectively.

The technically and economically feasible hydro potential figures are 189,300 GWh/year and 156,700 GWh/year, respectively. All these data were evaluated in 1997. So far, about 19.7 % of the technically feasible potential has been developed. Ecuador's total hydro capacity was 5,041 MW in August 2019.

The average annual generation from hydropower between 2006 and 2015 was 10,880 GWh, about 45 % of total generation. In 2018, generation from hydro was 20,696 GWh (70.2 %), a notable increase compared with the years mentioned above.

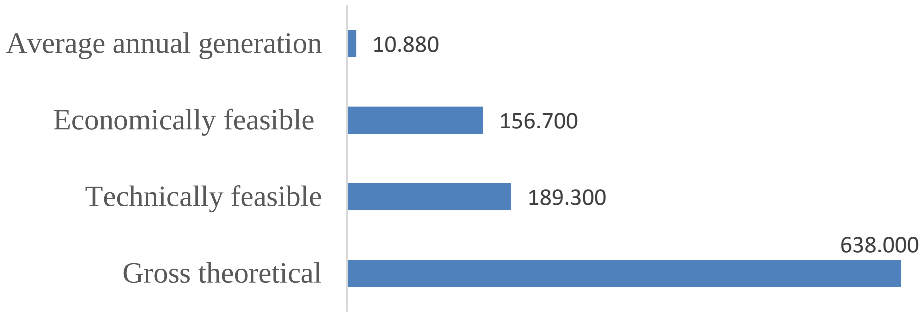

Figure 2: Hydropower potential in GWh/year in Ecuador - 2006-2015 average annual generation (data from H&D 2019)

Ecuador's six major river basins and geographical distribution of the Government's assessment of hydropower potential (GW) in two main regions - Pacific and Amazon, are shown in Figure 3 (Carvajal et al., 2019):

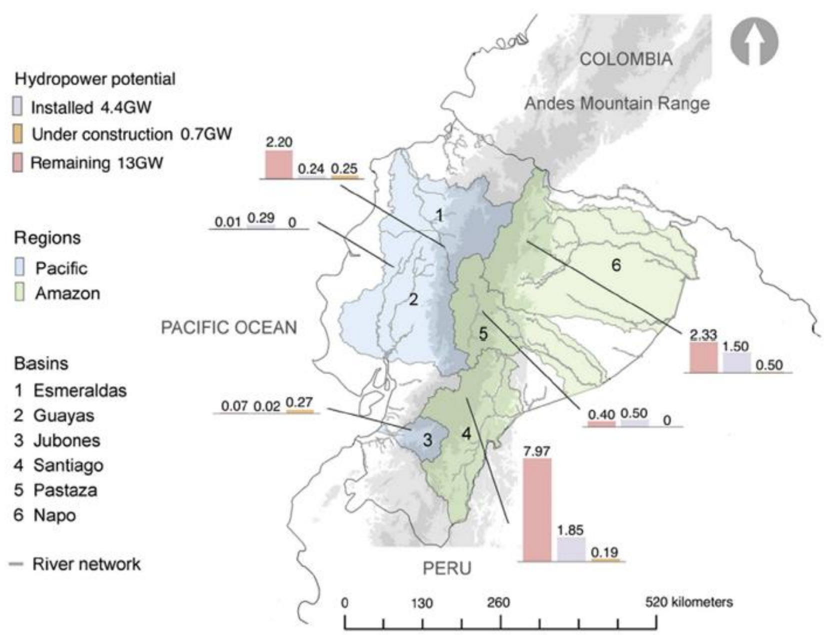

Figure 3: Ecuador's six major river basins and geographical distribution of hydropower potential of the Government's assessment (based on MEER, 2017)

There are 31 large hydro plants (>10 MW) in operation, with a total capacity of 4,973 MW (Figure 4).

