Hydropower Solutions

HYPOSO

Hydropower solutions for developing and emerging countries

D3.2
Report on framework analysis and research needs in five target countries

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1 Introduction

HYPOSO is a multi-approach project to tackle several objectives; identification and mapping of the European hydropower industry, hydropower stakeholders in the HYPOSO target countries, education of new hydropower experts through capacity building activities and bringing together relevant actors from the EU hydropower sector with stakeholders in the target countries. Interaction with stakeholders is therefore an integral part of the activities, as workshops, capacity building activities and interviews with national/local stakeholders are envisaged in all target countries which are outside the European Union, namely workshops in Bolivia, Colombia and Ecuador in Latin America, and in Cameroon and Uganda in Africa. Additionally, capacity building courses will be carried out in Bolivia and Ecuador, and in Cameroon and Uganda.

2 Executive Summary

This deliverable D3.2 is an outcome of the Task 3.1 **"Framework analysis and research needs in the target countries"** of the WP3 "**Framework analysis and research needs**" (Task leader: VDU, Partners: IMP PAN, CELAPEH, IHE Delft, HPAU, SHW, EPN, UMSS).

It analyses political, legal, financial and educational framework as well as financing opportunities for the prospective hydropower sector in the selected target countries of the project, namely Bolivia, Cameroon, Colombia, Ecuador and Uganda.

The present report provides the methodology of analysis and is structured of the following:

- Key facts;
- Power sector overview and renewable electricity policy;
- Hydropower sector and potential;
- Small hydropower (SHP) policy and market analysis;
- Educational framework, research situation and need for research;
- SHP financing opportunities and environment;
- Barriers to SHP development;
- Future prospects for large and small hydropower and
- References.

3 Methodology

The analysis was based on the following main steps:

1. Collection of existing information of the data holders and review a wide range of available papers and reports published in open sources and grey literature. Past and ongoing studies on hydropower issues were extensively used.
2. Two compressive questionnaires (Excel based) built on the previous experience and designated for the project partners and experts in the target countries, namely (see Annexes):
   a) D3.2.1. Framework analysis: Market, Policy, Financing, Education, Research
   b) D3.2.2. Inventory of R&D projects

The questionnaire D3.2.1. consists of Market data (Industrial and Economics), Policy data (Legislation and concession regime, and support), Financing, Education and Research needs.

The aim of the questionnaire D3.2.2. " Inventory of R&D projects" was to identify past and outgoing R&D activities, complementing them by Innovation (R&I) of hydropower sector in these countries in order to facilitate the European technology transfer from the laboratories to the market, enhancing the European industry position and helping it to keep its leadership in this field.

Bolivia

1 Key facts

Population	11.5 million	2018 estimate
Area	1.1 x 10^6 km^2	
Access to electricity	91.8 %	2017
Installed hydro capacity	734.84 MW	2019
Share of generation from hydropower	30 %	2019
Hydro generation	1,715 GWh	2019
Economically feasible hydro generation potential	40 TWh	
Small hydropower potential	>2,000 MW	
Small hydropower installed capacity	153 MW	2019

1.1 Climate

There are three main geographic zones: the Andean zone, the Sub-Andean zone and the Eastern Plains. The Andean zone has a desert polar climate, with maximum temperature of 20°C and minimum below 0°C. The Sub-Andean zone is featured by a very humid and rainy climate with average temperature varying between 15°C and 25°C. The average temperature of the Eastern Plains is around 30°C.

1.2 Topography

Bolivia is a landlocked country with geographic zones that feature enormous variations in elevation. The Andean zone is a mountainous zone formed by the Occidental, the Oriental, Royal, the central Cordillera and the “Altiplano”. The highest point is the Sajama peak at 6,542 meters above sea level (m a.s.l.), the average altitude along the Andean region is between 3,750 and 4,000 m a.s.l. The Sub-Andean zone, commonly known as the “Yungas” and “Valles”, are valleys of varying altitudes, with an average of 2,500 m a.s.l. The Eastern Plains, known as the “Llanos”, cover the tropical savannahs, the Amazonian forest, agricultural lands and the desert region of “El Chaco”. It occupies almost two thirds of the national territory. The region has an average altitude of 400 m a.s.l. and a minimum altitude of 90 m a.s.l..

1.3 Water resources

Bolivia has an average precipitation of 640 mm per year. The rainy season is between mid-October to March. Precipitation patterns are much more pronounced in the Sub-Andean zone and the Eastern Plains and range from 2,000 mm/year in the north to 600 mm/year in the south, in the valleys, reaching up to 6,000 mm/year. In the Andean zone, particularly at the Altiplano, it rains much less. Precipitation can be as low as 200 mm per year, except in the area surrounding Titicaca Lake basin (1,000 mm/year)

Bolivia's river systems can be divided into three areas: The Eastern area (a tropical and subtropical region), the Southern area (the arid, semiarid and sub-humid dry regions), and the Western area where Titicaca basin is located. The hydrographic system consists of three large basins:

- the Amazon Basin with surface area of approximately 724,000 km^2, covering 66 % of Bolivia's territory;
- the endorheic basin or Titicaca Lake basin, which with surface area of 145,081 km^2 or 13 % of the territory; and
- the South or Río Plata Basin, which covers 229,500 km^2 or 21 % of the country territory. It is the second basin in importance in the South American continent including the countries of Bolivia, Brazil, Paraguay, and Uruguay.

A representative indicator of the hydroelectric potential of a country is the density of hydropower potential called also specific potential and defined as the technical hydropower potential (or sometime gross theoretical) per area unit (square kilometre) of the country. For Bolivia it is estimated to be 0.11 GWh/(year·km^2). To compare, for Austria and Norway this specific indicator is around 0.66, Ecuador- 0.74 and Brazil - 0.15 GWh/(year·km^2).

2 Power sector overview

The major share of Bolivia's electricity is covered by the non-renewable thermal sources of natural gas combustion turbines Their installed capacity is 1,538.38 MW (62 %) and the energy produced in 2016 was 6,947 GWh (79.3 %). This is followed by hydropower sector with total installed capacity of 734.84 MW (30 %) and energy produced of 1,715 GWh (19.6 %). The share of other renewable energy sources is still insufficient. Figure 1 shows the annual electricity generation in Bolivia.

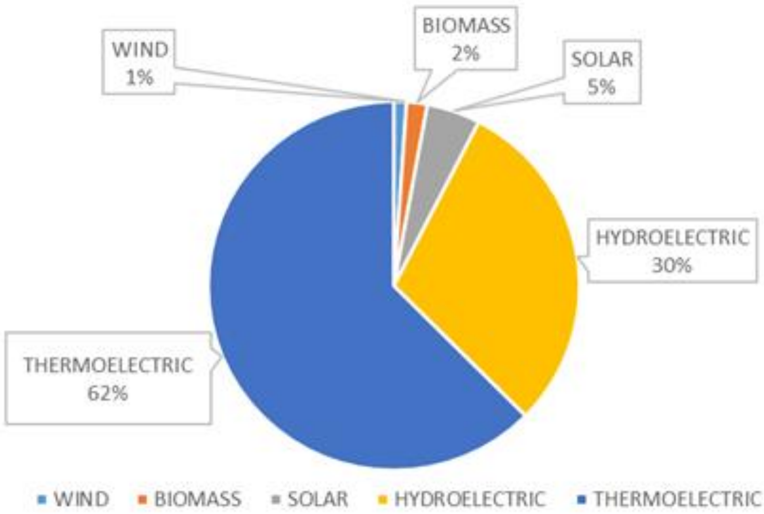

Figure 1: Annual electricity generation by source in Bolivia (MW) in December 2019 (CNDC, 2020)

Until 2016, the total installed capacity of the national grid was 1,855 MW, with 1,434 MW recorded maximum instantaneous power demand and the total demand reaching 8,378 GWh. Electricity demand has grown by 5.4 % in relation to 2015. There is no accurate data related to isolated networks, however it is estimated that the demand for them is around 600 GWh (2014). Access to electricity in Bolivia is estimated to rate 90 %, where the urban coverage is 99 % and rural access is 72 %.

The electricity sector of Bolivia comprises the national grid, known as "Sistema Interconectado Nacional" (SIN), the wholesale market, the end consumers and several isolated networks.

According to the energy sector authorities, annual electricity demand will reach 14,336 GWh by 2022 and will increase to more than 22,000 GWh by 2030, requiring a total installed capacity of 2,297 MW in 2022 and more than 3,500 MW in 2030.

Despite fossil fuels being the predominant energy source, electricity tariffs in Bolivia are amongst the lowest in South America. This is due to the subsidized gas and diesel prices for electricity production.

In 2016, the average energy marginal cost in the spot market was 16.8 US$/MWh and the corresponding average energy sales price was 17.3 US$/MWh.

The Government has plans to develop the electricity sector by increasing the country's installed capacity, which will be supplied mainly from hydropower schemes. The electrical energy will also be exported to neighbouring countries.

3 Renewable electricity policy

The Renewable Energy Policy Brief in Bolivia was compiled by International Renewable Energy Agency (IRENA, 2015). The framework for electricity generation in Bolivia is the 1994 electricity law (Law 1604). It empowers the federal government to set a minimum participation for hydropower in the electricity system. A new electricity law reflecting the 2009 constitutional changes is under development. The 2007 National Development Plan (Decree 29272) aims to diversify the energy mix for electricity generation.

The Framework Law for Mother Earth and Integral Development for Better Living (Law 300 of 2012) aims to gradually increase the share of renewable energy in electricity generation.

In 2011, Bolivia defined the Policies for Renewable Energy in the Electric Sector, including action through four programmes: (1) deployment of renewable energy, (2) rural electrification, (3) development of the regulatory framework; and (4) research and development (R&D).

In 2014, Decree 2048 established that remuneration prices for renewable energy producers would be set according to a methodology under development by the Ministry of Energy. A new Renewable Energy Law is also under development.

According to IRENA (2015), Bolivia has a renewable electricity target of 183 MW by 2025, as set by the 2014 Bolivia Electric Plan 2020-25. This given figure obviously doesn't include conventional hydro. Larger than 2MW are considered conventional, and as such do not qualify for this target.

4 Hydropower sector and potential

Bolivia has a gross theoretical hydropower potential of 178,000 GWh/year (Figure 2). The technically feasible potential has been estimated as 126,000 GWh/year, and the economically feasible potential is between 30,000 and 50,000 GWh/year. Hydropower plants generated about 2,500 GWh in 2018. Less than 2 % of the technically feasible potential has been developed so far.

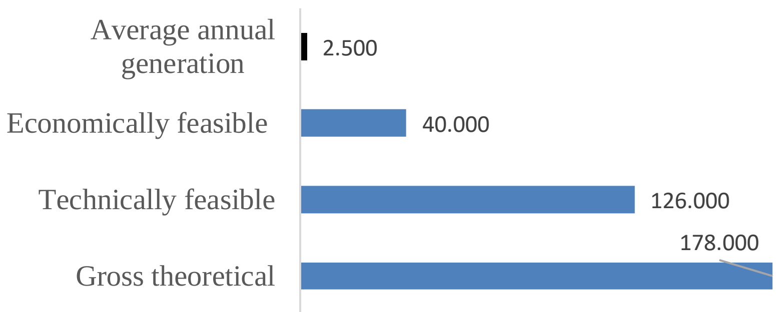

Figure 2: Hydropower potential in GWh/year in Bolivia (HP&D, 2019)

Bolivia has the potential to develop more than 40 GW of hydropower, estimated in 1984 by *Empresa Nacional de Electricidad S.A, Organizacion Latinoamericana De Energia* (Vargas et al., 2018, IHA, 2019). The most suitable region is the Amazonian basin with a potential capacity of 34.2 GW, followed by the Plata River basin with 5.4 GW, and the Andean Basin (Altiplano) with 0.3 GW.

A recent study based on GIS technologies identified the gross theoretical hydropower potential of 133 GW in Bolivia (Velpuri et al., 2016). Although protected areas were excluded from it, the real potential – technically or economically feasible potential remains still unknown.

As of 2019, Bolivia had 26 hydropower plants in operation with a total capacity of 5,829 MW (Figure 3). This inventory comprises only 5 small hydropower plants (up to 10 MW).

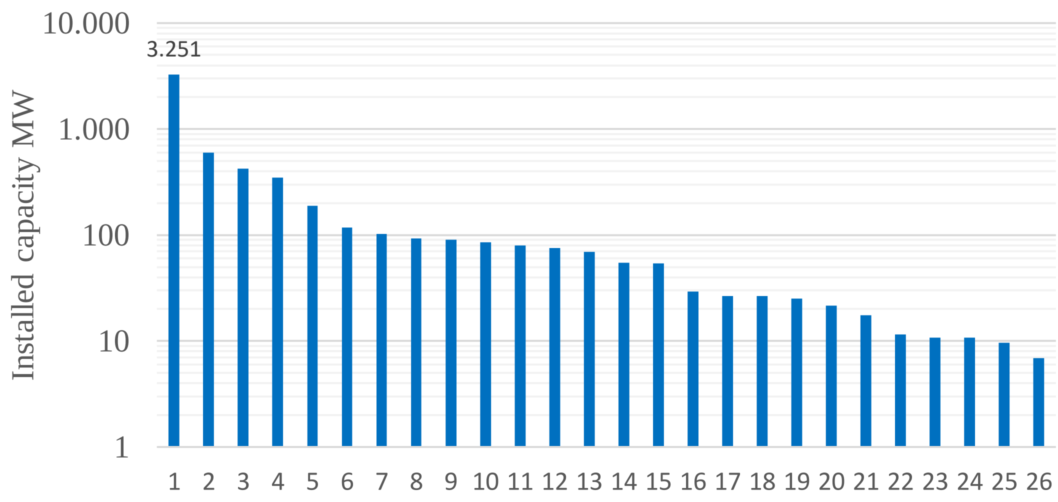

Figure 3: Operational hydropower plants in Bolivia as sorted by their installed capacity

Micro and small-scale hydropower is mainly confined to rural areas, as it is considered appropriate for dispersed and isolated communities. The definition of small hydropower in Bolivia is up to 5 MW, however for the purposes of this report, the standard definition of up to 10 MW is used.

So far, the small hydropower potential as expressed in real figures is not known as it is the case for all hydropower (see estimates above) nor reliable inventory of SHP plants (Table 1).

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

References	Potential, MW	Installed capacity, MW	Generation GWh/year	Number of operating SHP	Comments
WSHPDR, 2019	200	153	629	85	33 SHP plants are connected to the national grid, some 52 are off-grid or supplying local grid.
HP&D, 2019		104		64	

As it can be seen from this table, the estimates differ a lot, the small hydropower potential (200 MW) is obviously underestimated taking into account the fact that the country enjoys the enormous total potential. The best available technique to preliminary evaluate the small hydro potential is to take a portion of 5 to 10 % of the total hydropower potential, that is equal 40 GW in the country. Consequently, it will result to some 2,000 to 4,000 MW, a rough, but more realistic estimate of SHP potential.

After the highest estimate, there are 85 smalls, mini- or micro- hydro plants in operation, with individual capacities of up to 10 MW, and the total capacity of 153 MW, that generated 629 GWh in 2016. SHP plants belong to both private and public (ENDE) companies.

There is a considerable potential for the electricity production by micro-hydro in Bolivia, in valleys in the Andes at elevations between 1,800 and 2,900 m, which are characterized by extensive forests, many rivers, fertile soil, and varied agriculture. However, despite promotional efforts by the government, several NGOs and the University of La Paz, not much is known about the factors influencing diffusion of micro-hydro in Bolivia. Some projects have been evaluated, but the results have been neither disseminated nor compared. There is no umbrella organization to oversee MHP project implementation, no project coordination between implementing organizations, and an acute shortage of data (Drinkwaard et al., 2010). The current knowledge on the micro-hydropower status was acquired only some 10 years ago. Contrary to this unfavourable micro-hydro situation, the large hydro data repositories are accessible and in quite a good level.

5 SHP policy and market analysis

Micro or small hydropower is not a radically new technology in Bolivia. Micro hydro was used already centuries ago to generate mechanical power for the mining industry. However, it is only since the 1950s or 1960s that the technology has been used for small scale electricity generation. The first SHP was constructed in 1940s. And although the technology is relatively mature, other aspects, like organizational structures and financing mechanisms are far from being developed.

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

Some 18 contacts of stakeholders involved in one or another way in the hydropower sector were identified in Bolivia (HYPOSO D3.1,2019).

5.1 SHP policy

The small hydropower is integrated within the whole energy and hydropower sector. Key legal documents making up the legal framework to which hydropower must comply are listed in Table 2.

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

Name of legal document (not older than 5 last years but those still in force)	Type	Website	Summary and impact on development of hydropower (small or large)	Comments
Agenda Patriótica del Bicentenario 2025, (2015) 15 JUN, 2015, No 0650. (Bicentenary Patriotic Agenda 2025)	Energy Development	http://www.silep.gob.bo/	Positive, supports RES and hydropower.	
Ley de electricidad, (1994, last amendment on 2019) 21 DIC, 1994, No 1604. (Electricity Law)	Energy	http://www.silep.gob.bo/	Positive, supports RES and hydropower. - Concessions, licenses and provisional licenses - Prioritize rural electrification	Introduces division between the electricity producers, transmission/distribution system operators and distribution utilities; It opens the electricity sector to private participation, regulates competition between them, introduces the responsibility of the State towards rural electrification and encourages the generation of energy from renewable sources.
Ley Forestal, (1996) 12 JUL, 1996, No 1700 (Forestry Law)	Environmental	https://cebem.org/	Positive, supports RES and hydropower.	

Ley de promoción de Inversiones, (2014) 4 ABR, 2014, No 516 (Investment Law)	Economy	http://www.silep.gob.bo/	Positive, supports RES and hydropower.	The purpose of this law is to establish the general legal and institutional framework for the promotion of investments in the Plurinational State of Bolivia, in order to contribute to the economic and social growth and development of the country, for the "Living Well".
Ley del sistema de regulación sectorial (SIRESE), (1994) 28 OCT, 1994, No 1600 (Sectoral Regulation System Law)	Development Regulator	https://www.lexivox.org/norms/BO-L-1600.html	Positive, supports RES and hydropower.	Service regulation system, created by the Superintendency of Electricity, which is an autonomous regulatory entity regulating the national electricity sector (tariffs, concessions, competencies, etc.).

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

Name of legal document (not older than 5 last years but those still in force)	Type	Website	Summary and impact on development of hydropower (small or large)	Comments
Ley Marco de Autonomías y Descentralización "André Ibañez", (2010) 19 JUL, 2010, No 31 (Autonomy and Decentralisation Law)	Development	http://www.silep.gob.bo/	Positive, supports RES and hydropower.	It recognizes the indigenous, peasant and urban communities of the country, establishes social control mechanisms, redistributes resources equally among all inhabitants and finally establishes municipal governments with territorial jurisdiction transferring responsibilities in the health, education, roads, micro-irrigation sectors, natural resources and development.
Ley del Medio Ambiente (1992) 27 APR, 1992, No 1333 (Environmental Law)	Environmenta l	http://www.silep.gob.bo/	Prevents hydropower development, especially large one. Takes care about conservation of the environment and natural resources regulating the actions of man in relation to nature and promoting sustainable development	

The national authority in charge of water resources is the Ministry of Environment and Water Resources (Ministerio de Medio Ambiente y Agua, MMAyA).

A brief description of regimes for granting rights (concessions or authorisations) to use hydropower in Bolivia is summarized in Table 3.

Table 3: Regimes for granting rights (concessions or authorisations) to use hydropower in Bolivia

	Small Hydro (P < 10 MW)		Large Hydro
	New permits (authorizations)	Refurbishment or Relicensing	New permits
Type of permits needed & average time	It does not require a license for the power generation activities with capacity less than 500 kW.	Possible to get the relicensing if all parties agree. An amendment in the agreement is needed where the time or licensing is agreed upon.	Production license (0.2 years). Approval of the environmental terms (0.1 years and validity of 10 years) The duration of the permits (water use rights) is up to 40 years.
Number of plants granted during 2017 to 2019 period	No small hydropower plants (<10 MW) were registered at the National Company of Electricity which is the institution that regulates and control all kinds of electricity production		7 plants (from 90 to 200 MW) 3 plants (from 201 to 400 MW)

5.2 Industrial overview

Bolivia is a country with abundant potential for small hydropower development. There are many identified sites suitable for small hydropower facilities as well as existing plants in need of refurbishment. Despite the fact, that there are 85 SHP under operation, the access to their data was not possible, because most of them belong to the private sector and special permission was needed.

There are some 10 companies active in the small hydropower sector (Table 4). Well-developed hydropower equipment manufacturing industry is lacking with the exception of small turbines produced occasionally for micro-hydro facilities under design of Institute for Hydraulics and

Hydrology (Universidad Mayor de San Andres, UMSA). Only one company is acting for the equipment suppliers. 4 companies are involved in engineering activities. Operation & maintenance services are not well developed.

Table 4:Bolivia - Overview of companies acting in small hydro sector

Year: 2018-2019 (average)	Total Hydro	% of which Small Hydro (<10MW)
1) Direct number of companies	17	59
2) Direct Employment		
a) Equipment suppliers	4	75
b) Engineering activities	7	57
c) Operation & Maintenance services	4	25
d) Civil works (estimation)	2	

Some 10 years ago only a few companies in Bolivia had sufficient knowledge to construct micro hydro plants (Drinkwaard, 2009). Ingelec is a Bolivian company, specialized in the construction of large scale hydro and thermal power plants and installation of the transmission and distribution lines. It built several micro hydropower plants, especially under the projects of the government. The company operates internationally, especially in Latin America. Micro-hydro however is not the core business of Ingelec and they stopped their activities in this industry, because of a lack of specialized personnel. Icaro, a similar company, has taken over the place of Ingelec and is currently the only private company constructing micro hydro plants.

SHP economics overview

Some preliminary economic estimates for hydropower are presented in Table 5.

Table 5: Bolivia - Key economic estimates for hydropower

Year: 2015-2019 (average)	Small Hydro (<10 MW)	Medium to Large Hydro (>50 MW)
a) Average Investment cost (€/kW)	1,640	2,500
b) Average Cost per kWh produced (€)		0.074
c) Average O&M Cost (as % of total investment cost)	2	1.5
d) Average lifetime of the mechanical equipment (number of years)	30	30

e) Average Civil Works Cost (as a % of total investment cost)	37	

When analysing the average investment cost per kW installed (€/kW), one important issue must be highlighted. This important metric was 2 to 3 times higher for micro-hydro projects initiated and supervised by the VMEEA (*ViceMinisterio de Electricidad y Energías Alternativas*) and relying on funding of international donors than in case of projects implemented by local Bolivian companies (Drinkwaard et al., 2010).

Currently available support mechanisms in the country are listed in Table 6. Some of them are not clearly expressed in legal terms. All of them promote the use of energy from renewable sources by reducing the generation cost of this energy and increasing the price at which it can be sold.

Table 6: Bolivia - Support schemes for hydropower

Plant category	Type	Measurement
a) Small Hydro	Regulatory price-driven strategies, and Regulatory quantity-driven strategies	• Promoting rules to finance SHP and other RE developments by incentives to local governments when the installed capacity is < 2 MW and to the municipalities or to the indigenous authority when the project is of an installed capacity < 1 MW. • Exemption of taxes for importing equipment and construction • Subsides form the government • Guaranteed electricity purchase • Possible exemption of paying the transmission and to the grid administrator
b) Large Hydro	Regulatory price-driven strategies	The government is working to establish a policy in order to finance hydro and other renewable projects by creating a fund that allocates for a reduction in thermal production, in favour of subsidizing RE sources.
c) Both small and large	Regulatory price-driven strategies	Supreme decree #2048 promotes investment for hydro, wind, solar and thermoelectric energy projects. Foreign and local investment are welcome.

6 Educational framework

There are 10 state-funded and more than 23 private universities in the country. However, there is no narrowly specialised Hydropower or Hydropower engineering study program in the country education system. Hydropower is usually part of renewable or energy studies or even civil, power or mechanical engineering. At least 6 universities are offering undergraduate degrees. Only a few of them are providing master studies (Table 7).

Table 7: Bolivia - List of universities

No.	University	Hydropower as part of renewable or energy studies	Topics included in syllabus	Basic knowledge courses
1	Universidad Católica Bolivana	Undergraduate: Energy engineering	1 Hydropower energy 2 Transportation and energy distribution	1 Energy and environment 2 Planning energy 3 Energy and sustainable development
		Undergraduate: Civil engineering		1 Hydraulics 2 Hydrology 3 Civil works
		Short course: Renewable and alternative energies: Geothermal, Lithium and Biomass	Energy efficiency	
2	Universidad del Valle	Undergraduate: Electromechanical engineering	Hydropower plants	1 Hydraulic and Pneumatic Machines 2 Fluid mechanics
		Undergraduate: Civil engineering		1 Hydrology 2 Hydraulics 3 Hydraulic works 4 Environmental Engineering

3	Universidad Privada Boliviana (UPB)	Undergraduate: Civil engineering	Fundamentals of Electrical Engineering	1 Hydrology 2 Hydraulics 3 Hydraulic works 4 Environmental Engineering
		Undergraduate: Electromechanical engineering		
4	Universidad Mayor de San Simón (UMSS)	Undergraduate: Electro mechanic Engineering		1 Hydraulic and Pneumatic Machines 2 Fluid mechanics
		Undergraduate: Civil engineering		1 Hydrology 2 Hydraulics 3 Hydraulic works 4 Environmental Engineering
5	Universidad Autónoma Gabriel René Moreno (UAGRM)	Postgraduate (Master's): Renewable Energy	Hydraulic and micro power plants	Energy and climate change
		Undergraduate: Civil engineering		1 Hydrology 2 Hydraulics 3 Hydraulic works 4 Environmental Engineering
6	Universidad Mayor de San Andres (UMSA)	Post-grade: Energy: Technologies, Management and Planning	Alternative Energies	1 Thermal and Electrical Principles for Power Generation 2 Applied Technologies in Conventional Energies and their Industrialization
		Undergraduate: Electromechanical engineering	Hydropower plants	1 Hydraulic machines 2 Fluid mechanics

		Undergraduate: Civil engineering	Micro power plants	1 Hydrology 2 Hydraulics 3 Hydraulic works 4 Environmental Engineering

Main gaps to bridge the knowledge for small hydropower sector are as follows (Table 8).

Table 8: Bolivia - Identified needs for improving knowledge level at hydropower sector

No	Level	Identified needs
1	Government	Expand knowledge at operational, legislative and environmental levels
2	Private sector	Expand knowledge in the Environmental Legislative Framework and technical operations
3	Supervision of Electricity sector	Expand knowledge on maintenance and operability to make IEA procedure more flexible

7 Research situation and needs

Instituto de Hidraulica e Hidrologia (Institute for Hydraulics and Hydrology, IHH) is a research unit of the Universidad Mayor de San Andres (UMSA), the university in La Paz. They are specialized in micro/small hydro technology and have been conducting research on it for more than 30 years. In the past, Pelton and Banki-Michell (cross-flow) turbines have been developed and adapted for local manufacture and to fit specific local conditions. Furthermore, IHH has done research on the construction of the civil construction parts of micro-hydro plants and has developed its own methods (Drinkwaard, 2009).

Laboratorio de Hidraulica (Hydraulics Lab) is a research unit of Universidad Mayor de San Simon (UMSS), the university in Cochabamba. They have the specialization in numerical modelling river flow and hydropower operation for more than 30 years. They also have experience in constructing scale models of hydropower plants for assessing their operation.

7.1 R&D projects

In this project, the definition of R&D goes beyond its pure conception. Considering the practical issues and situation in the research field of the target countries, there was added the term of Innovation (R&I). 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 19 R&D project were identified conducted over the period of 2011 to 2019 (Table 9). Five of them are dealing with large hydro. The majority of these projects were implemented during the last 5 years. Almost all the projects were conducted by universities. No fundamental research (also known as basic research or pure research) elements have been identified.

Table 9: Bolivia - List of R&D topics, their number and key words (based on the conducted survey)

No	R&D project topic	Quantity	Key words
1.	General	2	Economics of climate change and power sector
2.	Administrative and marketing aspects	1	Renewable energy, energy mix scenarios
3.	Maps, potential assessment	1	Criteria for location SHP
4.	Multipurpose projects and rehabilitation	1	Optimization of operation, dams, hydropower plant
5.	Weirs and water storage/reservoirs	1	Modelling, sediments
6.	Methods and equipment for construction, maintenance, repair and overhaul of hydropower plants	2	Diameter of pipes, new technologies and appropriate protocols
7.	Turbines	2	Technical criteria for turbine selection, Modelling

8.	Electrical equipment	2	Electrical components, batteries, sizing of synchronous generators, auxiliary electric services
9.	Control & monitoring	3	Maintenance, Electronic maintenance, RSM (Reliability centred maintenance), ISO 14224, Electronic maintenance, risk-based maintenance
10.	Environment integration, EIA, hydropower social acceptance	4	SHP, Micro-Hydro, environmental flow, social and environmental impact, fish communities, isolated communities

7.2 Research needs

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

- Hydrological studies, including the analysis of short- and long-term climate change impact.
- Evaluation of multi-purpose projects for hydroelectric industry perspective.
- Diagnostic studies of the current state of micro and small hydro plants, evaluating the operability and efficiency of the plant.
- Studies to increase efficiency in hydroelectric power plants (upgrade and adding capacity)
- Studies of new technologies that allow the maintenance of the facilities with minimal outages.
- Improvement in home electrical connection systems in the rural area.
- Hydropower socio-environmental and economic impact studies.

8 SHP financing opportunities

In Bolivia many organizations currently finance or have financed one or several projects ranging between micro and small hydro. The investment frameworks include international NGO projects, international bank programs, bilateral agreements etc, just to mention:

- *Kreditanstalt für Wiederaufbau* (KfW) - the German development bank;
- UNDP/GEF Small Grant Program (SGP), funded by the Global Environment Facility (GEF) and co-ordinated by the United Nations Development Program (UNDP).

- *Alisei* - an Italian NGO that started a program for rural development in Bolivia, in 1996, co-financed three micro-hydropower installations and supervised some other ones.

The most important local financing organizations are listed below in Table 10.

Table 10: Local financing institution acting in Bolivia

No	Financing institution	Description
1.	Banco Los Andes	Promotes “green” funds destined to finance actions in renewable energies and in energy efficiency. They offer credits with a rate of 2 points lower than the nominal ones, depending on the sector to which it is directed, this can mean a final rate between 8 % and 10 % annually.
2.	Banco Unión	Promotes funds for clean energy with rates around 6 % per year.
3.	Cooperación Alemana	Finances micro hydro in rural communities.
4.	Energy and Environment Partnership (EEP)	Offer grants for the development and/or expansion of inclusive business models and provides base capital for the initial phases of sustainable energy projects with local and international partners. The maximum financing per project is 200,000 euros.
5.	Banco Interamericano de Desarrollo (BID)	InfraFund provides support to public, private and mixed capital associations in Latin America and the Caribbean for the identification, development and preparation of financing, sustainable and high-infrastructure projects. There is a high probability of achieving a financial closure. The InfraFund also promotes the formation of public-private partnerships for infrastructure provision. Projects can obtain a maximum funding of US $ 1.5 million and there is a rapid approval process for projects of less than US $ 500,000.
6.	FUNDAPRO	Finances clean energy projects and energy efficiency
7.	Banco Central de Bolivia (BCB)	Provides loans for medium and large projects

8.	Desarrollo de América Latina (CAF)	Offers credits for developing projects.

A couple of years ago, *Empresa Nacional de Electricidad* (ENDE) invited bids to build a SHP in the country and carry out studies of small and medium hydroelectric plants under KfW (the German Development Bank) support, with German financial cooperation funds. ENDE is to construct the El Condor small hydro plant via a turnkey contract.

Concessional loans from international donors for the development of renewable energy projects are accepted by law on a case-by-case basis. Regarding hydro, mostly large schemes were financed so far (the Development Bank of Latin America (CAF), Inter-American Development Bank (IADB). For instance, the hydropower assessment of Bolivia (Velpuri et al, 2016) was carried out with cooperation of the Development Bank of Latin America (CAF).

Some studies, but mostly for large hydro, are being undertaken with Brazilian authorities to determine the potential design and locations of future hydropower projects. These studies are located close to the Brazilian border in the east northern part of Bolivia. Chinese companies, since the last 10 years, are very active in constructing large hydropower plants (e.g. San Jose 1, San Jose 2 and Ivirizu).

9 Environment

The national authority in charge of water resources is the Ministry of Environment and Water Resources, (Ministerio de Medio Ambiente y Agua, MMAyA). The Law of the Environment of 1992 created a number of institutions related to environmental quality management.

Currently some of large hydro projects (e.g. the 600 MW Rositas HPP and the 3,676 MW El Bala HPP) are facing troubles, they have been delayed due to environmental and social issues.

10 Barriers to SHP development

The main challenges to consider for developing small hydropower projects in Bolivia are, but not limited to (WSHPDR, 2019) the issues as below.

- The Government is favouring large hydropower schemes to export energy to neighbouring countries/
- Renewable energy development framework, rules and conditions have not been established yet/
- Low energy prices are not very attractive for private investments/
- Hydrological information, climate and other statistical data, especially for rural areas, are scarcely available.

- Private investments are not well favoured, it is hard to establish a private company
- Acceptance and development of an economically viable and competitive private hydropower project price is a true challenge.
- Hydropower projects encounter low social acceptance and heavy bureaucracy obstacles in their initial stage
- Some rural communities hardly accept hydropower projects due to local tradition linked with ancestral uses of water

11 Future prospects

11.1 Large Hydro

Despite the fact that there is currently a surplus of power generating capacity, Bolivia is constructing new power projects with the aim to become a major power exporter. There is an ambitious target to generate as much as 70 to 78 % of domestic electricity from hydropower by 2025. An important reason to encourage hydroelectric projects is because of the country's enormous hydropower potential.

The target of ENDE is to have 3,000 MW of hydropower capacity as soon as possible, which would allow the country soon to use about 1 GW for electricity export purposes. Hydropower is a key part of this plan. In the medium term, an estimated US$ 16.7 billion will be invested in new hydropower projects (HP&D, 2019, IHA, 2019). This plan is heavily reliant on two large hydropower schemes. The export to Brazil and Argentina is very attractive in terms of power price that is about seven times higher than the price established for the local market, which has been subsidized for energy production (WSHPDR, 2019)

11.2 Small hydro

The Government's strategic plan includes the development of renewable hydropower projects considered to be up to 30MW classified as follows (WSHPDR 2019):

- Micro: P < 500 kW;
- Small: 500 kW < P < 5 MW;
- Medium: 5 MW < P < 30 MW.

The strategic plan includes small hydropower projects of approximately 30 MW for grid connection and another 20 MW for isolated networks, all of them in progress of identification. Such projects as well as other endeavours can be studied, developed and constructed by public or private investment. This prospective total capacity (50 MW) is also pointed out in the HP&D (2019).

The Government is also working on the structure and rules to finance small hydropower and other renewable energy technologies, such as by assigning incentives to the local governmental departments when the installed capacity is below 2 MW; and to the municipalities or to the indigenous authorities when the project is of an installed capacity less than 1 MW.

The energy tariffs for new projects are not defined yet, nor financial mechanisms exist. Regulations and investment frameworks are in the process of being implemented. Each project will have to be negotiated in order to establish the energy price through a purchase agreement according to ENDE's requirements, the interests of the investor and AE's authorizations.

It is worth to mention that most of the SHPs in Bolivia belong to private companies, such as the Zongo cascade system (8 power plants), located in the northeast of La Paz city, or Synergia in Cochabamba city.

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Colombia

1 Key facts

Population	about 48.2 million	2018 census
Area	1,142,000 km^2	
Access to electricity	97 %	2018
Installed hydro capacity	11,771 MW	2019
Share of generation from hydropower	86 %	2017
Hydro generation	58.3 TWh	2017
Economically feasible hydro generation potential	140 TWh/year	2015
Small hydropower potential	ca 5,000 MW	2015
Small hydropower installed capacity	955 MW	2019

Colombia is located in the north of South America and is crossed in the south of the country by the equator line.

1.1 Climate

The climates in Colombia are characterized for having tropical rainforests, savannas, steppes, deserts and mountain climate, mountain climate further divided into *tierra caliente* (hot land) t*ierra templada* (temperate land) *tierra fría* (cold land), *tierra helada* (frozen land) and Páramo. Each region maintains an average temperature throughout the year only presenting variables determined by precipitation during a rainy season.