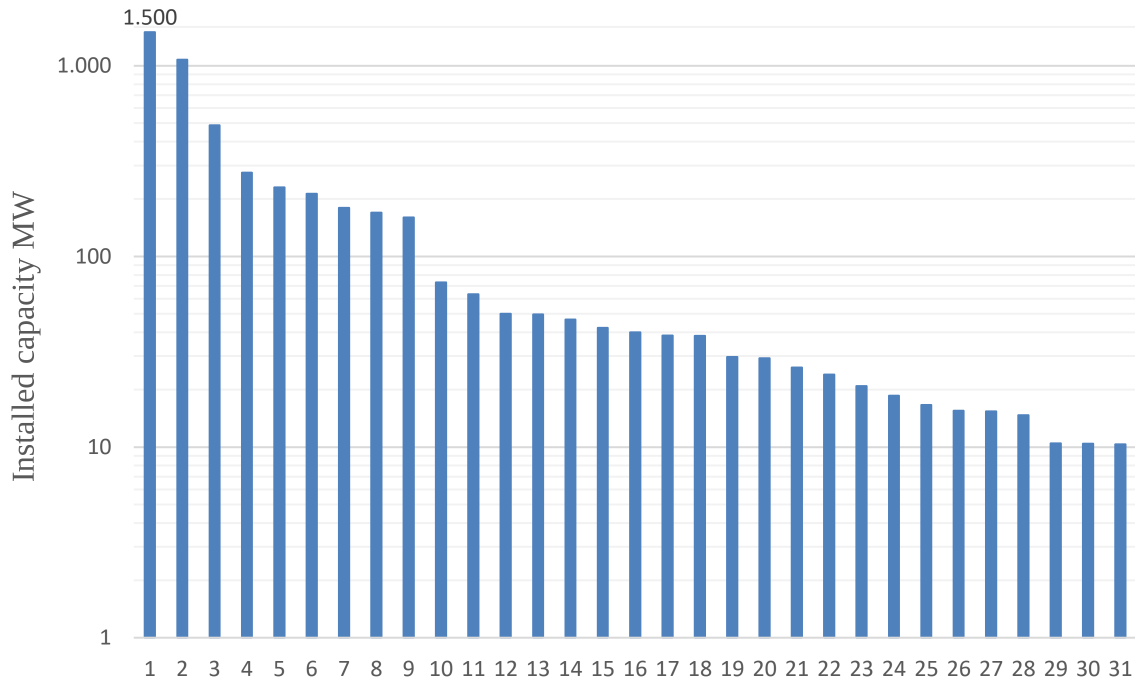

Figure 4: Operational large hydropower plants (P > 10 MW) in Ecuador as sorted by their installed capacity

There are 41 small, mini or micro hydro plants (<10 MW) in operation, with the total capacity of about 102 MW (Figure 5).

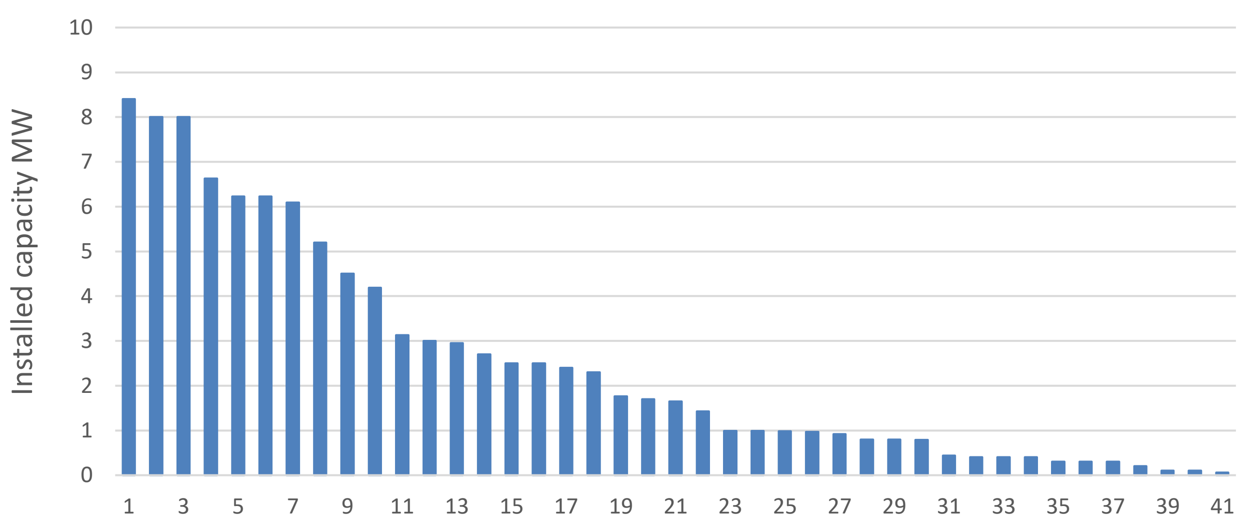

Figure 5: Operational small hydropower plants (P < 10 MW) as sorted by installed capacity in Ecuador

The definition of small hydropower 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.