1.2 Topography

Colombia's topography is characterized by the Andean Cordillera range, situated in the west-central part of the country, and which stretches from north to south, almost along the whole length of the country. The Andes are composed of three parallel ranges: the Eastern Cordillera, the Central Cordillera, and the Western Cordillera. Between the Cordilleras there are high plateaus and fertile valleys which are crossed by the country's major river systems.

1.3 Water resources

The average annual precipitation is 500 to 3,240 mm but varies greatly from year to year and from place to place from 267 to 9,000 mm per year.

In Colombia 9,139 river basins had been evaluated and grouped into six hydrological areas, divided into sixteen hydrological regions, which include a total of 56 hydrological zones. There are many important rivers in Colombia. The major ones are: the Magdalena River, Cauca River, Caquetá, Putumayo, Guaviare, Meta and the Atrato Rivers.

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 (km2) of the country. It is estimated to be 0.18 GWh/(year·km^2) in Colombia. To compare, for Austria and Norway this specific indicator is around 0.66, Ecuador- 0.74 and Brazil - 0.15 GWh/(year·km^2), respectively.

2 Power sector overview

Colombia has a rich endowment of energy sources and the country is heavily reliant on installed hydropower (from 70 to 80 % per of annual electricity generation), which provides cost effective electricity. It has the third largest installed hydropower capacity in South America, at 11,771 MW.

The Colombian power market was established in 1995, driven primarily by concerns about the reliability of supply in the largely hydro-based domestic power system. Power supply continues to rely on hydroelectricity backed by thermal (mostly gas and oil-fired) generation, with increasing but still minor contributions from other generating technologies (Rudnick and Velásquez, 2019).

In 2015, Colombia had a total installed electricity generation capacity of 16.4 GW, with a share of 62.1 % of large hydropower (plants with an installed capacity bigger than 100 MW), 4.2 % of medium hydropower (20 to100 MW), and 3.7 % of SHP (<20 MW). Other renewable energies have minimal representation in Colombia’s energy market. The remaining 30 % corresponded mainly to thermal generation, as shown in Figure 4.

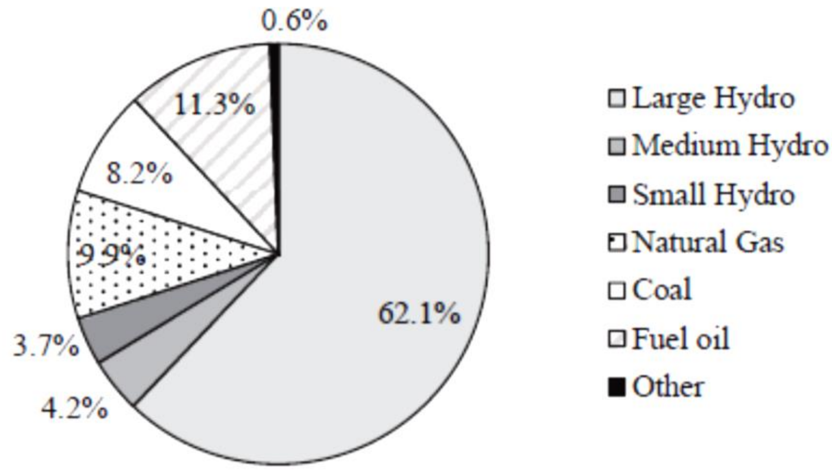

Figure 4: Composition of installed power generation capacity in Colombia in 2015 (Arias-Gaviria et al., 2017)

In 2018, the total installed electricity generation capacity reached 17.7 GW. While the generation increased since then, the ratio between large, medium and small hydropower has remained similar since (UPME, 2018). The average annual hydro generation of the hydro plants in operation was 60,620 GWh/year, which was 84.1 % of the national power production in 2018. This includes 56, 193 GWh/year from large plants (78.0 %) and 4,427 GWh/year (6.1 %) from small hydro plants (UPME, 2018a).

In Colombia, the Energy Generation Expansion Plan from 2014 to 2028 aims at increasing the installed capacity represented mainly by hydroelectric plants, thermal gas, and coal (UPME, 2015). There is vast hydrological potential thanks to the country's privileged geographic location. This potential has been widely explored in large hydropower projects benefiting big cities and other significant consumption centres, excluding in many cases, non-interconnected rural zones. In some regions, there are various SHP projects at their exploratory phases, while other regions totally ignore the hydropower potential they have.

3 Renewable electricity policy

Apart from the abundant hydropower resources, Colombia has strong potential for non-conventional sources of energy generation, particularly solar, wind and biomass (NRF, 2017). Law 1665 of 2013 (the New Renewable Energy Law, REL) was adopted in April 2014. The REL approved the International Renewable Energy Agency Statute as an attempt to promote the adoption and sustainable use of all forms of renewable energy.

Colombia's electricity and energy sector are under the jurisdiction of the Ministry of Mines and Energy (MME). The MME has adopted the Indicative Action Plan and established a target of achieving 3.5 % of on-grid and 20 % of off-grid generation from renewable sources by 2015. This is to be increased to 6.5 % and 30 %, respectively, in 2020. However, there are no legislative targets associated with the accomplishment of these goals.

In 2017 the Colombian Government issued Decree 1543, through which it created the Fund for Unconventional Energies and Efficient Energy Management ('Fenoge Fund'), in accordance with the provisions of Law 1715 (of 2014). This fund has the priority of providing resources for research and for pilot plans for projects related to the production of clean energy. As a complement to the General Royalty System, which is supported by Law 1530 (of 2012), it seeks to give a boost to the scientific, technological, innovation and competitiveness of the regions (H&D, 2019).

4 Hydropower potential and sector

Colombia has the second largest hydropower potential in Latin America, after Brazil (OLADE, 2013). The gross theoretical hydropower potential of Colombia is about 1,000 TWh/year, of which 200 TWh/year is technically feasible. 140 TWh/year was economically feasible according to estimates made several years ago (H&D, 2019). (Figure 5).

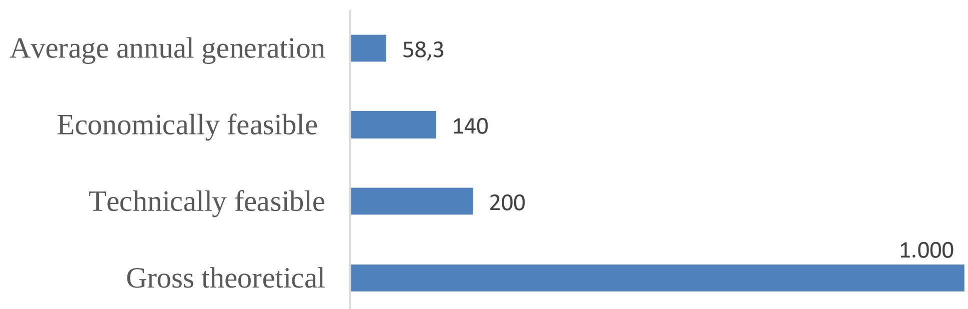

Figure 5: Hydropower potential in TWh/year in Colombia (H&D, 2019)

According to the data from the Colombia's National Mining and Energy Planning Unit (UPME) and the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), the theoretical hydropower potential is estimated at 56 GW countrywide (UPME, 2015). This includes 8,113 MW at plants of 20 to 40 MW, and 43,129 MW at plants larger than 40 MW. Of the total potential, 41.1 % is in the Magdalena Cauca hydrographic basin, 23.7 % in the Orinoco basin, 22.1 % in the Amazon basin, 6.8 % in the Caribe basin, and 6.4 % in the Pacific basin.

During 2017, Colombia increased hydropower installed capacity by 100 MW, with a focus on smaller capacity hydropower projects (IHA, 2018). As of February 2019, the total installed hydropower capacity is 11,771 MW (including 22 plants of at least 50 MW capacity), which is 68 % of total installed capacity (H&D, 2019).

About 55 % of the hydro capacity is privately owned. Three main utilities EPM (public), *Emgesa* (mixed capital) and ISAGEN (private) account for 75 % of installed hydropower capacity.

In 2015, a comprehensive atlas of Colombia's Hydropower Potential was launched (UPME, 2015). An extract of this atlas, including locations of small hydropower plants (10 to 20 MW of capacity) is shown in Figure 6.

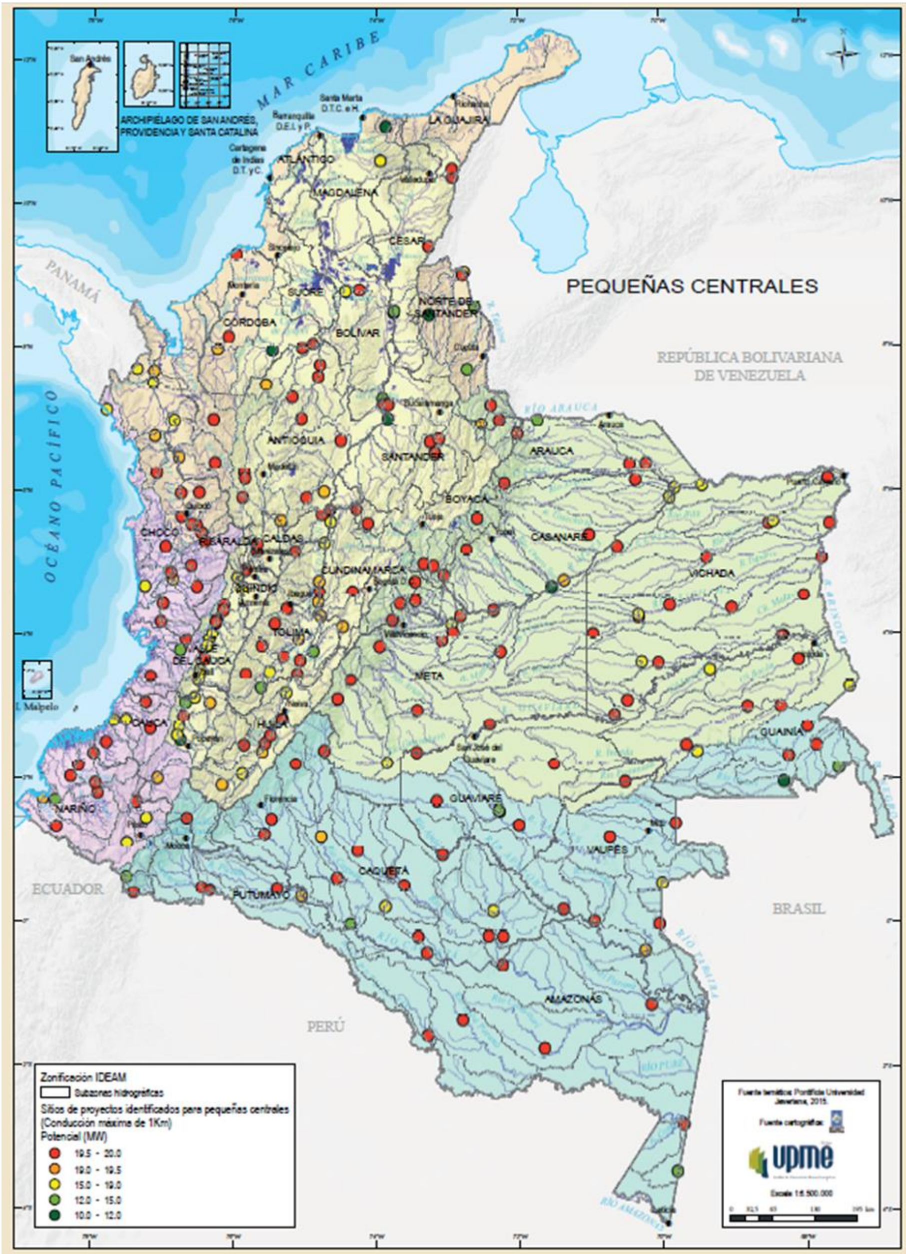

Figure 6: Location of small hydropower plants (10 to 20 MW) in Colombia (UPME, 2015)

In Colombia, the UPME has adopted the IEA definition of SHP, that involves a plant capacity less than or equal to 20 MW and that operates at run-off-river, with no water storage (Duque et al, 2016; Arias-Gaviria et al., 2017). Other sources indicate two times lower SHP capacity limit in this country – 10 MW (WSHPDR, 2019). Based on a study conducted by the Institute of Nuclear Sciences and Alternative Energies, SHP potential of 25,000 MW, located mainly in the Andean region, was included into the National Energy Plan. The above-mentioned atlas of hydropower potential (UPME, 2015) indicates 4,947 MW hydro potential for plants of up to 20 MW capacity.

The breakdown of distribution of potential for small hydropower plants by geographic regions in Colombia is shown in Figure 7 (Arias-Gaviria et al. 2017).

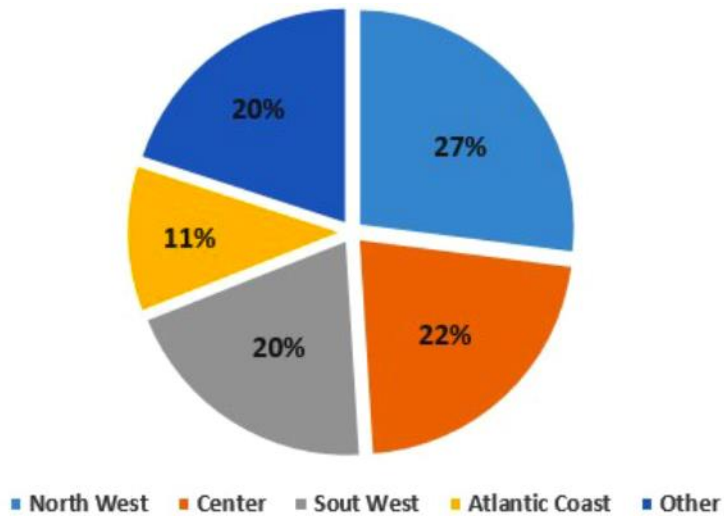

Figure 7: Breakdown of distribution of potential for small hydropower plants by geographic regions in Colombia (based on data of UPME)

As of February 2019, there were 831 MW of small hydro capacity in operation (H&D 2019). It should be pointed out that in 2014, the total installed capacity of SHP was 683 MW from which 620 MW were in operation, and 530 MW of these connected to the national grid (Arias-Gaviria et al, 2017).

There are some 35 SHP companies registered and trading energy through the stock market, with about 120 SHP stations and an installed capacity of 955 MW. Additionally, there are at least 200 smaller power plants, not registered at the stock market, and more than thousand abandoned or dismantled SHPs. There is no comprehensive, centrally processed data for such power plants. Therefore, the estimates for SHP plants vary a lot (Table 11).

Table 11: Colombia - Small hydro characteristics according to various sources

References	Potential, MW	Installed capacity, MW	Number of operating SHP	Comments
WSHPDR, 2019	25,000	215		SHP limit <10 MW
H&D, 2019		831		Limit of capacity not known

HYPOSO	4,947	955	ca 320	SHP limit < 20 MW

Small hydropower plants are owned and operated mainly by small municipal entities, natural persons and rural industries. The whole interconnected system is operated centrally by a governmental institution which runs the national energy bourse. The Colombian Government is currently working on the implementation of small hydropower projects in non-interconnected zones.

5 SHP policy and market analysis

The exploitation of Colombian hydro potential dates back to 1900, when a power plant of 1.86 MW was built to supply electricity to Bogota, the largest city and the capital of Colombia (Arias-Gaviria et al, 2017). Since then, more than 200 SHP plants have been built to electrify different regions in the country. By 1930, the installed capacity of SHP in Colombia had reached almost 35 MW and it continued increasing until the late 1960s. During the 1970's only, few plants were built, and some old ones were decommissioned, mainly due to lack of maintenance and the start of the roll-out of grid-connected large hydro. By the end of the 1980s, the cumulative installed capacity of the country was about 320 MW of SHP, but only about 50 % was in operation.

In the early 1990s, hydropower plants represented 80 % of the total installed capacity which made the Colombian electricity sector highly vulnerable to sufficient water availability. Low levels of rain caused by El Nino which caused in Colombia dry seasons more extreme and longer than usual, reduced the country's total water reserves below 40 % in 1992, and led to an energy crisis. The lack of government financing of the required expansion of the electricity system, and the ambition to increase the efficiency of the power sector were important driving forces for the deregulation of the power system and the establishment of a liberalized electricity market in 1994. The new electricity market was introduced with the Electric Law in 1994, by which the private sector started to participate in the electricity market, and different funds for rural electrification were created. As a consequence, programs for installation of SHP in both grid and non-grid connected areas have been developed, which led to an increasing interest in SHP with 363 MW being newly installed during the last three decades.

A comprehensive overview of SHP sector in Colombia is given in Morales et al. (2015). It considers current installed capacity and existing potential of hydropower resources, reveals the barriers that hinder the development of SHP in the country, presents main perspectives for the future.

In Colombia and the neighbouring countries SHP lobbying and other activities are implemented by CELAPEH - a non-profit organisation founded by six Colombian and international institutions (CELAPEH, 2020). The main goal is to promote SHP development in Latin America, especially in the rural areas, in order to provide environmentally sound electrical energy to the communities living in such areas. Main tasks include:

- Technical and financial pre-feasibility studies for public and private stakeholders of SHP projects;
- Promoting execution of feasible SHP projects by searching and managing, as appropriate, required technical and financial resources;
- Coordinating and managing execution of SHP projects upon request from public, private and institutional project stakeholders;
- Creating and running, with support of the Latin American and international institutions, a training center for SHP, equipped with physical and operational facilities as required to train people involved in design, construction, operation and maintenance of SHP stations and, at a future step, carry out applied research and technology development in regard with SHP;
- Providing the Latin American governments and public institutions with advice and support to formulate and implement policies aimed to foster rural electrification programs based on renewable energy sources and specially on the small hydro potential.

5.1 SHP policy

The small hydropower is integrated within the whole energy and hydropower sector. Notwithstanding this, mostly small hydro policy is to be highlighted herewith. Key legal documents making up the legal framework to which hydropower must comply are listed in Table 12.