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		102	41	

It should be pointed out that SHP potential as given in this table (296.6 MW) is obviously underestimated taking into account the fact that total hydropower potential is so abundant (the economically feasible is 25,550 MW). SHP potential must be roughly at least 5 to 10 times bigger than given in the report of WSHPDR (2019). This approach to make a preliminary assessment is based on the “rule of thumb” but substantiated by practical experience.

5 SHP policy and market analysis

Micro or small hydro power is not a radically new technology in Ecuador. Micro hydro was already used centuries ago to generate mechanical power. 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 and therefore electricity was not a capable of promoting Ecuador's economic and technical take off. The installed capacity was insufficient. 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). 35 % of the population were supplied with electricity generated in 60 % by thermal power plants and in 40 % by hydroelectric installations. The country 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. For the period 1971-1985, the focus was on taking advantage of the river flows to generate hydroelectric power, which was probably the optimum approach from various points of view. It foresaw developing two types of networks: the National Interconnected System, with 4 large selected hydroelectric projects (Pisayambo, Paute, Toachi and Montúfar) and the Regional Electric Systems. In 2008, in order to avoid electricity shortages, having occurred in the period 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 that 93 % of hydroelectric, a clean and renewable energy production system.

It is difficult to clearly separate small and large hydro policy and other relevant issues of the sector as there is no in the country specific legalisation related to the sizes of hydropower plants, moreover as their nature is the same, they usually overlap each other.

Some 19 contacts of stakeholders involved in one or another way in the hydropower sector were identified in Ecuador (HYPOSO D3.1, 2019).

5.1 SHP policy

The small hydropower is integrated within the whole energy and hydropower sector. Notwithstanding this, mostly small hydro policy will be highlighted herewith. Key legal documents making up the legal framework to which hydropower must comply are listed in Table 2.

Regulations for granting rights (concessions or permits) to use hydropower in Ecuador are summarized subsequent in Table 2.

Table 2: Ecuador - Key legal documents regulating RES and hydropower

Name of legal document	Name of legal document	Type	Website	Summary and Impact on development of Hydropower (small or large)
Constitución de la República del Ecuador. Registro Oficial No. 449 (20 Oct,2018; última modificación 13 Jul,2018)	Constitution of the Republic of Ecuador. Official Record 449 (20 Oct,2018; latest amendment 13 Jul,2018)	National	https://www.planificacion.gob.ec/wp-content/uploads/downloads/2016/02/Constituci %c3 %b3n-de-la-Rep %c3 %bablica-del-Ecuador.pdf	Legal Legislation of Ecuador
Ley Orgánica del Servicio Público de Energía Eléctrica - LOSPEE. Registro Oficial No 418 (16 Ene,2015; última modificación 20 Aug,2018)	Organic Law on Public Service of Electric Energy (LOSPEE -Spanish initials) Official Record 418 (16 Jan,2015; latest amendment 20 Aug,2018)	Energy	http://www.cenace.org.ec/index.php?option=com_phocadownload&view=category&id=25:lospee&Itemid=1	Private participation mechanisms, procedures for authorizations of hydropower plants´ operation and grants.
Ley Orgánica de Servicio Público - LOSEP. Registro Oficial No 249 (06 Oct,2010; última modificación 11 Jun, 2015)	Organic Law on Public Service (LOSEP-Spanish Initials). Official Record 249 (06 Oct,2010; latest amendment 11 Jun, 2015)	Public Service	https://www.planificacion.gob.ec/wp-content/uploads/downloads/2016/02/Ley-Org %c3 %a1nica-de-Servicio-P %c3 %bablico-LOSEP.pdf	Regulation of power generation service for public companies.
Ley Orgánica de Empresas Públicas-LOEP. Registro Oficial No 48 (19 May,2017; última modificación 19 May,2017)	Organic Law on Public Companies (LOEP-Spanish initials). Official Record 48 (19 May,2017; latest amendment 19 May,2017)	Public Companies	https://www.planificacion.gob.ec/wp-content/uploads/downloads/2016/02/Ley-Org %c3 %a1nica-de-Empresas-P %c3 %bablicas-LOEP.pdf	Regulation of power generation for public companies.