Table 12: Colombia - Key legal documents regulating RES and hydropower

Name of legal document	Type of activities addressed	Website	Summary and impact on development of hydropower (small or large)
LAW 1715 OF 2014	Energy sector	http://www.secretariasenado.gov.co/senado/basedoc/ley_1715_2014.html	The purpose of this law is to promote the development and use of non-conventional energy sources, mainly those of a renewable nature, in the national energy system, through their integration into the electricity market, their participation in non-interconnected areas and other uses.
LEY 697 DE 2001	Energy sector	https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=4449	Through which the rational and efficient use of energy is promoted, the use of alternative energies is promoted and other provisions are issued.
LEY 1530 DE 2012	Environmental protection	http://www.secretariasenado.gov.co/senado/basedoc/ley_1530_2012.html	In accordance with the provisions of article 360 of the Political Constitution, the purpose of this law is to determine the distribution, objectives, purposes, administration, execution, control, efficient use, and destination of income from the exploitation of natural resources, specifying the conditions of participation of its beneficiaries. This set of income, allocations, organs, procedures and regulations constitutes the General System of Royalties.

A brief description of regimes for granting rights (concessions or authorisations) to use hydropower in Colombia is summarized in Table 13.

Table 13: Conditions for granting rights (concessions or authorisations) to use hydropower in Colombia

	Small Hydro (P < 20 MW)		Large Hydro (P ≥ 20 MW)	
	New permits (authorizations)	Refurbishment or relicensing	New permits	Refurbishment or relicensing
Type of permits needed	Environmental impact assessment (EIA), environmental mitigation plan, environmental license, basin study permit, permit to connect to the country's interconnected network; building permit, exploitation of construction materials, use of water, exploitation of forestry, water concessions, dumping permits and riverbed occupancy permits.	EIA, environmental mitigation plan, environmental licence, permit to connect to the country's interconnected network, exploitation of construction materials, use of water, water concessions, dumping permits	EIA, environmental license, basin study permit, permit to connect to the country's interconnected network, building permit, exploitation of construction materials, use of water, exploitation forestry, water concessions, dumping permits and riverbed occupancy permits.	EIA, environmental mitigation plan, environmental licence, permit to connect to the country's interconnecte d network, exploitation of construction materials, use of water, water concessions, dumping permits.
Numbe r of plants granted during 2017 to 2019 period	n/a	n/a	4	n/a

5.2 Industrial overview

Nearly 60 contacts of stakeholders involved in one or another way in the hydropower sector were identified in Colombia (HYPOSO D3.1, 2019). Only 9 of them are specifically involved in SHP activities. Over 50 technical or engineering universities, institutes are in the country. 3 famous European manufacturers of electrical and electronic equipment are operating in Colombia. Over 60 SHP owners and 10 generator producers are in the country.

There are 12 main companies involved in the generation of electricity in Colombia. They generate 90.3 % of the total electricity produced in the country, while the remaining 9.7 % is due to smaller companies. Most of these companies are in some degree involved in the hydropower sector. The list of the 12 major companies is presented in Table 14.

Table 14: Main companies in the generation of electricity in Colombia (UPME, 2018a)

Company	Installed capacity [MW]	Share
EMGESAS.A. E.S.P.	3,526.0	19.90 %
EMPRESAS PUBLICAS DE MEDELLIN S.A. E.S.P.	3,468.2	19.57 %
ISAGENS.A. E.S.P.	2,988.9	16.87 %
EMPRESA DE ENERGIA DEL PACIFICO S.A. E.S.P.	1,530.4	8.64 %
AES CHIVOR & CIA. S.C.A. E.S.P.	1,019.7	5.75 %
TERMOBARRANQUILLA S.A. E.S.P.	918.0	5.18 %
GENERADORA Y COMERCIALIZADORA DE ENERGIA DEL CARIBE S.A. E.S.P.	723.0	4.08 %
ZONA FRANCA CELSIA S.A E.S.P.	610.0	3.44 %
EMPRESA URRAS.A. E.S.P.	338.0	1.91 %
GESTION ENERGETICA S.A. E.S.P.	332.0	1.87 %
TERMOCANDELARIA S.C.A. - E.S.P.	314.0	1.77 %
CELSIA S.A E.S.P. OTROS AGENTES	233.8	1.32 %
Other	1,718.5	9.70 %
TOTAL	17,720.5	100 %

These companies are involved in four major fields of the power sector (Table 15).

Table 15: Colombia - Number of companies depending on their field of activity (UPME, 2018)

Year	2016	2017	2018
Commercialization	103	97	109
Distribution	31	31	37
Generation	65	76	87
Transmission	15	12	13

As a common rule all over the world, hydropower generation is also cost-effective in Colombia (Table 16).

Table 16: Comparison of average investment cost of the installed kW and cost per kWh produced for a range of power technologies in Colombia (Bonilla & González, 2017; Botero, 2020)

Type	US$/kW	US$/kWh
Wind	1200-1600	0.01-0.02
Small Hydro	900 - 3000	> 0.05
Solar	6000-10000	0.15
Geothermal	> 2400	0.01-0.016
Diesel	100-300	0.02- 0.08
Combined cycle	500-800	0.004-0.006
Coal	1250-1700	0.005-0.008

5.3 SHP economics overview

Some preliminary economic estimates for hydropower are presented in Table 17.

Table 17: Colombia - Key economic estimates for hydropower

Year: 2015-2019 (average)	Small Hydro (<10 MW)		Medium to Large Hydro (>50 MW)
	Low head (<20 m)	Medium (20 to 100 m) to high head (H>100 m)	
a) Average Investment cost (€/kW)	2,000		
b) Average Cost per kWh produced (€)	0.02		
c) Average O&M Cost (as % of total investment cost)	10*		6*
d) Average lifetime of the mechanical equipment (number of years)	45	55	65

* In Colombia estimated as % of energy production

Civil works consists of a major component of the total construction cost of SHP plant and constitutes up to 60 % of total investment costs in Colombia. Costs of research and studies for a SHP in capacity of few kW to 10 MW range between 1 to 7 % of the total (Osorio Londoño, 2017).

Indicative distribution of civil woks according to various components of erection of SHP plant is given in Table 18. They do not differ a lot from a common small hydropower practice.

Table 18: Colombia - Break down of distribution (percentage) of civil works of a small hydropower plant (Ramiro, 2005)

Type		Pico	Micro	Mini	SHP
Capacity (kW)		5	50	500	10,000
Works	Access road (% / km*kW)	0.0	0.0	0.0	4.1
	Dam (% / kW)	5.4	8.2	3.3	3.3
	Settling basin (% / kW)	11.4	11.5	14.6	10.0
	Penstock (% / km * kW)	0.1	0.1	0.1	0.1
	Power house (% / kW)	15.5	8.7	10.7	11.2
	Discharge (% / kW)	0.0	0.0	0.0	0.0
	Unforeseen works (% / kW)	4.9	4.3	4.3	3.4
	Mitigation measures (% / kW)	0.3	0.3	0.3	0.3
Total works (% / kW)		37.6	33.0	33.3	32.5
Hydro machines (% / kW)		37.5	45.3	48.5	52.5
Contingencies (% / kW)		3.0	3.6	2.4	2.6
Total equipment (% / kW)		40.5	49.0	51.0	55.1
Line transmission (% / km * kW)		0.5	1.0	2.6	0.5
Substation (% / kW)		0.2	0.3	0.9	0.5
Total transmission (% / kW)		0.7	1.4	3.4	1.0
Studies (% / kW)		5.5	4.2	1.8	0.9
Design (% / kW)		15.7	12.5	10.5	10.6

The Financial Support Fund for Energy Provision in Interconnected Zones (FAER) was created in 2000 by Law 633 of 2000. This fund has proven to be an important tool for the financing of projects in areas not connected to the national grid. The fund focuses on energy expansion using both renewable and non-renewable energy sources and has become an important instrument for financing projects in these regions. Another significant aspect of Law 633 is the creation of the Fund for Non-Conventional Energies (FENOGE), which will help to finance initiatives in nonconventional energy with public and international resources. Investors in renewable energy projects can obtain a 50 per cent annual deduction of taxable income for the first five years following an investment. Equipment and machinery are excluded from VAT and, if such equipment and machinery is imported, customs duties are exempted.

Finally, the government has regulated the self-generation (prosumption) of energy through Decree 2469 of 2014. Legal or physical persons will be considered prosumers if the electricity they produce is for their own consumption and if they do not use national transmission or distributions systems. However, if there are surpluses, prosumers may deliver electricity to the national network in accordance with the regulation established by the Energy and Gas Regulation Commission (CREG). Large-scale prosumers must be represented in the wholesale electric market by a distribution agent who will market the surplus to the National Network. In addition, large-scale self-prosumers have to enter into a backup contract with the network operator which sets out the fees and charges for the electrical energy distribution services performed by the operator (NRF, 2017).

A number of support schemes available for small hydropower are outlined in the Table 19.

Table 19: Colombia - Support schemes for hydropower

Support scheme	Support measures
FAER: Financial Support Fund for Electrification of Interconnected Rural Areas	It allows the electric distribution companies in their area of activity to manage prioritized investment plans, programs and projects for the construction and installation of the new electrical infrastructure within the SIN *(Sistema Interconectado Nacional).* Law 1376 of 2010 extended the support mechanism validity" December 31, 2018, on the other hand, Law 1753 increased its recourse to $ 2.10 per kilowatt hour dispatched on the Wholesale Energy Exchange
FAZNI: Financial Support Fund for Electrification of Non-Interconnected Areas	The objective of this fund is to finance plans, programs and projects for investment in energy infrastructure in non-interconnected areas. It was also indicated that the resources will be $ 1.00 for each kilowatt hour dispatched in the Wholesale Energy Exchange. Since 2016 there was introduced new incentive for dispatched electricity (Wholesale Energy Exchange Bourse).
PRONE: Electrical Network Standardization Program	Its purpose is to finance plans, programs and investment projects for the normalization of electricity networks located in municipalities within the SIN. PRONE's resources were increased by Law 1753 to $ 1.90 per kilowatt hour dispatched on the Wholesale Energy Exchange

6 Educational framework

The Colombian higher education system is composed of technical institutes focused on vocational education, university institutions focused on technological education, and universities focused on undergraduate and postgraduate education. The country has both public and private universities (more than 110). Most public universities conform to the State University System, and most departments have at least one public university. Several private universities are affiliated to the Roman Catholic Church or are non-sectarian.

Hydropower subject is included in many universities study programs (Table 20). However, there is an urgent need for practical operation and training in SHP.

Table 20: Colombia - List of universities or institutes offering hydraulic / water related subjects

No	University	Hydropower study and different program
1	Universidad Nacional	Yes
2	Universidad de los Andes	Yes
3	Universidad Pontificia Javeriana	Yes
4	Universidad de Antioquia	Yes
5	Universidad de Medellin	n/a
6	Universidad Pontificia Bolivariana	Yes
7	Escuela de Ingenieria de Antioquia	Yes
8	Universidad Industrial de Santander	Yes
9	Universidad del Valle	Yes
10	Over 50 universities and institutes, each with several engineering and technology faculties	n/a

7 Research situation and needs

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

The fundamental research work on hydropower engineering is not carried out in Colombia, because necessary facilities at universities or research entities are not available

Based on the conducted survey 9 R&D projects were identified as carried out by the Universidad Nacional de Colombia, Universidad Católica de Colombia, Universidad Distrital Francisco José de Caldas and Universidad Libre de Colombia between 2011 and 2018. Two projects of this package were exclusively designated to large hydropower and analysed cost issues and endangered species. The other two projects dealt with micro and mini hydro and the remaining ones investigated micro, small and medium hydro.

A PhD thesis on optimising management of the hydropower reservoirs in a cascade was prepared. One project analysed possibility of incorporating a small hydropower plant into a micro-grid o at the local distribution system. A physical laboratory model of an electricity generating unit using hydraulic ram phenomenon as applied to the stored rainwater was investigated. Other projects dealt with technical and economic performance of turbines at SHP plants as well as predictive maintenance of generators. There should be mentioned also master theses carried out at universities (cited in this report).

The development of the already mentioned Atlas of Colombia's Hydropower Potential is to be highlighted in this context. The Atlas was produced in 2015 by the Energy Mining Planning Unit (UPME) in conjunction with *Colciencias* (the Administrative Department of Science, Technology and Innovation) and the Javeriana University. As proponents affirm, this atlas is a tool that guarantees adequate planning for the country's energy supply. To elaborate it, research groups from the Javeriana University, with the collaboration of the Agustín Codazzi - IGAC Geographical Institute - were created. The latter provided the base cartography of the maps. The Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) provided hydrological data on flows and water availability in rivers (UPME, 2015).

The Law 697/2001 makes available incentives for research and development in the field of SHP. Moreover, the Government's recent engagement to determine the quantity and localities of non-conventional energy sources (*Fuentes No Convencionales de Energia*) is in the process of producing SHP potential map (WSHPDR, 2019).

Among others, CELAPEH is looking for possibilities to create and operate, with support of Latin American and international institutions, a training center for SHP. It should be equipped with physical and operational facilities as required to train people involved in design, construction, operation and maintenance of SHP plants and, at a future step, carry out applied research and technology development in regard with SHP. It would be the best way to facilitate European technology transfer from laboratory to the market and keep its leadership in this field.

A short review of the papers published in peer-reviewed journals available at ScienceDirect data base revealed that applied research level for Colombian hydropower sector is quite satisfactory. Some of their papers are cited in this report.

8 SHP financing opportunities

No SHP specific financing funds or institutions are available. In the future it is expected to get financial resources from the Climate Change Fund.

There are many credit sources: public institutions, international institutions, private investors, commercial banks. Loans cover average 70 % of required investment. 30 % must be own capital. Major part of SHP project owners does not have enough resources to cover pre-investment costs, even for less than 30 % share of investment. The majority of SHP projects are not bankable.

Large hydroelectric projects are mainly financed through a mix of multilateral development banks loans, commercial banks loans and own resources. For SHP projects following financing schemas are used:

- For private developers, own resources, commercial loans and investors participation
- PPA and public development funds for public project developers
- Government funds and international development agencies for mini and micro power stations at isolated areas to benefit poor rural communities

There is a government fund to finance energy solutions (as much as possible based on RES) to the poorest and most isolated communities outside the interconnected zones. However, funding rules require the benefitted communities to dispose of a certain level of organization and resources, which in many cases cannot be provided.

9 Environment

The Ministry of the Environment and Sustainable Development is a national-level public entity for dealing with the management of the environment and renewable natural resources. The National Authority for Environmental Licenses (ANLA), under the Ministry of Environment and Sustainable Development, has published new terms of reference for the preparation of environmental impact studies for the construction and operation of hydropower plants. To begin construction, hydropower projects over 100 MW need to obtain an environmental licence from the Ministry of Environment and Sustainable Development, while those under 100 MW need to obtain a licence from the Regional Autonomous Corporation.

In January 2017, ANLA denied, for the second time, the environmental licence to the 960 MW Cañafisto hydropower project. Isagen (a private energy generation and commercialization company with seven generation plants totalling 3,032 MW out of which are 2,732 hydraulic and 300 thermal) is already undertaking feasibility studies for an alternative project that would be a smaller version of the original one with 380 MW of installed capacity (IHA, 2018).

Following a ministerial meeting in September 2017, Colombia's Ministry of Environment and Sustainable Development and China's Ministry of Water Resources announced a Memorandum of Understanding to cooperate and advance shared interests in hydraulic infrastructures and flood protection.

The National System of Protected Areas (Spanish: *Sistema Nacional de Áreas Protegidas,* SINAP) is the Colombian national park administrator. It is a department under the Ministry of the Environment, Housing and Regional Development responsible for the conservation and sustainable use of biological diversity. In total 59 areas belong to the National Natural Parks System, covering 169,545 km^2. The areas are categorized in six divisions, defined in Article 329 of *Código de Recursos Naturales (CNR*): national parks (*parques nacionales*), flora and fauna sanctuaries (*santuarios de fauna y flora*), flora sanctuaries (*santuarios de flora*), nature reserves (*reserva natural*), unique natural areas (*área natural única*) and road parks (*vía parque*).

10 Barriers to SHP development

The main challenges to consider for developing small hydropower projects in Colombia are, but not limited to (WSHPDR, 2019) the issues as below:

- There are substantial climatic variations in Columbia, which produce lower rainfall impacting energy production.
- The Government is inclined to reduce concrete SHP promotion strategies and incentives in order to slow down SHP development and implementation in Colombia due to the fear of high dependency on a climatic vulnerable energy source.
- Although microfinance institutions (MFIs) are available in Colombia, only three out of the 29 MFIs offer low income loans for micro-, small, medium and large borrowers, thus significantly reducing the support available for SHP investors.
- There is a lack of support systems to identify mechanisms that could be better suited to the characteristics of Colombia.
- There is a deficit in outlined budgeting for scientific research and development.
- Technical norms need to be defined and standardized.
- Rural and urban technical support is lacking.
- Local political instabilities also hinder foreign investment in SHP as many sites are located in areas where guerrilla activities have taken place.

11 Future prospects

Despite the untapped large hydropower potential and the developed atlas of hydropower potential in the country, comprehensive data regarding small hydropower potential is not available. Large numbers of potential sites have not been evaluated (or even identified) because they are mostly located in the upper parts of basins, with very difficult access. Furthermore, there are numerous abandoned hydropower plants in Colombia.

However, concerns about the environmental impact of hydropower, and the fact that large-scale hydroelectric plants are already located in the best places, are likely to put a halt on further developments in SHP sector (NRF, 2017).

In the near past, Colombia's hydropower sector has experienced a negative impact of droughts. It is evident that the climate change is jeopardizing the future of hydropower plants. Uncertainties are to be considered about the prospects for this type of power generation, given estimates of significant drought periods in the long run.

The high share of hydroelectric resources in the energy matrix makes electricity generation dependent on climatic variables. Specifically, the El Niño weather phenomenon causes periods of droughts that force the generation system to temporarily increase thermal generation. For instance, in December 2015 El Niño caused a drought during which thermal generation accounted for 44,6% of total electricity production, in comparison to December 2014 when thermal energy accounted only for 26,6% of overall electricity generation (Zárate M.T.N. & Vidal A.H.,2016)

11.1 Large hydro

In total, 125 hydropower projects are in the pre-feasibility stage according to the Energy and Mining Planning Unit (UPME), under the Ministry of Energy and Mines. These would add about 5,600 MW to existing installed capacity. By comparison, over 300 solar and wind projects are also registered, representing 2,775 MW of additional installed capacity (IHA, 2018).

According to the H&D (2019) some 212 projects were registered by June 2016, with a total capacity of 7,585 MW, including 128 hydropower projects with a total capacity of 4,227 MW.

11.2 Small hydro

There is a Central Register Office for projects planned for construction. As of February 2019, there were thirty more small plants, with a total capacity of 285 MW, having their feasibility studies or designs ready (H&D, 2019).

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Cameroon

1 Key facts

Population	about 24 million	2017 census
Area	475,000 km^2	
Access to electricity	63.57	2017
Installed hydro capacity	947 MW	2017
Hydro capacity under construction	80.7 MW	2019
Share of generation from hydropower	73 %	2017
Hydro generation	5,090 GWh	2017
Economically feasible hydro potential	105 TWh/year	
Small hydropower potential	630 MW	2016
Small hydropower installed capacity	>15 MW	2020

The Republic of Cameroon is a sub-Saharan African country, *located* at the Gulf of Guinea *in* Central and West Africa.

1.1 Climate

Cameroon is sometimes described as "Africa in miniature" because it exhibits all the major climates and vegetation of the continent. The country can be classified into four zones differentiated by geography, climate and vegetation: the Sudano-Sahelian, the savanna, the coastal, and the tropical forest This climate varies with terrain, from tropical along the coast to semiarid and hot in the north near Chad. Exceedingly hot and humid, the coastal belt includes some of the wettest places on earth. For example, Debundscha, at the base of Mount Cameroon, has an average annual rainfall above10,000 millimetres (Molua & Lambi, 2006).

1.2 Topography

There are four geographical regions. The western lowlands (rising from sea level to 600 m) extend along the Gulf of Guinea coast and average about 100 km in width. The north-western highlands consist of forested volcanic mountains reaching over 2,440 m in height. The central plateau region extends eastward from the western lowlands and northwest highlands to the border with the Central African Republic and northward to the Bénoué River. It includes the Adamawa Plateau, at elevations of 900 to 1,500 m. This is a transitional area where forest gives way to savanna. The northern region is essentially a vast savanna plain that slopes down to the Chad Basin.

1.3 Water resources

Average annual precipitation is 1,600 mm. It is highest in the coastal and mountainous regions. The country's two rainfall regimes (unimodal and bimodal) show a gradual reduction in amount from the coastal region in the south to the Chad plain in the north.

The main catchment basins are: the Atlantic basin, the Congo basin, the Niger basin, and the basin of Lake Chad tributaries. The Sanaga River, flowing into the Atlantic Ocean and with discharge reaching 2,000 m^3/s is the country's longest river (920 km). Its catchment basin covers approximately 140,000 km^2 or 30 % of the country's territory.

A representative indicator of the hydroelectric potential of a country is the density of hydropower potential called also specific potential and defined as the technical hydropower potential (or sometime gross theoretical) per area unit (square kilometre) of the country. For Cameroon it is estimated to be 0.24 GWh/year per square kilometre. To compare, for Austria and Norway this specific indicator is around 0.66 and Brazil - 0.15 GWh/(year·km^2).

2 Power sector overview

MINEE (*Ministere de l'Eau et de l'Energie*) and the Electricity Development Corporation (EDC) are responsible for the energy sector in Cameroon. The utility company ENEO, which replaced AES-SONEL, is in charge of the generation and distribution of electricity. The National Company for Electricity Transmission Network (SONATREL) is the TSO (voltage above 30 kV). ENEO, Kribi Development Corporation (KPDC), Dibanba Development Corporation (DPDC) and the Emergency Thermal Programme (PTU) supply all electricity to the national grid (H&D, 2019).

The Rural Electrification Agency (AER) is in charge of promoting rural electrification and managing the Rural Energy Fund.

The Electricity Sector Regulation Agency (ARSEL) approves electricity tariffs and determines electrical standards. The Agency also monitors the sector's activity and financial equilibrium, examines concession licence applications, authorizes electricity generation and distribution in rural areas, protects consumers, promotes competition and facilitates private sector involvement. The Electricity Development Corporation (EDC) is a state-owned company that is in charge of the development of the electricity sector including all hydropower projects.

A development plan for the electricity sector, known as PDSE 2030 (*Plan de Developpement du Secteur de l'Electricite Horizon 2030*) was established in 2006 and updated in 2014 to meet the 2035 energy target. This Electricity Sector Development Plan presents estimates of the rate of energy consumption within the country up to 2035. Cameroon also intends (since cop21 in France) to increase the share of renewable energy in energy mix from 1 % to 25 % by 2035. It recommends development of hydropower plants, interconnection between the south grid and the north grid, and also interconnection with neighbouring countries. Along it, the government points out that hydropower sources are vulnerable to drought, thus threatening the country's energy security. Therefore, there is a need to diversify Cameroon's energy mix to ensure energy security.

The total installed capacity of all powerplants (as of 2017) is 1,529 MW, of which 816 MW is hydro. Total production in 2017 was 6,973 GWh (latest available data), of which 5,090 GWh was contributed by hydro (73 per cent) (H&D, 2019). About 26 % of national electricity production is based on the use of imported fuels (Figure 8).

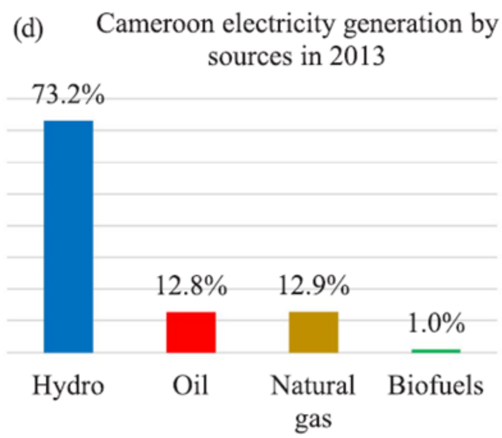

Figure 8: Cameroon - electricity generation by source in 2013 (Muh et al, 2018)

3 Renewable electricity policy

In spite of the well-established power sector framework, there is still a lack of adequate regulation and institutional setting for the off-grid and on-grid, renewable energy and energy efficiency sectors. The government is currently working on a specifically dedicated text for renewable energies and another on energy efficiency. In order to meet up with all the aforementioned challenges, Cameroon possesses a significant amount of resources to enhance the supply of electrical power.

While many developing countries already have specific renewable energy policies, some form of national policy targets or support scheme for renewable energy, Cameroon is still putting in place specific renewable energy targets and promotion policy. In 2005, the government of Cameroon developed the National Energy Plan for Reducing Poverty (Egute et al, 2017). It has key strategic areas which include capacity building of stakeholders in management, planning, operation and maintenance of energy systems; rural energy; productive uses of energy and promotion of private sector investment in rural electrification. In addition, the country is finalizing a very large electrification program including interconnection of the south and north grids. This will lead to a high increase of the demand.

4 Hydropower potential and sector

The country has the fourth largest hydropower potential in Africa behind the Democratic Republic of Congo, Madagascar, and Ethiopia (Kenfack and Hamandjoda, 2012). But harnessing of hydropower resource started relatively recently, some 70 years ago (Figure 9).

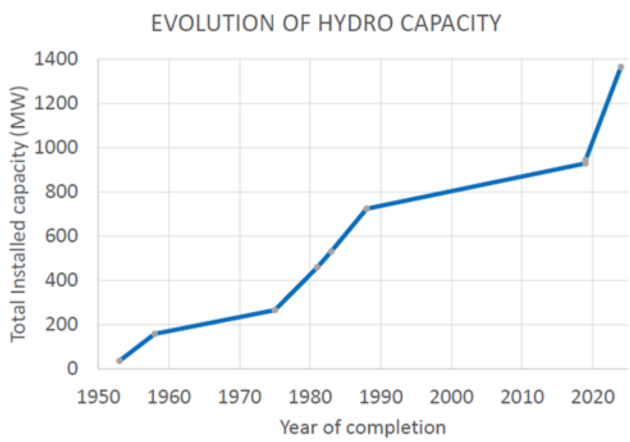

Figure 9: Cameroon - Evolution of hydropower capacity (Kenfack, 2019)

Preliminary sites locations are shown in Figure 10.

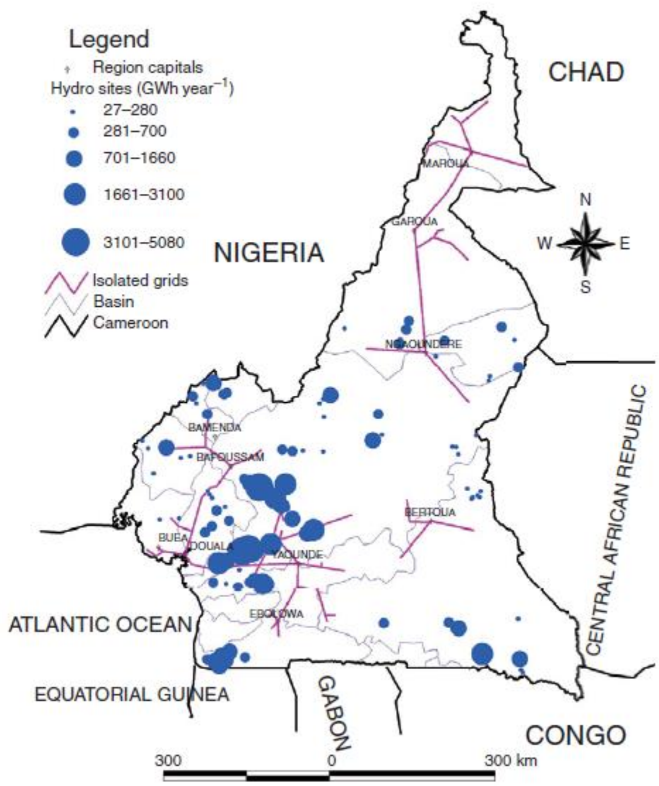

Figure 10: Location of hydropower sites in Cameroon (Kenfack and Hamandjoda, 2012)

The gross theoretical hydro potential of Cameroon is 294 TWh/year. Of this, 115 TWh/year is considered technically feasible, and 105 TWh/year economically feasible (Figure 11, average annual generation is 2017 estimate). Only about 4 per cent of the technically feasible capacity has been developed. There was 816 MW of hydro capacity in operation (in 2017). The total installed capacity of all power plants (as of 2017) is 1529 MW, of which 816 MW is hydro. Total production in 2017 was 6,973 GWh (latest available data), of which 5,090 GWh (73 %) was contributed by hydro (H&D, 2019).

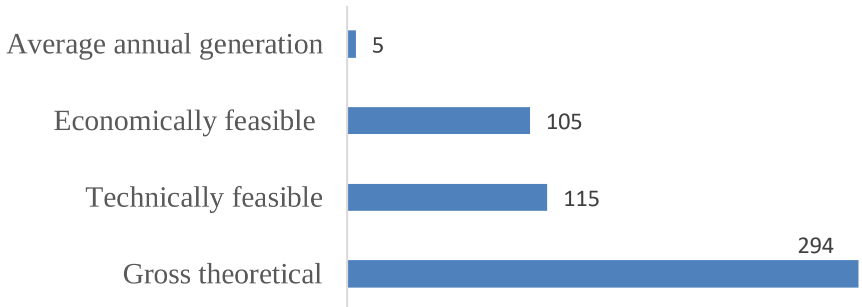

Figure 11: Hydropower potential in TWh/year in Cameroon (H&D, 2019)

As of 2019, only 8 hydropower plants are operational or under construction, out of which three are small schemes in the country (Figure 12).

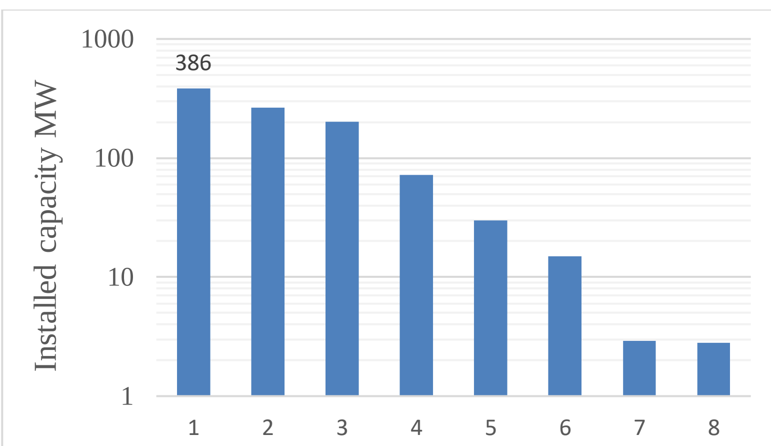

Figure 12: Operational hydropower plants sorted by installed capacity in Cameroon

There are five hydropower plants in operation with individual capacities greater than 10 MW (Lagdo, 72 MW; Edea, 276 MW; Songloulou, 384 MW; Memve'ele (80 MW - to be uprated to 211 MW) and, Mekin, completed and under commissioning, 15 MW). All hydropower capacity is owned and operated by ENEO-Cameroon, independent power producers Dibamba Power Development Corporation, Kribi Power Development Company and now the state with Mekin and Memve'ele.

The upper capacity limit of SHP in Cameroon is 10 MW. The complete assessment of small hydropower potential is yet to be done. It is believed that Cameroon has the second largest small hydro potential in middle Africa - behind Angola. The country is still looking for funds to make an in-depth assessment of the small hydro potential. A very preliminary list of locations of sites for potential micro to small hydropower plants is freely accessible (ONUDI, 2019).

As of 2017, the installed capacity of SHP was at least 1 MW, however, comprehensive and accurate data on total installed capacity are not currently available (Table 21). The small hydropower potential is estimated to be at 970 MW (WSHPDR, 2019). Other sources provide SHP power generation potential estimated at 1.115 TWh, concentrated mainly in the Western and Eastern regions (Nematchoua et al. 2015). Recently, erection of the first private installation - the 1.4 MW Mbakaou Carriere SHP was initiated.

Table 21: Cameroon - Small hydro (<10MW) characteristics according to WSHPDR

Reference	Potential, MW	Installed capacity, MW	Number of operating SHPs	Comments
WSHPDR, 2019	970	1.0	1	2017 data

The 2.9 MW Gassona Falls (ERD Rumpi project) is under construction and it is reported that the total of 15 MW of small hydro capacity is at the planning stage in the Southern and South-western regions, which could produce more than 105 GWh/year. About 20 small schemes have been identified for the next 10 years (H&D, 2019).

5 SHP policy and market analysis

Despite the fact that hydropower sector is still not well developed in Cameroon, a large number of stakeholders (some 60) are involved in one or another way in the sector (HYPOSO D3.1, 2019). This clearly shows that Cameroon is experiencing economic growth accompanied by increasing energy demand and inadequate supply and therefore hydropower market is rapidly expanding. Seven of these stakeholders represent EU companies (including UK), 12 - China and 1 - USA. Research and training entities account for 5.

5.1 SHP policy

It is obvious, that small hydropower is integrated within the whole energy and hydropower sector. Notwithstanding this, mostly small hydro policy is to be highlighted herewith. Key legal documents making up the legal framework to which hydropower must comply are listed in Table 22.

Table 22: Cameroon - Key legal documents regulating RES and hydropower

Name of legal document (not older than 5 last years but those still in force)	Type of activities addressed	Summary and impact on development of hydropower (small or large)
Law N ° 2011/022 of 14 December 2011 governing the electricity sector, which replaces Law n ° 98/022 of 24 December 1998;	Electricity sector	Texts related to the sector
Decree No. 2012/2806 / PM of 24 September 2012 implementing certain provisions of Law No. 2011/022 of 14 December 2011 governing the electricity sector in Cameroon	Electricity sector	
Decree No. 2001/021 / PM of 29 January 2001 fixing the rate, the methods for calculating, recovering and distributing the royalty on the activities of the electricity sector	Electricity sector	Tariffs
Decree No. 2000/464 PM of 30 June 2000 governing the activities of the electricity sector	Electricity sector	Texts governing the sector
the order n ° 0193 / A / MINEE of April 28th, 2014 concerning the composition of the files of the application for concession, license, authorization and declaration, as well as the expenses relating thereto which replace the decree n ° 061 / CAB / MINMEE of January 30, 2001	Electricity sector	Files for titles
Law N° 96/12 of 5th August 1996 Relating to Environmental Management in Cameroon	Environmental protection	EIA
"Decree N° 2001/718/PM of 3 September 2001 The organization and functioning of the Interministerial Committee on the Environment"	Environmental protection	EIA
"Decree N° 2005/0577/PM of 23 February 2005 Defining the conditions for undertaking EIA"	Environmental protection	EIA

"Ministerial Order N° 0069/MINEP of 08 March 2005 - Defining the categories of operations subject to EIA"	Environmental protection	EIA
"Rule n° 0070/MINEP of 22nd April 2005 fixing the different categories of operations submitted to the realization of an EIA (article 19 of the law)"	Environmental protection	EIA
Law No. 98/005 dated 14 April 1998 – relating to water (the "Water Act");	Environmental protection	
"Decree No. 2001/164/PM dated 8 May 2001 – "Decree on Utilisation of Water", which sets the conditions of utilisation of water for business or industrial purposes"	Water management	Water use
"Decree No. 2001/165/PM of 8 May 2001 decree on the "Protection of Water", which sets the conditions of the protection of surface and groundwater against pollution"	Water management	Water protection

Learning conditions for granting water rights and authorisations to use hydropower (concessions or permissions) is the first step for potential investors. Type of permits needed & average time for a small hydro scheme are as follows:

Production License (6 months procedure) + Approval of Environmental Terms (around 8 months) + Power Purchase Agreement (3 months) + Declaration of public interest (up to 1 year) = around 3 years' time to take all the licenses. Several actions can be initiated simultaneously. The duration of permits (concession) can be granted up to 35 years.

For comparison, to develop large hydro scheme all procedures require more or less the same time.

5.2 Industrial and economic overview

Less than 28 % of rural areas and only 63.57 % of the population of Cameroon have access to electricity grid. Irrespectively of the above, Cameroon has a huge hydropower potential which could be harnessed. Mini grids, powered by pico- and micro- hydropower plants, are a relatively new rural electrification strategy in Cameroon. Several of such mini grids have been developed in the mountain regions of the country (Ministry of Energy, 2018).

There are many sites suitable for small hydropower facilities, however so far, they have not been developed. Only few companies are involved in the small hydropower sector (*EdF*, *IED-Invest,* *Synohydro*). Hydropower equipment manufacturing industry does not exist at all. But this situation is going to change very soon (see "Future prospects).