Ley Orgánica de Economía Popular y Solidaria (LOEPS). Registro Oficial No 444 (10 May,2011; última modificación 23 Oct,2018)	Organic Law on Popular and Solidarity Economy (LOEPS-Spanish Initials). Official Record 444 (10 May,2011; latest amendment 23 Oct,2018)	Public Companies	https://www.seps.gob.ec/interna-npe?760	Regulation of financial system for public companies.
Código Orgánico del Ambiente. Registro Oficial Suplemento 983 (12-abr-2017- vigente)	Environmental Organic Code. Official Record Supplement 983 (12-abr-2017- current)	Environmental	https://www.ambiente.gob.ec/wp-content/uploads/downloads/2012/09/REGLAMENTO-AMBIENTAL-PARA-ACTIVIDADES-ELECTRICAS.pdf	Environmental Code for power generation activities.

Table 2: Key legal documents regulating RES and hydropower (continued)

Name of legal document	Name of legal document	Type	Website	Summary and Impact on development of Hydropower (small or large)
Reglamento a Ley Organica del Servicio Público de Energia Electrica. Excecutive Order 856. Registro Oficial Suplemento 21 (23 Ago,2019 - vigente)	Regulation of the Organic Law on Public Service of Electric Energy. Excecutive Order 856. Official Record Supplement 21 (23 Aug,2019 - current)	Energy	http://www.eeq.com.ec:8080/documents/10180/24600913/REGLAMENTO+A+LA+LEY+ORG %C3 %81NICA+DEL+SERVICIO+P %C3 %9ABLICO+DE+ENERG %C3 %8DA+EL %C3 %89CTRICA/d3f53b87-ac86-4fca-90fc-93f4fdd6534a	Regulation that applies the LOSPEE Law.
Ley Orgánica de Recursos Hídricos, Usos y Aprovechamiento del Agua (LORHUYA). Registro Oficial No 305 (06 Ago,2014)	Organic Law on Water Resources, Uses and Water Development (LORHUYA-Spanish Initials). Official Record 305 (06 Aug,2014)	Water Management	http://www.regulacionagua.gob.ec/wp-content/uploads/2019/06/Ley-Org %C3 %A1nica-de-Recursos-H %C3 %ADdricos-Usos-y-Aprovechamiento-del-Agua.pdf	Water Uses and Management. Control water use authorization.
Reglamento Ley Recursos Hídricos Usos y Aprovechamiento del Agua. Decreto Ejecutivo No. 650. Registro Oficial Suplemento 483 (20 Abr, 2015; última modificación: 21 Ago, 2015)	Regulation of the Organic Law on Water Resources, Uses and Water Development. Excecutive Order 650. Official Record Supplement 483 (20 Apr, 2015; latest amendment: 21 Aug, 2015)	Water Management	https://www.agua.gob.ec/wp-content/uploads/2012/10/REGLAMENTO-LEY-RECURSOS-HIDRICOS-USOS-Y-APROVECHAMIENTO-DEL-AGUApdf.pdf	Regulation to apply the LORHUYA Law.

Table 3: Conditions for granting rights (concessions or permits) to use hydropower in Ecuador

Concessions	Small Hydro (P < 5 MW)		Medium Hydro (5 MW < P < 50 MW)		Large Hydro (P > 50 MW)	
	New permits	Refurbishment or Relicensing	New permits	Refurbishment or Relicensing	New permits	Refurbishment or Relicensing
a) Type of permits needed & average time	Authorization for Hydroelectric development Responsible Entity: Ministry of Energy and Non-renewable resources (MEERNNR) (0.5 years' time to get it) "Productive Water Use Authorization for Power Generation" Responsible Entity: National Water Secretary (SENAGUA). It takes 1-year time to get it, validity for 10 years "Environmental Licence for projects, works and activities that produce high and medium impact and environmental risks". Responsible Entity: Ministry	Just for productive water use. Authorization for power generation. Responsible entity: SENAGUA, validity for 10 years	Authorization for Hydroelectric development Responsible Entity: Ministry of Energy and Non-renewable resources (MEERNNR) (0.5 years' time to get it) "Productive Water Use Authorization for Power Generation" Responsible Entity: National Water Secretary (SENAGUA). It takes 1-year time to get it, validity for 10 years" "Environmental Licence for projects, works and activities that produce high and medium impact and environmental risks. Responsible Entity:	The same	Authorization for Hydroelectric development Responsible Entity: Ministry of Energy and Non-renewable Resources (MEERNNR) (0.5 years' time to get it)" "Environmental Licence for projects, works and activities that produce high and medium impact and environmental risks. Responsible Entity: Ministry of Environment (MAE), validity: during the useful life." "Construction License for installations on 1st and 2nd category" Responsible Entity:	The same