Average investment cost for small (low head <20 m) and medium to large hydro (>50 MW) schemes is 2,689 and 3,482 (€/kW), respectively. Average cost per kWh electricity produced is 8.3 and 6 eurocents, respectively.

No feed-in tariff system to support renewable electricity deployment has been introduced. But cost of service to ensure cost effectiveness of projects exists. ARSEL is responsible to assure the operator to obtain average profits in normal conditions of activity.

Investment support for large hydro is available, needed to be arranged with the government.

6 Educational framework

There are nine state-run universities in Cameroon: Buea, Bamenda, Douala, Yaounde I & II, Dschang, Maroua and Ngaoundere and Ebolowa. Cameroon's tertiary education is made up of thriving private universities such as the Bamenda University of Science and Technology (BUST), International University, Bamenda and the Fotso Victor University in the Western province.

However, there is no narrowly specialised hydropower or hydropower engineering study program in the country education system. Hydropower is usually part of renewable or energy studies or even civil, power or mechanical engineering. At least 4 universities are offering undergraduate degrees. Only one is providing the master studies (Table 23).

Table 23: List of universities in Cameroon offering energy and hydropower engineering subjects

No	University	Hydropower study and different program	Hydropower as part of renewable or energy studies	Topics included syllabus	Basic knowledge courses
1.	University of Yaounde I (Polytechnic)	Master of energy	yes, but less than 15 hours	general knowledge	Renewable energy
2.	University of Maroua (Polytechnic)	Bachelor program	yes	ongoing	Comprehensive renewable knowledge
3.	University of the Mountains	Pico and micro hydro	yes, but pico and micro	general knowledge	Renewable energy

4.	University of Dschang	Pico and micro hydro activities	yes, but pico and micro	general knowledge	Renewable energy
5.	University of Douala	no	no	general knowledge	Renewable energy

There are a number of NGOs, international organisations and associations promoting hydropower in the country (Table 24).

Table 24: Organisations established in Cameroon and acting in hydropower sector

No	Organisation	Contact person	Educational level in the organisation
1.	Friedrich Ebert foundation	Nina Netzer	Dialogue facility
2.	UNIDO	Francis Nzukou	Hydro promotion program under completion
3.	GIZ	Projects office	n/a
4.	France Development agency		n/a
5.	State Secretariat for Economic Affairs SECO (Switzerland)		n/a
6.	ICOLD	Adrien Towa	n/a

Main gaps to bridge the knowledge for small hydro in universities are as follows (Table 25).

Table 25: Cameroon - Identified needs for improving knowledge level at universities

No	Level	Identified needs
1.	University of Yaounde I (Polytechnic)	Master program in small hydro and equipment of hydro lab
2.	University of Maroua (Polytechnic)	Creation of hydro lab and curricula
3.	University of the Mountains	Establishing the curricula for micro hydro
4.	University of Dschang	Establishing the curricula for micro hydro

5.	University of Bamenda	Establishing the curricula for micro hydro, create a lab

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

- Small hydro laboratory exists in University of Yaoundé I (Polytechnic) designated for bachelor, master and PhD students, but needs equipment upgrade and a small hydro curriculum;
- First hydropower engineers have been trained at University of Maroua. The curriculum needs revising and updating, furthermore, operational hydro plants are too distanced from the university more than 600 km (for placement students to vocational practice);
- The same is valid for master programs;
- Didactic micro hydropower equipment is available at University of the Mountains in Bangangté, but needs putting in place hydropower course;
- SHP pilot projects should be promoted for students training.

7 Research situation and needs

7.1 R&D projects

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

Only one R&D project conducted by University of Yaoundé has been reported related to establishment of small hydro laboratory. A couple of applied projects dealing with micro hydro power plants were completed at National Advanced School of Engineering, University of Yaoundé (Kengne Signe et al, 2017, 2019).

The search of the publications (mainly papers in peer reviewed journals in English) in ScienceDirect database (a website which provides subscription-based access to a large database of scientific and medical research) revealed that hydropower research is progressing in this country.

At least a dozen papers directly or indirectly related to hydropower issues were published during last 8 years in the scientific journals of Renewable Energy, Renewable and Sustainable Energy Reviews, Energy Procedia, Energy Policy, Environmental Science & Policy. Papers and other publication written by Cameroonian researchers and directly referred to hydropower are present in the bibliography list.

7.2 Research needs

The most needed, small hydro oriented research directions are well recognised and already reflected in the abovementioned bibliography. The following needs may be considered essential from the point of view of human life quality and natural environment protection:

- further recognition of the hydropower potential of the country;
- development of technologies suited for electrification of remote areas;
- better understanding of hydropower multi-aspect environmental impact.

Some more detailed research topics are listed below:

a. hydrology studies aimed at development of ever more detailed hydrological characteristics of rivers and other water courses, including the climate change impact on the country water balance;
b. identification of the most suitable small hydro development sites so as to prepare the basis for developing the national small hydro master plans;
c. analysing technical and economic feasibility of applying some innovative technologies (e.g. hydrokinetic turbines) in remote areas of the country;
d. hybrid installations with hydropower components for isolated grids in remote areas, including dedicated smart grid software;
e. optimised management of multipurpose river cascades;
f. environmental studies aimed at determining the current status at selected water courses so as to streamline future environmental decisions;
g. environment friendly hydropower technologies.

8 Environment

The Ministry of Environment and Nature Protection is responsible for environmental protection in the country. A Law on the Environment was enacted in 2005 by the Government, concerning the assessment of all types of project and operational units.

The Ministry of Water and Energy (MINEE) is responsible for water resources. Water for industrial and domestic consumption is supplied by *La Camerounaise des Eaux* (CDE). Cameroon Water Utilities Corporation (*Camwater*) manages the infrastructure used for water supply.

In Cameroon, all land belongs to the state. The Cameroon legislation makes provision for 33 % of the national territory to be classified as protected areas. The Ministry of Forestry and Wildlife is responsible for the management of its protected areas. Mapping of protected areas evolution in Cameroon is given in Tchindjang et al. (2005).

9 Barriers to SHP development

The progress in renewable energy in Cameroon is hindered by several issues: inadequate policies, regulations and institutions; information, awareness and technical capabilities; and financial constraints due to the high initial capital investments associated with the implementation of renewable. Insignificant financial resources are devoted to the development of renewable energy in Cameroon despite its vast potentials (Muh et al, 2018).

The main challenges to consider for developing small hydropower projects in Cameroon are, but not limited to (WSHPDR, 2019):

The Government is favouring large hydropower schemes - expected to export electrical energy to the neighbouring countries;

Renewable energy development framework, rules and conditions have not been established yet;

Low energy prices are not very attractive for private investments;

Scarce information hydrological, climate and other statistical data, especially for rural areas, are available;

Private investments are not well favoured, it is hard to establish a private company in hydropower sector;

Acceptance and development of an economically viable and competitive private hydropower project price is a true challenge

Hydropower projects encounter low social acceptance and heavy bureaucracy obstacles in their initial stage

Some rural communities hardly accept hydropower projects due to local tradition linked with ancestral uses of water

From the point of view of potential investor in small hydro the following barriers are to be expected:

- No support for start-up companies in private sector, means no money for equity;
- Only local commercial banks available instead of investment banks;
- XAF (Central African CFA Franc) financing mechanism is very expensive (very high interest rate);
- Lack of guaranty from the governments or local banks;
- Risk of devaluation for XAF mechanism (not controlled locally);
- Difficulties in money transfer issues (not easy);
- No support for funding project maturation process;
- No data bank for projects to be developed ;
- Lack of accurate data on the potential, leading to poor reliability of financial models.

10 Future prospects

10.1 Large Hydro

The substantial hydropower potential presents many investment opportunities for the future. Cameroon shares borders with all CEMAC countries, has the highest gross national product and the greatest hydro potential. Given this large hydro potential, the development of hydro plants could make the country a net electricity exporter in the future. Four neighbouring countries, Chad, Nigeria, Gabon and Equatorial Guinea, have already expressed interest, and there are plans to build transmission lines between the four countries as soon as more hydro plants are developed (H&D, 2019).

However, the negative effect of climate change should be underlined. So far persistent power outages used to take place throughout the country, especially in the dry seasons when water levels in reservoirs are low (Muh et al., 2018).

The Lom Pangar dam is already under operation at the Lom river and the 30 MW plant is under construction at the toe of the dam. Construction of Bini a Warak HPP (75 MW) is underway in the Adamoua region. The Lom Pangar dam will increase the year-round production capacity of the two hydropower plants on the Sanaga river, Edea and Song Loulou, with the interconnection of the Northern and Southern grid The dam will also enable development of a cascade of hydro plants to be built downstream.

Private developer *Joule Africa* plans to implement the 485 MW Kpep scheme. This will be the first stage of a cascade development, which could eventually have a total capacity of 850 MW. The project is scheduled for completion within three years.

Another private developer, *Platinum Power*, is expected to construct the Makay complex (400 MW) on the Nyong river.

Meanwhile, financial closure has been reached, and all final agreements signed, for the 420 MW Nachtigal scheme. The plant is now under construction. A consortium of French, Belgian and Moroccan contractors were awarded the construction contract in 2018. Final binding agreements for the scheme were signed between the EdF, the IFC, and the Government of Cameroon. In January Mott MacDonald was appointed as the lenders' technical advisor, and also early this year the World Bank Group's Multilateral Investment Guarantee Agency (MIGA) issued guarantees worth € 164.5 million to the investors, and it was announced that construction would begin shortly.

A project development agreement is ongoing for the 398 MW Songdong scheme.

EDC invited recently (2019) expressions of interest to carry out a study for the optimal development of the hydropower potential of the Sanaga river basin. The selected consultant will review and update the Sanaga water resources inventory, taking into account existing developments, and outline studies for each hydropower site. Studies are also ongoing for the development of Grand Eweng project (up to 1,800 MW).

The 600 MW Chollet scheme is planned to be developed with the Republic of Congo. It will be built on the river Dja, on the border of the two countries. Both governments are committed to implementation of this scheme, on which agreement was reached in late 2014.

10.2 Small hydro

About 20 small schemes have been identified for the next 10 years. There are a number of plants (20 kW to 3 MW) abandoned due to grid extension and political instability (civil war in some regions). A very preliminary list of locations of sites for potential micro to small hydro plants is freely accessible (ONUDI).

The Cameroonian government is struggling to cope with a low electricity access rate in the country. The lack of private investment is the root cause for the low electricity access rates in rural areas in Cameroon. Therefore, it has drafted policies favouring participation of private investors in the sector that started working.

Tens of memorandums of understanding (MoU) from a few MW to hundreds of MW in hydro capacity are being concluded. The companies are coming from almost all over of the world.

Companies with memorandum of understanding (MoU) for projects above 5 MW are listed below:

- Asian Pacific; Hydrochina Corporation; Grenor Cameroon SA;
- A2Z Maintenance & Engineering Services Limited & Eurofina S.A.; Club Millenium; African Energy Company; Hydromine Inc; TBEA; Kedjom Power Project (KPP); TBEA
- Xinjiang Beixin Construction and Engineering; CWE; Sino Hydro; Joule Africa; Ximcor; SUHN; China National Electric Equipment Corporation; APICA; Alpha Technology

MoU for Small hydro (shares 1 to 2) are:

- Green Watt; Bamusso City Council; Fabien M. Assigana & Associates International Consulting; Fokoué City Council; Berkeley Energy; Adeid; Solarhydrowatt; Bill; Hydromekin; Alpha Technology; Kedjom Power Project; Minee/Aer/UNIDO; AER / Plan VER; AER / Erd Rumpi; AER / Projet Fed.

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Ecuador

1 Key facts

Population	17.3 million	August 2019 estimate
Area	256,370 km^2	
Access to electricity	97.05 %	2018
Installed hydro capacity	5,066 MW	2018
Hydro capacity under construction	328 MW	2019
Share of generation from hydropower	70.45 %	2018
Hydro generation	20,678 GWh	2018
Economically feasible hydro generation potential	156,700 GWh	1997
Small hydropower potential	297 MW	
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 five projects are already in advanced construction stages and will be fully operational by 2021 (Carvajal et al.,2019). The Quijos project will probably be fully operational by 2023.

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 13).

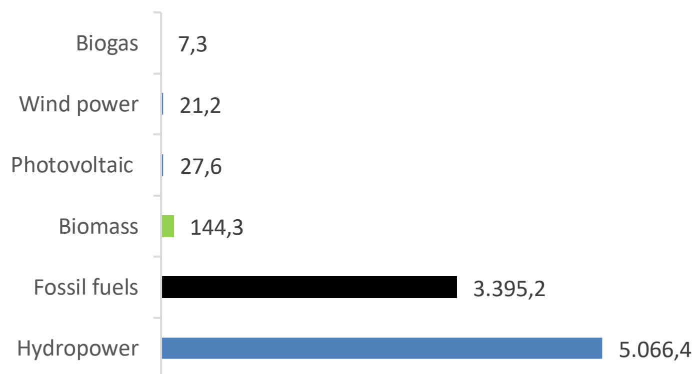

Figure 13: Ecuador - Effective installed capacities of the Ecuadorian power system in MW (ARCONEL, 2018)

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 Ecuadorian Electrification Master Plan 2018-2027, developed by the Ministry of Energy and Non-Renewable Natural Resources (MERNNR, www.recursosyenergia.gob.ec), jointly with other relevant entities envisages 19 hydropower projects totalling 3.6 GW of new capacity by 2027, as well as an additional 550 MW of solar, wind and other non-conventional renewables

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.

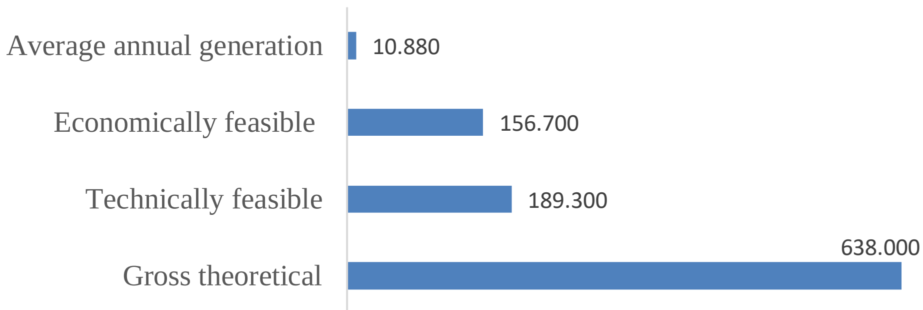

Figure 14: Hydropower potential in GWh/year in Ecuador - 2006-2015 average annual generation (data from H&D 2019)

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 15 (Carvajal et al., 2019):

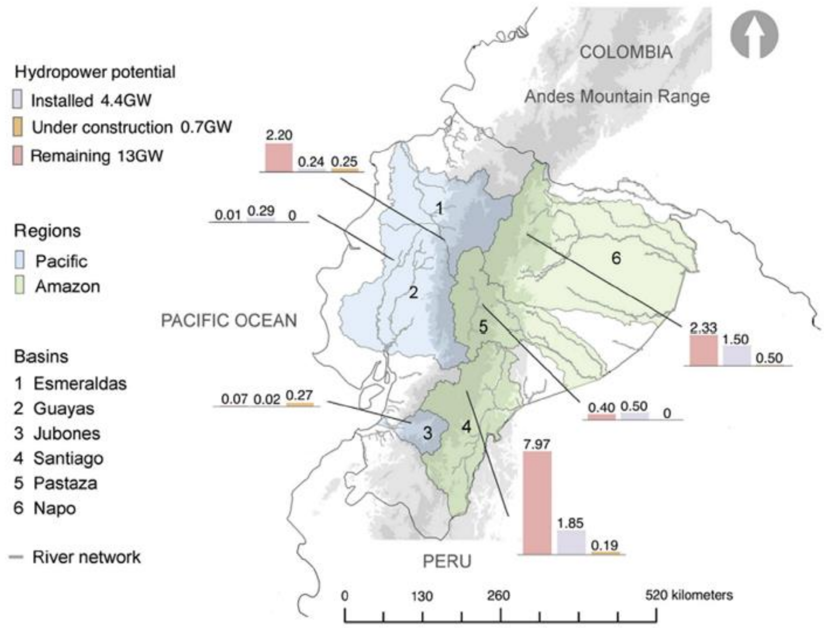

Figure 15: Ecuador's six major river basins and geographical distribution of hydropower potential of the Government's assessment (based on MERNNR, 2019)

There are 31 large hydro plants (>10 MW) in operation, with a total capacity of 4,973 MW (Figure 16).

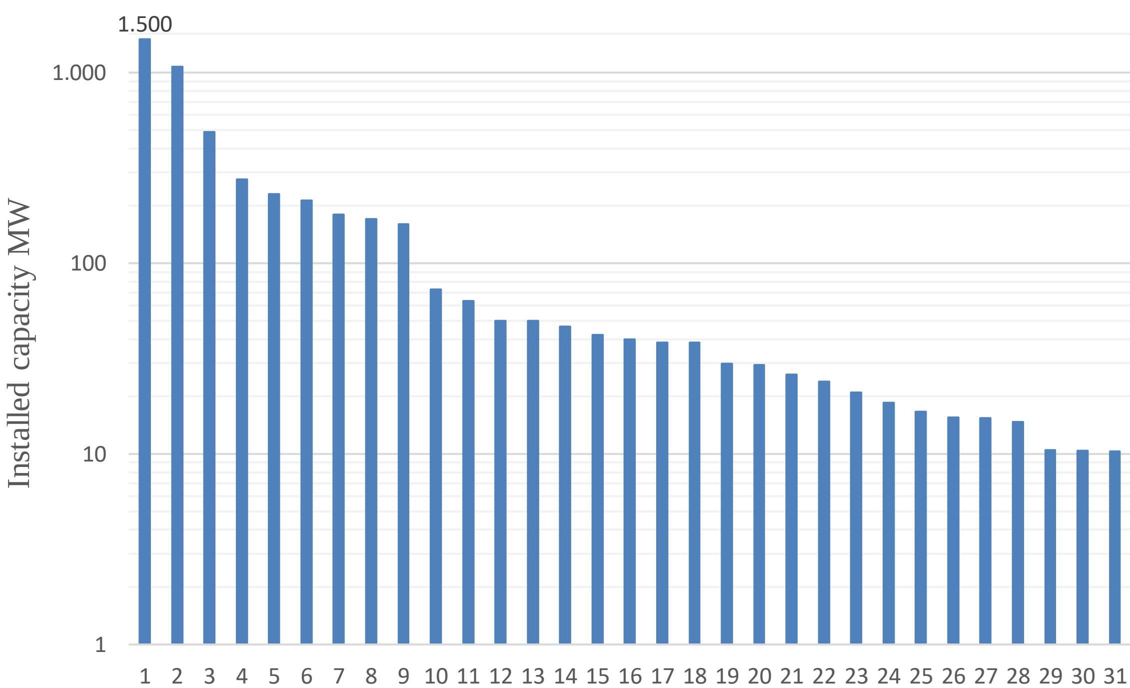

Figure 16: Operational large hydropower plants (P > 10 MW) in Ecuador as sorted by their installed capacity

There are 41 small, mini or micro hydro plants (<10 MW) in operation, with the total capacity of about 102 MW (Figure 17).