	of Environment (MAE), validity: during the useful life.		Ministry of Environment (MAE), validity: during the useful life."		MERNNR, validity: during construction" Operation Permit and Maintenance Licence	
	Hydropower plants < 1 MW don´t need environmental licence, just an environmental plan." "Construction License for installations on 1st and 2nd category" Responsible Entity: MERNNR, validity: during construction" Operation Permit and Maintenance Licence		"Construction License for installations on 1st and 2nd category" Responsible Entity: MERNNR, validity: during construction" Operation Permit and Maintenance Licence			
b) Number of plants granted during the period	No small hydropower plants were registered		21 hydropower plants (from 6.2 MW to 49.7MW)		3 hydropower plants (from 180 MW to 275 MW)	

5.2 Industrial and economic overview

According to various sources, the number of existing SHP plants is confined between 31 and 41 with the total installed capacity 101 MW (see Table 1). The final design studies were conducted for some 40 SHP projects with total capacity of 225 MW.

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 4.

Table 4: 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).

Ecuador is one of the very few Latin American countries that implemented a feed-in tariff (FIT) scheme for renewable energy (Vargas et al. 2018). The FIT scheme was approved in 2013 by the Government of Ecuador. 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.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 857851.

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, Ecuador's 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, while the sole off-taker of the generated energy will be state-owned utility Corporacion Electrica de Ecuador, S.A. (CELEC).

6 Educational framework

There is no narrowly specialised hydropower or hydropower engineering study program in the country education system. Hydropower is usually part of civil, renewable or environmental engineering. Out of 59 universities in Ecuador 23 universities in the country are offering study programs that include water related subjects which constitutes a necessary background for hydropower engineering (Table 5).

Table 5: List of universities in Ecuador offering water and hydraulic engineering related subjects

No	University	Topics included in syllabus	Basic knowledge courses
1.	Escuela Politécnica Nacional (Civil Eng.)	Hydraulic projects, hydraulic structures	Hydraulics, hydrology, economic evaluation
2.	Universidad Central del Ecuador (Civil Eng.)	Hydraulic projects, hydraulic structures	Hydraulics I, II and III, hydrology, economic evaluation, fluid mechanics, civil works.
3.	Escuela Politécnica del Litoral (Civil Eng.)	Hydraulic projects, hydraulic structures	Hydraulics, hydrology, economic evaluation, fluid mechanics, civil work management
4.	Universidad de Cuenca (Civil Eng.)	Hydraulic design	Hydraulics I, hydraulics II, hydraulic design
5.	Universidad Politécnica Salesiana (Civil Eng.)	Same as above	Hydraulics I & II, hydrology, economic evaluation, hydrology, applied hydrology, hydraulic works
6.	Universidad Católica del Ecuador (Civil Eng.)		Hydraulics, hydrology, economic evaluation

7.	Universidad San Francisco de Quito (Civil Eng.)		Fluid mechanics, hydraulic and laboratory
8.	Escuela Politécnica del Ejército (Civil Eng.)		Hydrology, Fluid mechanics, Hydraulics I, Hydraulics II, Civil works, Hydraulics structures, Construction Regulatory Framework, Building technics.
9.	Universidad Técnica del Norte (Renewable Energy Eng.)		Geology, geomorphology, hydraulic energy, economical energy, electric and hydraulic machines, applied hydropower, energy legislation, transport and energy distribution, energy systems simulation
10.	Universidad Católica de Santiago de Guayaquil (Civil Eng.)		Hydraulics I & II, Hydrology, Hydraulic design
11.	Universidad del Azuay (Civil Eng.)		Hydrology, Hydraulics, Civil works.
12.	Universidad Estatal de Milagro UNEMI (Environmental Eng.)		Hydraulics, fluid mechanics, renewable energy
13.	Universidad Nacional de Loja (Environmental Eng.)		Hydrology, Hydraulics, Alternative energies.
14.	Universidad Estatal del Sur de Manabí (Civil Eng.)		Hydraulics I, II, Applied Hydraulics I & II, Hydrology, hydraulic projects
15.	Universidad Espíritu Santo (Civil Eng.)		Fluid mechanics, hydraulic works
16.	Universidad Internacional SEK (Civil Eng.)		Hydrology, Fluid mechanics, Hydraulic works, Water conduction systems.
17.	Universidad Técnica de Ambato (Civil Eng.)		Fluid mechanics, Hydrology, Applied hydraulics I & II, Computerized Design Hydraulics
18.	Universidad Técnica Particular de Loja (Civil Eng.)		Fluid mechanics, hydrology, Hydraulic Engineering I & II

19.	Universidad Técnica Equinoccial UTE (Civil Eng.)		Fluid mechanics, Water intake and conduction, Sustainable project management
20.	Universidad Estatal Amazónica (Environmental Eng.)		Hydraulics, Water basins management, Alternative energies
21.	Universidad Estatal Península de Santa Elena (Civil Eng.)		Hydrology, Hydraulics, Applied hydraulics.
22.	Universidad Católica de Cuenca (Civil Eng.)		Fluid mechanics, Hydrology
23.	Universidad Técnica de Machala (Civil Eng.)		Fluid mechanics, Hydraulics, Hydrology, Hydraulic design

There are also some engineering unions associations specialising in civil and mechanical engineering (e.g., *Colegio de Ingenieros Civiles de Pichincha* and *Colegio de Ingenieros Mecanicos*).

A few suggestions to improve hydropower studies are given in Table 6.

Table 6: Ecuador - Detected needs for improving hydropower studies

No	University	Detected needs
1.	Escuela Politécnica del Litoral	To integrate the main parts of the hydropower (Civil structures, electromechanical devices)
2.	Escuela Politécnica Nacional	Sediment transport, environmental studies, ecological flows

There are some organised training workshops or specialised courses in civil engineering for the staff of hydropower plants for civil engineers, and separate courses for electrical engineers. For mechanical engineering, they have also specific courses.

It would be ideal to have a complete integrated hydropower project with all the components that students from different fields (civil, electrical and mechanical eng.) could develop in the framework of their study course.

There is no specific course for hydropower or any topic related in the new syllabus for civil engineering at public universities. A couple of months ago, the Higher Education Council (abbreviation in Spanish - CES) sent a new reform to all public institutions to reduce the number of semesters in the study program (from 9 to 8 semesters and a maximum load of 15 credits per semester). This means that lots of courses had to be merged or removed. in the civil engineering study program, most of the subjects related to water resources have gone through this change and civil engineering has been modified to be more focused on structural design.

only a few subjects for basic knowledge in hydrology or hydraulics have been kept but very difficult that hydropower education can be taught in more detail.

That is why it is important that courses and training workshops in hydropower studies are developed to cover the gap of this new overhaul that affects the study field in hydropower.

7 Research situation and needs

7.1 R&D projects

In this project, the definition of R&D goes beyond its pure conception. Taking into account the practical issues and particular situation in the research field of the target countries, the term of Innovation (R&I) was added. Although the conception of R&D is not always the same as R&I and vice versa, here we assume their interchangeability.

In total, some 29 R&D projects were identified conducted over the period of 2013 to 2019 (Table 7). Twelve of them are dealing with medium or large hydro, only one is a demonstration project.

Almost all the projects were conducted by universities, most frequently by *Escuela Politécnica Nacional* (EPN). No fundamental research (also known as basic research or pure research) elements have been identified. Although for some applications the state-of-the art numerical modelling (CFD, 3D Flow) is used.

Table 7: Ecuador - List of R&D topics, their number and key words (based on conducted survey)

No	R&D project topic/ category	Quantity	Key words
1.	General, administrative and marketing aspects	1	Renewable energy, energy mix scenarios
2.	Know-how and information dissemination	7	System reliability, Business Management Solutions, Automated Control, Economic Management, Life cycle analysis, 3D flow modelling
3.	Multipurpose projects and rehabilitation	2	Flood risk mitigation, Hydropower plant
4.	General design, civil work & engineering	7	3D Numeric Modelling, Flow energy dissipation
5.	Weirs and water storage/reservoirs	2	Advanced weir design, Reservoir rule curves,
6.	Methods and equipment for construction, maintenance, repair and overhaul of hydro plants	3	Electric Protection, dam, Flow energy dissipation,
7.	Electromechanical equipment	6	Dynamic programming, Electrical System
8.	Turbines	5	Numerical Methods, CFD, Fluid Dynamics, Fluid Mechanic, Turbomachines, Pumps
9.	Electrical equipment	2	Generators
10.	Control & monitoring	6	SCADA System, Control algorithm, Voltage variations, Losses, Automation.
11.	Environment integration, EIA, hydropower social acceptance	2	Flood risk mitigation, Psychosocial risk.