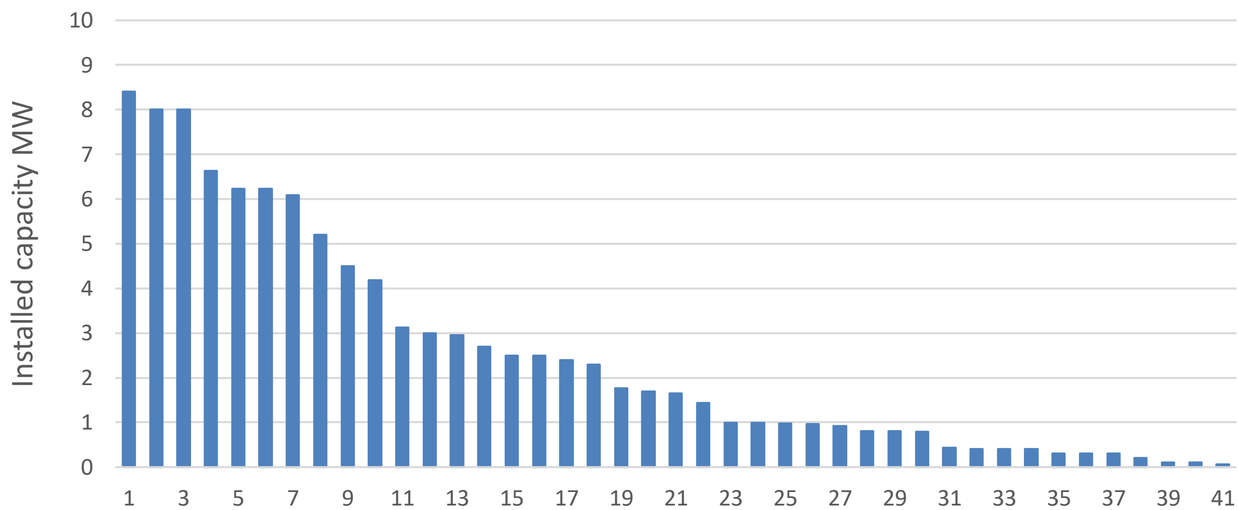

Figure 17: Operational small hydropower plants (P < 10 MW) as sorted by installed capacity in Ecuador

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 26.

Table 26: 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. In 1897, a 200 kW hydroelectric plant was built in Quito, on the Machángara River. Additionally, in 1899, in the city of Loja, in the south of Ecuador, a 24 kW power plant began operating, in two hydraulic turbines installed on the Malacatos River. Between 1900 and 1960, several hydroelectric plants were installed throughout the country, run by the municipalities. 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, which was in charge of the provision of electricity service throughout Ecuador and built the large generation plants and the Interconnected National System, 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 27.

Regulations for granting rights (concessions or permits) to use hydropower in Ecuador are summarized subsequent in Table 28.

Table 27: 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 27: 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 28: 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.	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.		Responsible Entity: 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 26). 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 29.

Table 29: 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.

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 30).

Table 30: List of universities in Ecuador offering water and hydraulic engineering related subjects

	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 31.

Table 31: Ecuador - Detected needs for improving hydropower studies

	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 32). 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 32: Ecuador - List of R&D topics, their number and key words (based on conducted survey)

No	R&D project topic/ category	Quantity	Key words
11.	General, administrative and marketing aspects	1	Renewable energy, energy mix scenarios
12.	Know-how and information dissemination	7	System reliability, Business Management Solutions, Automated Control, Economic Management, Life cycle analysis, 3D flow modelling
13.	Multipurpose projects and rehabilitation	2	Flood risk mitigation, Hydropower plant
14.	General design, civil work & engineering	7	3D Numeric Modelling, Flow energy dissipation
15.	Weirs and water storage/reservoirs	2	Advanced weir design, Reservoir rule curves,
16.	Methods and equipment for construction, maintenance, repair and overhaul of hydro plants	3	Electric Protection, dam, Flow energy dissipation,
17.	Electromechanical equipment	6	Dynamic programming, Electrical System
18.	Turbines	5	Numerical Methods, CFD, Fluid Dynamics, Fluid Mechanic, Turbomachines, Pumps
19.	Electrical equipment	2	Generators
20.	Control & monitoring	6	SCADA System, Control algorithm, Voltage variations, Losses, Automation.
21.	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.

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 18).

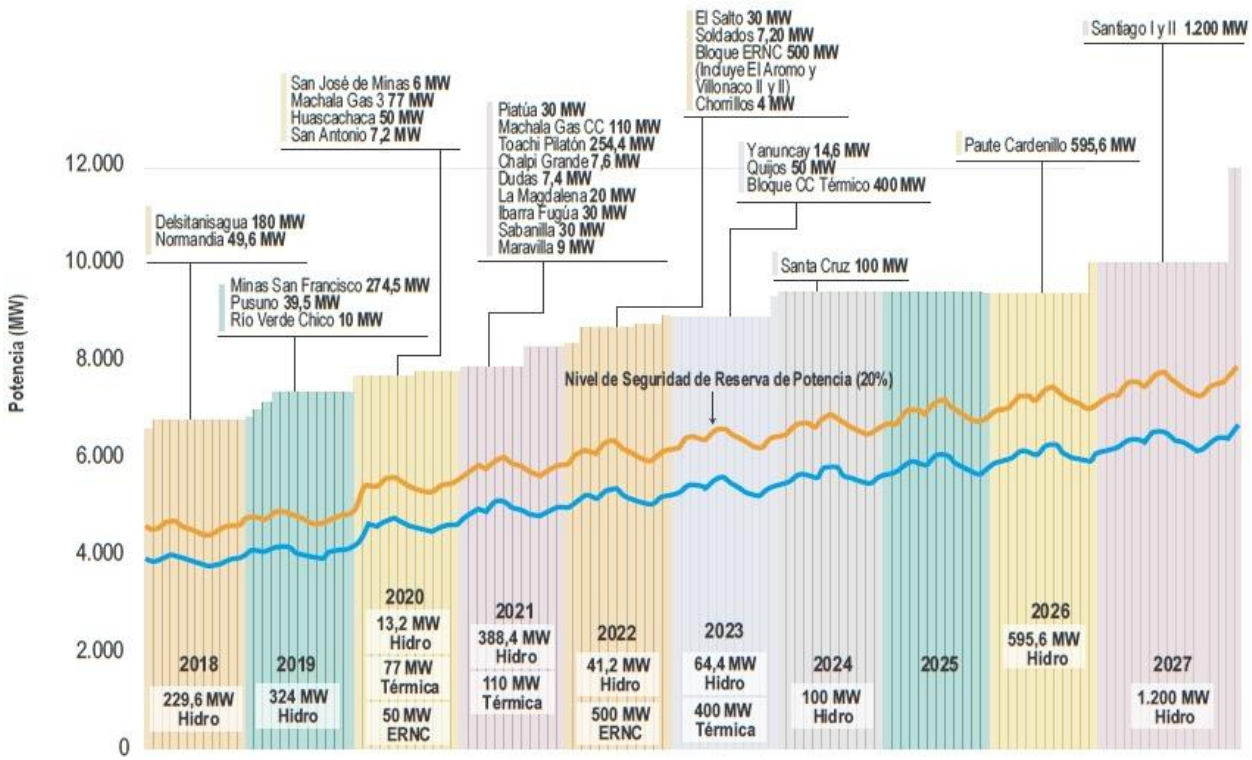

Figure 18: Ecuador - Sequence of projects that will be implemented until 2027 (MERNN, 2019)

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.

More information can be found in the 2018-2027 Electricity Master Plan (PME) available for download (MERNNR,2019).

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Uganda

1 Key facts

Population	44.2 million	2018 estimate
Area	241,551 km^2	
Access to electricity	50 %	2019
Installed energy capacity	1,252.4 MW	2019
Installed hydro capacity	1,004.2 MW	2019
Hydro capacity under construction	765 MW	2019
Share of generation from hydropower	80 %	2019
Hydro generation	3,638 GWh	2018
Economically feasible hydro generation potential	12,500 GWh	
Small hydropower potential	400 MW	
Small hydropower installed capacity	145.3 MW	2019

1.1 Climate

Uganda is located south of the Sahara in the central-eastern Africa, the most southern part crossed by the equator line. The climate is tropical and generally rainy with two dry seasons, from December to February and from June to August. In the north-east, Uganda is semi-arid. The average temperature is approximately 26°C (maximum temperature ranging between 18°C and 31°C and minimum temperature between 15°C and 23°C). The average annual precipitation in Uganda is between 1,000 and 1,500 mm, of which the majority is occurring between March and June with rainfall of more than 500 mm. The south is generally wetter than the north with the south-west receiving the heaviest rainfall. The north-east has the driest climate and is prone to droughts.

1.2 Topography

The greater part of Uganda consists of a plateau 800 to 2,000 m a.s.l. in height. Along the western border, in the Ruwenzori Mountains, Margherita Peak reaches a height of 5,109 m, while on the eastern frontier Mount Elgon rises to 4,321 m a.s.l. By contrast, the Western Rift Valley, which runs from north to south through the western half of the country, is below 910 m a.s.l. on the surface of Lake Edward and Lake George and 621 m a.s.l. on the surface of Lake Albert (also Mwitanzige).

1.3 Water resources

Uganda lies almost completely within the Nile basin. Eight main drainage basins can be distinguished in the country. These include; Lake Victoria, Lake Kyoga, River Kafu, Lake Edward, Lake Albert, River Aswa, Albert Nile and Kidepo Valley. The flow from these catchment basins, though small as compared with the total Nile flow, dominates the water resources potential within Uganda. Major water bodies include lakes Victoria, Kyoga, Albert, George, Edward and another 149 smaller lakes interconnected by a river system. In the north-eastern part of the country, many of the water courses are seasonal. Uganda is home to Lake Victoria, the largest lake in Africa and the second largest freshwater lake in the world with an area of 69,000 km^2. River Nile, is the only outflow from this lake and the country is lying almost entirely within its drainage basin. The discharge of the Nile at the point of outflow is estimated at 31 km^3/year. Lake Victoria and the Nile are the basis of the existing and future major hydro schemes in Uganda (Nsubuga et al. 2014).

The specific hydropower potential (density) of the country can be regarded as quite a moderate potential – approx. 0.05 GWh/year per km^2. To compare, for Austria and Norway this specific indicator is around 0.66, for Cameroon - 0.24 GWh/(year·km^2).

2 Power sector overview

Only about 50 % of the population has access to electricity, and in rural areas access at least 3 times less. Uganda has one of the lowest levels of per capita electricity consumption in the world with 215 kWh per capita per year.

The electricity supply system in Uganda was developed during the 1950s and 1960s with the construction of the Owen Falls Hydropower Station (later renamed Nalubale Power Station) with a total installed capacity of 150 MW. Later the power station was refurbished and upgraded to 180 MW and a new power station, Kiira, was constructed with a capacity of 200 MW.

Uganda is well-endowed with energy resources distributed throughout the country including hydropower, biomass, solar, geothermal, peat and fossil fuels. According to the Uganda Bureau of Statistics (2019), about 50 % of the population has access to electricity. Consumption of electricity is among the lowest in the world at 215 kWh per capita per year, less than half that of the Sub-Saharan African average of 552 kWh. Biomass is the most important source of energy for most of the population, accounting for 90 % (IHA, 2018).

In 2017, electricity generation in Uganda totalled 3,874 GWh with a clear dominance of hydropower share (Figure 19).

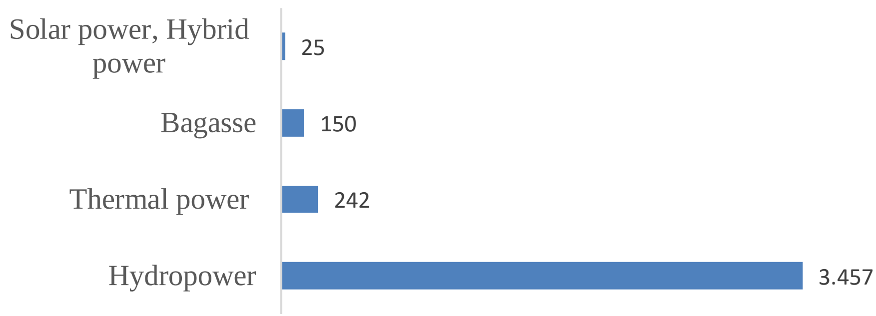

Figure 19: Annual electricity generation by source in Uganda (GWh) in 2017 (ERA, 2018)

As of March 2020, the national electricity sources were as illustrated in the table below (Energy in Uganda, 2020).

Table 33: Sources of electricity in Uganda as at March 2020

Source	Quantity (MW)	Percentage of Total
Hydroelectricity	1,007	80.4
Heavy fuel oil	100	8.0
Solar power	50	4.0
Co-generation	95	7.6

The current contribution of hydropower in Uganda's electricity generation mix is 87 per cent. This figure will go up to 92 % once large Karuma HPP is commissioned. Hydropower is a key component in electricity generation expansion plan in line with Uganda Vision 2040 strategy (NPA, 2007; IHA,2019).

In the second National Development Plan (NDPII April 2010) the Government invested in the necessary infrastructure to facilitate the exploitation of the abundant renewable energy sources including hydropower, geothermal and nuclear, so as to increase generating capacity to 2,500 MW by 2020 and prepare for achieving the required 41,738 MW by the year 2040.

The Electricity Regulatory Authority (ERA) is endorsed to issue licences, regulate the operations of all electricity operators, including independent power producers (IPPs) and private distribution companies, and establish the tariff structure. Other key players in the energy sector are the Ministry of Energy and Mineral Development (MEMD) and the Rural Electrification Agency (REA). The MEMD provides policy guidance, creates an enabling environment to attract investment in the energy sector, acquires data on the country's resource potential and regulates activities of private companies in the sector. The REA was established in order to facilitate acceleration in rural electrification. One of its key objectives is to promote equitable rural electrification access with special regard to marginalized communities. Its vision is to achieve a universal electricity access by 2035.

3 Renewable electricity policy

Uganda is a landlocked country with substantial RE potential that is distributed evenly across its territory (Fashina et al., 2017) and involves such energy forms and conversion technologies as wind- and hydropower, solar, peat, geothermal, biomass and biogas based generation, biomass-based cogeneration. However, hydropower remains the national dominant source for electric energy production with a potential of over 4,100 MW (NRFC, 2015). In general, the overall RE power generation potential is estimated to be about 7,200 MW (Karekezi, 2002; NRFC, 2015).

The Renewable Energy Policy, initiated by the Government of Uganda in 2007 (GoU, 2007) stated the goal to increase the use of modern renewable energy as well as the introduction of FiT remuneration mechanism and standardization of Power Purchase Agreements. This has encouraged both individual investors and companies to invest in the generation of RE in Uganda. Furthermore, the scheme has increased the financial support base for RE generation and motivated the rapid sustainable development of renewable energy technologies in the country.

To fast-track the development of on-grid small renewable energy projects, Uganda took an early lead in East Africa in implementing the Feed-in-Tariff (FiT) system, adopting the Global Energy Transfer Feed-in-Tariff (GET-FiT) Program launched in 2013 (IHA, 2019).

The renewable energy institutional framework of Uganda comprises the following stakeholders (WSHPDR, 2019):

- Ministry of Energy and Mineral Development (MEMD) keeps the overall responsibility for the renewable energy policy (REP) and oversees, and coordinates its implementation with other stakeholders;
- Electricity Regulatory Authority (ERA) sets tariffs, issues generation licences and maintains the renewable energy feed in tariff (REFiT);
- Uganda Electricity Transmission Company Limited (UETCL) is the system operator and single buyer; generation companies agree on a power purchase agreement with UETCL;
- Renewable energy generation companies (subject to fulfilment of relevant conditions);
- Distribution licence holders.

4 Hydropower sector and potential

The gross theoretical hydropower potential of the country has not been fully assessed (H&D, 2019). The technically feasible potential of Uganda is 20,833 GWh/year and the economically feasible one

- 12,500 GWh/year (Figure 20). The presented data is an average annual generation estimate for 2018.

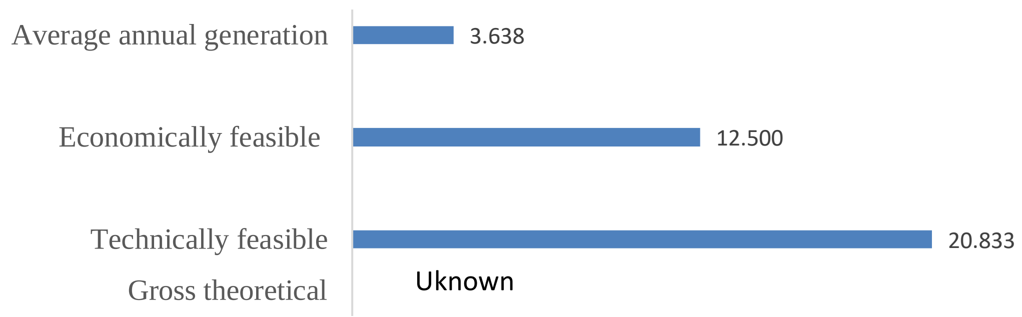

Figure 20: Hydropower potential in GWh/year in Uganda (H&D, 2019)

About 15 % of the technically feasible potential has been developed so far. In 2018, hydro plants generated 3,638 GWh, which was 89 % of the total generation. Generally, the contribution of hydro each year is more than 80 per cent.