In the past *Universidad de Cuenca* was one of four main universities in Ecuador that carried out studies for the government in 2006 of 23 hydroelectric projects totalling 168 MW. Later, Ecuador's Power and Renewable Energy Ministry has signed a contract with this university to carry out feasibility studies of four small hydroelectric projects totalling 29.3 MW. This fact clearly shows that knowledge level and expertise for designed hydropower plants in the country is quite sufficient.

7.2 Research needs

The survey conducted in Ecuador revealed the following research topics to be undertaken in the future, but not limited to:

1. Sediment management in civil works for hydropower plants;
2. Solid flow production in Andean micro-basins;
3. Sediment transport in mountainous rivers and increased downstream sediment concentration due to operation of hydropower plants.
4. Hydrologic variability and climate change in high elevation mountain rivers;
5. Geological information survey in micro-basins;
6. Lahars transit effects on potential hydropower sites (threat levels, alternative approaches);
7. Promotion of hydraulic modelling for civil works optimization (water intake, desilting basin);
8. Electro mechanical equipment for small hydropower plants;
9. Environmental flow assessment in different micro-basins;
10. Sharing best practices of international environmental policies to be potentially applied in Ecuador
11. Downstream channel stability and environmental impact due to flow releases of dams and reservoirs (including hydropeaking issues);

8 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,

Different companies are in charge of the development of SHP projects. *Hidrosierra* S.A. supervises the installation of a small hydropower plant of 10 MW. *Hidroequinoccio* EP was also awarded a 10 MW hydropower project which. CELEC EP will be supervising construction of two plants, one of 7.19 MW and another of 4 MW. Lastly, San Jose de Minas S.A. is in charge of construction of a 5.95 MW power plant (WSHPDR, 2019).

9 Environment

The provision of basic services such as water and electricity are the responsibility of the State. The government entity responsible for water management is the National Secretariat of Water (*Secretaría Nacional de Agua*, SENAGUA). Responsibility was delegated to public companies, and it is possible for private companies to invest in renewable energy projects.

Ecuador's new constitution places special emphasis on environmental protection in all fields of development, but in particular in relation 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. State policy dictates that communities and neighbouring towns may participate in, and benefit from, new projects. The Ministry of Energy and Non-Renewable Natural Resources 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. Some community opposition remains, particularly regarding private and large hydro projects.

10 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 with regard to economic and technical potential of SHP in Ecuador 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 substantially the planning process uncertainty.

There is a need to define a more comprehensive strategy on small hydropower project implementation and on encouraging future public-private partnerships.

The sustainability of rural electrification programs in Ecuador, paying special attention to programs targeting small indigenous communities in the Amazon basin was analysed (Feron et al., 2016). They conclude that progress regarding environmental awareness, social acceptance, and cultural justice, is still needed for ensuring the sustainability of rural electrification efforts in the Ecuadorian Amazon basin.

11 Future prospects

11.1 Large Hydro

According to the studies carried out by the National Institute of Energy Efficiency and Renewable Energy, the total energy demand between 2013 and 2050, will increase from 14 % to 24 %, respectively. For this analysis scenario, the most important hydroelectric projects, which currently cover the national demand, have been considered to achieve an installed capacity of 33,854 MW in the year 2050.

The MERNNR announced the Government's target to have 80 per cent of the country's electricity supplied from renewable sources, mainly hydropower. The construction of new plants will be conducted with great emphasis on environmental protection, in accordance with existing guidelines. Priority will be given to private enterprises to develop hydro projects, solar PV, wind, biomass, biogas and other possible renewable energy installations as well.

Currently the largest investment in hydropower projects, focuses on projects of medium and large capacity, which must be financed economically with foreign credits from countries that have agreements with the government. For instance, large hydropower plants have been recently financed by the *Chinese Exim Bank* and built by the *Sinohydro Corporation*.

Even when they do not always show the best economic conditions, these credits will be used for the construction of this type of strategic projects. It is important to point out that foreign investment, both in the public and private sectors, becomes the base on which several hydroelectric, and other kind of infrastructure projects have been developed. It should be considered that the investment is directly influenced by the economic situation of the country, but also by political, technical, social, environmental aspects, among others.

The project findings show, that at least 100 hydropower project studies were carried out in the country, which resulted in the total power capacity exceeding 4,150 MW, out of which some 40 projects fall under the fleet of small-sized plants with a total capacity 225 MW. The country expects to meet the national domestic energy demand and export surplus energy to Colombia and Peru.

ANDRITZ HYDRO, an EU based global supplier of electromechanical systems, has a long history in Ecuador. Their equipment for HPP Riobamba was delivered back in 1923. Since then this manufacturer delivered and rehabilitated more than 60 units with a total output of about 2,000 MW, representing an impressive 88 % of the nation’s hydropower capacity.

11.2 Small hydro

As of 2019, the following SHP projects were under construction or prepared to go ahead on construction very 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), *Hidroulb*a SA, private funds, expected to begin operation in 2021.
- Others: Soldados (7.20 MW), Chorrillos (4 MW), expected to begin operation in 2022

As it was mentioned above, some 40 SHP projects with a total capacity of 225 MW already completed the final design stages and are ready to go ahead for construction (Figure 6).

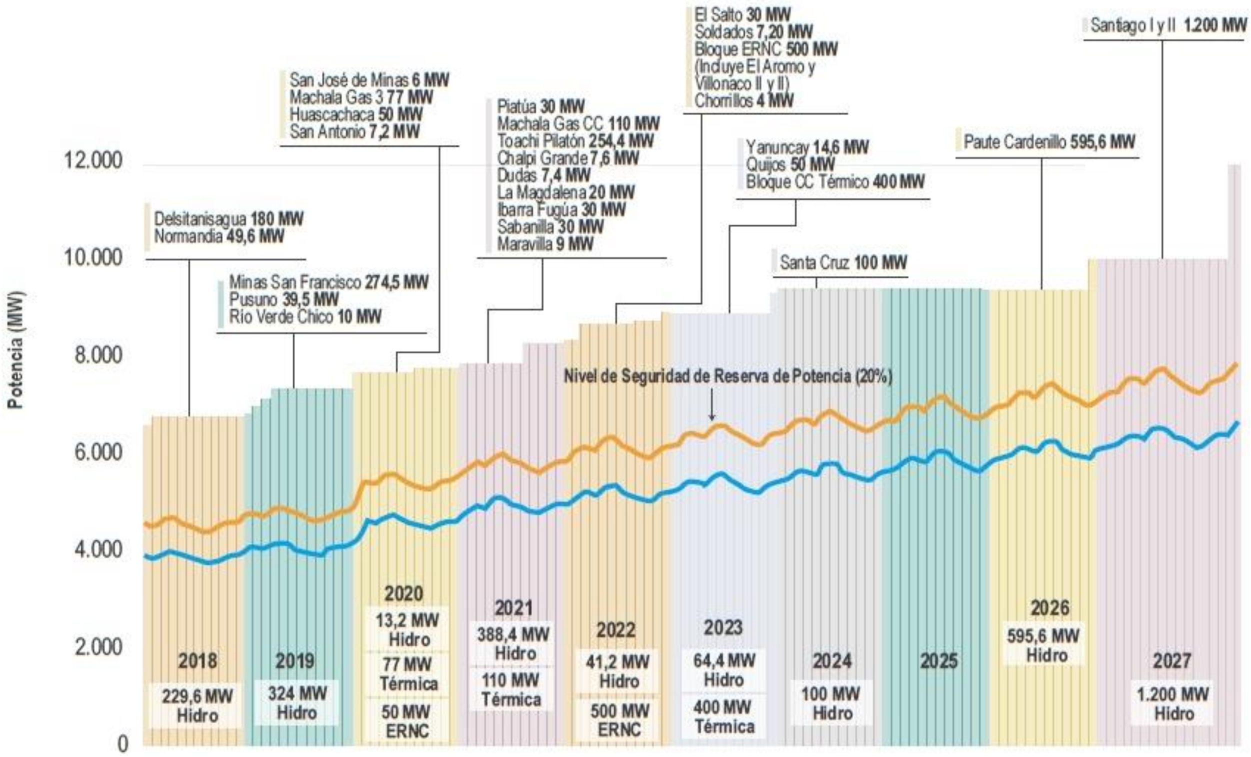

Figure 6: Ecuador - Sequence of projects that will be implemented until 2027 (MERNN, 2019)

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.

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