A Hydropower Development Master Plan has been developed with support from the Japan International Cooperation Agency (JICA, 2011). According to it Uganda has considerable hydro resource potential estimated to be over 2,000 MW (mainly on the Nile). A more recent study indicates two times bigger potential 4,137 MW (NRFC, 2015).

As of 2019, Uganda had 32 hydropower plants that were in operation, with a total installed capacity of 1,667 MW. (Figure 21). This inventory comprises some 20 micro and small hydropower plants (up to 10 MW).

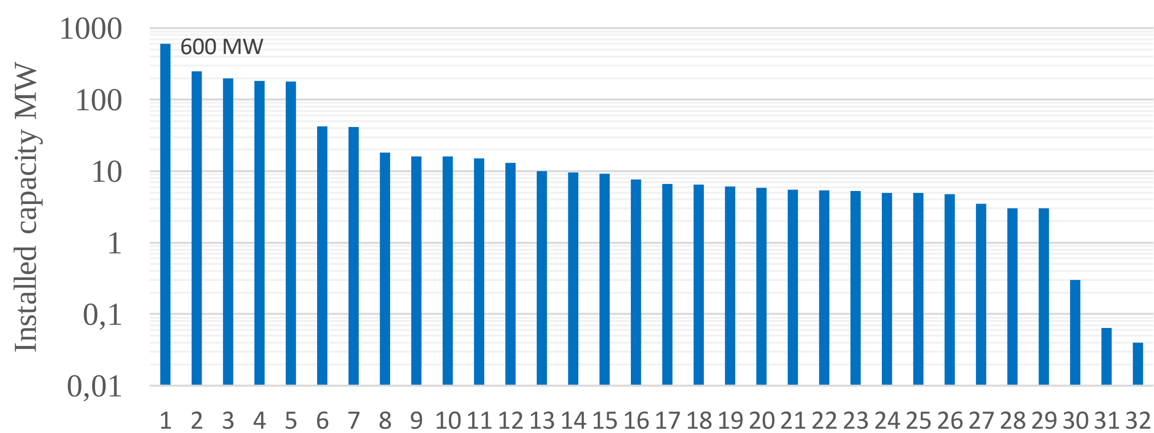

Figure 21: Operational hydropower plants in Uganda as sorted by installed capacity (project estimation)

There are four large hydropower plants in operation: Nalubaale (180 MW), Kiira (200 MW), Bujagali (250 MW), and Isimba (183 MW) which was commissioned in 2019. In total, 765 MW of hydro is under construction (2019), according to UEGCL (Uganda Electricity Generation Company Ltd), of which 600 MW is large hydro, 83 MW is medium scale, and 82 MW is small hydro (H&D, 2019).

Based on this project findings, the total hydropower installed capacity has been recently increased from 764 MW to 1,004.2 MW at the end of 2019.

In Uganda, small hydropower (SHP) is generally defined as hydropower plants with installed capacity of up to 20 MW (ERA). Unlike large-scale hydropower, the small- and medium-hydro sites are not located on the Nile, but they also possess potential resources which are yet to be exploited. These sites are located mainly in the Western and the Eastern regions of the country which are hilly and mountainous. About 50 potential small hydropower sites have been identified at the Ugandan rivers.

So far SHP potential has not been fully assessed in the country, only rough estimates can be provided (Table 34).

Table 34: Uganda - Small hydro (< 10 MW) characteristics according to different sources

References	Potential, MW		Installed capacity, MW	Number of operating SHP
	MW	GWh		
WSHPDR, 2019	200		52	
H&D, 2019		>400	110	
HYPOSO	~400	~1,250	102	20

As it can be seen from this table, the estimates differ a lot, the given potential (200 MW) is obviously underestimated. The best available technique to conduct a preliminary evaluation of the small hydro potential is to take a portion of 5 to 10 % of the technically or economically feasible potential. The latter approach can be considered as a lower limit that is 12,500 GWh/year in the country. Consequently, it will result to some 1,250 GWh, a rough, but more realistic estimate of SHP potential.

Powerplants which began commercial operation in 2018 included five small hydro stations: Nyamaghasani (9.2 MW); Lubiia (5.4 MW); Nkusi (9.6 MW); Mahoma (2.7 MW); and, Wakio (4.8 MW). Examples of small-scale hydropower schemes currently under development (some are known by the name of the developer) are: Kyambura (7.6 MW); Sindila (5.24 MW); Ndugutu (5.9 MW); Nyamaghasani 1 (6 MW); Nyamaghasani 2(15 MW); Siti 2 (16.5 MW); and Nyagak (5.5 MW). A 1.75 MW hydro scheme is going ahead as part of the Angololo multipurpose scheme, on the border with Kenya. An agreement had been signed for the first cross-border project between Uganda and Tanzania. It will be a 14 MW scheme at Kikagati (H&D, 2019).

The African hydropower database for Uganda provides a list of operational hydropower plants, those under development and only one potential site (Hydro 4 Africa, 2020).

5 SHP policy and market analysis

5.1 SHP policy

Small hydropower is integrated within the whole energy and hydropower sector. Notwithstanding this, mostly small hydro policy is to be highlighted herewith. Key legal documents making up the legal framework to which hydropower must comply are listed in Table 35.

Table 35: Uganda - Key legal documents regulating RES and hydropower

Name of legal document (not older than 5 last years but those still in force)	Type of activities addressed	Website	Summary and Impact on development of Hydropower (small or large)
Electricity Act, 1999, Cap 145; Laws of Uganda	Power, Energy and Electricity Sector	https://www.era.or.ug/index.php/resource-centre/regulatory-instruments/laws/86-the-electricity-act-1999/download	Gives the developer exclusivity to develop the site, the right to do necessary feasibility studies and the knowledge that no conflicting projects are being developed
The National Environment Act, 1995	Environment	www.nema.go.ug	Allows NEMA to ensure that the project and its mitigation plans comply with Ugandan standards for environmental and social impact
The Water Statute, 1995	Water management	www.mwe.go.ug	Allows DWRM control over the use of surface water so that no other parties, for example farmers are negatively affected and so that no other negative effects on the surface water system occur
Energy Policy of Uganda, 2002	Energy	https://www.era.or.ug/index.php/resource-centre/regulatory-instruments/policies/83-energy-policy/download	Ensures widespread access to affordable modern energy
Renewable Energy Policy, 2007	Renewable Energy	https://www.era.or.ug/index.php/resource-centre/regulatory-	Diversifies the energy supply sources and technologies in the country, through

		instruments/policies/221-the-renewable-energy-policy-for-uganda/download	enabling negotiations for appropriate financing for large projects and feed in tariffs for small projects
Global Energy Transfer Feed-In Tariff (GET-FiT) Program, 2012	Renewable Energy	https://www.era.or.ug/index.php/sector-overview/programmes/getfit	Fast-tracks development of renewable energy generation projects of 1 MW – 20 MW, promoted by private developers, with a total installed capacity of about 170 MW/ 830 GWh per annum.
Electricity (License Exemption) (Isolated Grid Systems) Order 2007	Electricity	https://www.era.or.ug/index.php/resource-centre/regulatory-instruments/regulations-codes/93-the-electricity-license-exemption-isolated-grid-systems-order-2007/download	Provides for developers of exempted projects under 2.0 MW to upgrade license if they need to connect to the grid
National Environment Management Policy, 1994	Environment	http://nema.go.ug/sites/all/themes/nema/docs/national_environment_act.pdf	Encourage hydropower development with environmental protection in mind
The Wildlife Policy, 2014	Wildlife	https://www.ugandawildlife.org/news-events/news/wildlife-policy-to-be-revised	Hydropower projects that give priority to the protection of the natural flora and fauna are supported
The National Wetlands Policy, 1995	Wetlands	http://nema.go.ug/sites/all/themes/nema/docs/wetlands_riverbanks.pdf	Encourages development of hydro power resources, especially along the Nile, while recognizing protection and preservation of wetlands

The National Wetland Conservation and Management Policy, 1995	Wetlands	http://nema.go.ug/sites/all/themes/nema/docs/wetlands_riverbanks.pdf	Encourages development of hydro power resources, especially along the Nile, while recognizing protection and preservation of wetlands
Master Plan for Hydropower Development, 2010	Hydropower	https://www.seforall.org/sites/default/files/Uganda_AA_EN_Released.pdf	To maximise Uganda's electric hydro power potential for increased national social-economic development
Power Sector Investment Plan, 2011	Power Sector	www.energyandminerals.go.ug	To maximise Uganda's electric hydro power potential for increased national social-economic development
Occupational Health and Safety (OHS) Policy	Health and Safety	www.mglsd.go.ug	To ensure that all employees work in a healthy and safe environment, are adequately protected and compensated for their labour
Uganda Vision 2040	National Policy	www.npa.go.ug	Uganda to develop and generate modern energy to satisfy demand of 41,738 MW by 2040 and increase electricity per capita consumption to 3,668 kWh and access to the national grid to 80 %
Rural Electrification Strategy and Plan 2013-2022	Energy	www.rea.go.ug	The RESP is aligned towards universal electricity access by 2040, to achieve an accelerated pace of electricity access and

			service penetration to meet national development goals
Policy and Regulatory Framework			
National Environment Act, Cap 153 and Associated Regulations	Environment	http://nema.go.ug/sites/all/themes/nema/docs/national_environment_act.pdf	Regulating the impact of renewable energy investments on the environment, through award of certificates of environmental clearance
The Water Act, CAP 152	Water management	http://nema.go.ug/sites/all/themes/nema/docs/water_act.pdf	Managing water resources in an integrated and sustainable manner through issuing Surface Water Abstraction and Construction Permits to Project Developers
The Uganda Wildlife Act, 2000	Wildlife	www.ugandawildlife.org	
Land Acquisition Act	Land	www.mlhud.go.ug	Land acquisition and compensation, plus handling way-leaves issues
The Fish Act, Cap 197	Fisheries	www.agriculture.go.ug	Provision for the control of fishing, the conservation of fish during project development
The Rivers Act, Cap 347	Water management	www.mwe.go.ug	Provides for the control of activities like dredging and use of steam vessels by developers

A generation licence may be granted to a developer following the submission of an application to the ERA, which processes the licence application within a maximum of 180 days. These include:

- ERA for the generation licence / license exemption,
- DWRM for water abstraction permit;
- NEMA for environmental permit;
- UETCL for PPA agreement

The process involves publication of notices in the National Gazette and national newspaper to solicit objections to the project, if any.

A brief description of regimes for granting rights (concessions or authorisations) to use hydropower in Uganda is summarized in Table 36.

Table 36: Regimes for granting rights (concessions or authorisations) to use hydropower in Uganda

Concessions	Small Hydro. New permits (authorizations)	Large hydro. New permits (authorizations)
Type of permits needed & average time	Permit to undertake studies and other activities - not less than 180 days since the day of application	Permit to undertake studies and other activities - not less than 180 days since the day of application

In Uganda SHP lobbying and other activities are implemented by the HPAU (Hydro Power Association of Uganda) - a non-profit organization (HPAU, 2020). It brings together private companies dealing in various aspects with hydropower development. HPAU seeks to contribute to the national, regional and global development and sound management of hydropower resources for sustainable access to energy for improved socio-economic progress.

5.2 Industrial overview

Uganda is a country with abundant potential for small hydropower development. There are many identified sites suitable for small hydropower facilities. Small schemes are generally privately owned and operated by the IPPs. Some of them supply electricity to isolated grids. To date there is 20 SHP under operation, but the access to their data, particularly in terms of economic evaluation is restricted. Currently, on average the investment costs to-date are approx. US$3 to 4 million per MW installed.

Some 40 stakeholders are acting in the hydropower sector, mostly in small-scale hydro. No hydraulic machinery equipment producers were identified (only a few dealers) so far (HYPOSO D3.1, 2019).

5.3 5.3 Support schemes and financing opportunities

REFITs were introduced under the Renewable Energy Policy (2007) to promote a greater private sector engagement in power generation from renewable energy sources. The REFIT applies to systems of prescribed priority technologies (SHP and other renewables) of installed capacity in the range of 0.5 to 20 MW, as defined by the Electricity Act, 1999. In addition, to qualify for the REFIT, the projects must be connected to the national grid. Plants including additional capacity resulting from the project modernization, repowering and expansion of existing sites, but excluding existing generation capacity, also qualify for the REFIT. The REFITs are shown in Table 37.

Table 37: Uganda - Support schemes (REFIT) for hydropower

No	Type	Size	Measurement
	(a). Micro Hydro	Hydro (500 kW ><= 1 MW)	Feed-in Tariff (US$/kWh) = 0.115; repayment period 20 years
	(b). Mini Hydro	Hydro (1 ><= 9 MW)	Linear Feed-in tariff; repayment period 20 years
	(c). Small Hydro	Hydro (9 ><= 20 MW)	Feed-in Tariff (US$/kWh) = 0.085; repayment period 20 years
	(d). Large Hydro	Hydro => 20 MW	No Feed-in Tariff; Required to negotiate a tariff and Power Purchase Agreement with the System Operator, on a case by case basis
	Small Hydro =< 20 MW	Uganda Renewable Energy Feed-in Tariff (REFIT) Guidelines, Phase 4	https://www.era.or.ug/index.php/resource-centre/regulatory-instruments/guidelines-and-standards/463-uganda-renewable-energy-feed-in-tariff-refit-guidelines-phase-4/download
	All project sizes	Amended Guidelines for Fixing Quantum of Royalties paid by Hydro Generation Licensees	https://www.era.or.ug/index.php/resource-centre/regulatory-instruments/guidelines-and-standards/54-the-amended-guidelines-for-fixing-the-quantum-of-royalties-payable-by-hydro-generation-licensees-in-uganda-2012/download
	All project sizes	Standardized Power Purchase Agreements	https://www.era.or.ug/index.php/resource-centre/regulatory-instruments/forms-templates/97-standardised-power-purchase-

			agreement-ppa-for-the-getfit-program/download

There is a financial gap in the development of renewable energy sources in Uganda, however, as the existing renewable energy developments have been financed through various mechanisms including the Government, IPPs, development partners and public-private partnerships (WSHPDR, 2019).

The key sources of funding among these are the Global Energy Transfer Feed-in-Tariff (GET FIT) Programme and the support from Power Africa (GET FiT Uganda, 2018). The main objective of the GET FiT Program is “to assist East African nations in pursuing a climate resilient low-carbon development path resulting in growth, poverty reduction and climate change mitigation”. Roll-out of the program will start in Uganda in Phase 1. Through the roll-out in Uganda in phase 1 of the program, a portfolio of currently 17 small-scale renewable energy generation projects, including SHP promoted by private developers with a total installed capacity of roughly 160 MW will be fast-tracked.

One of the instruments of the GET FIT Programme is the GET FIT Premium Payment Mechanism (GFPPM). Small-scale renewable energy projects selected through a competitive bidding process apply for premium payments. These premium payments constitute an “incentive grant designed to enhance the financial viability of the selected projects and are payable to the project developers in addition to the relevant REFIT tariffs determined by the Electricity Regulatory Authority (ERA)”. Through the GET FIT Programme, a total of 158 MW of renewable energy is to be added to the national grid from a total of 17 projects utilizing various renewable energy technologies, including SHP, solar PV and bagasse (GET FIT, 2018).

6 Educational framework

Makerere University in Kampala has about 95 % of the total student population in Uganda's universities. More than 20 private universities and a smaller number of non-university institutions are providing education. Vocational and Technical Education is a necessary aspect of the education system in Uganda. Some programs provide graduate engineering level education to students seeking education at the tertiary or post-secondary level.

There is no hydropower engineering study program in the country education system. Hydropower is usually part of renewable or energy studies (Table 38). Universities such as Kyambogo, Busitema, Ndejje, Nakawa VTI are offering also renewable or energy study programs.

Table 38: Uganda - Makerere University Renewable Energy program

University	Hydropower as part of renewable or energy studies	Topics included
Makerere	MSc Renewable Energy	Development, design, installation, and operation of small hydropower plants

Uganda currently has a good number of hydro power projects that are being run and implemented by both public and private entities. The challenge however is that the availability of manpower to operate and manage the smooth running of such power stations is still lacking. Therefore, the East African Centre for Renewable Energy and Energy Efficiency (EACREEE) partnered with the Uganda National Renewable Energy and Energy Efficiency Alliance (UNREEEA) and the Centre for Research in Energy and Energy Conservation (CREEC) and its partners organized East African regional training course on development, design, installation, and operation of small hydropower plants at Makerere University (CREES,2020).

Main weaknesses of the education system and gaps to bridge the knowledge for the hydropower sector are as follows:

1. General level of understanding hydropower is low;
2. No university/technical education programs specifically on hydropower;
3. Technicians get hydropower training only on the job;
4. Technical training generally is too theoretical;
5. O&M personnel lack re-training & expansion of skills;
6. Reliance on outside expertise not only technically but also for studies, design & equipment;
7. Link between classroom and field/industry training missing or inadequate;
8. Capacity building aspect not backed up by energy policies.
9. Limited hydrological data and consequently - a lack of specialists for hydropower assessment.

7 Research situation and needs

Previous section outlines that high education programs for hydropower are inexistent. Renewable energy programs proposed by universities are not offering in-depth or sufficient knowledge on hydropower issues. This suggests that research level in the hydropower are is quite weak. This fact can be confirmed by the HYPOSO project survey on R&D projects conducted recently in Uganda. Neither fundamental nor applied research projects for hydropower were reported. On the contrary, only main features and challenges of hydropower plants projects under developments or already under operation, including a few of them of demonstration type are provided.

To support the above-mentioned statement, a search of the publications in Science Direct database for Uganda was carried out. This database is a website which provides subscription-based access to a large database of scientific and medical research (mainly papers in peer reviewed journals in English). The search was intended to identify publications with the authors or co-authors from Uganda. During last eight years at least 5 papers related on one or another way with hydropower topic were published and affiliated to Makerere, Mbarara and Kampala International Universities, and Centre for Research in Energy and Energy Conservation (CREEC).

There should be also indicated Ugandans studying abroad, in European universities with specialisation in hydropower. For instance, a master thesis was prepared aiming at evaluating how well GIS tool was able to estimate the hydropower potential from the runoff maps and terrain/elevation (Gimbo, 2015). All above outlined conclude that the research related to the hydropower sector possesses minor potential.

Since hydropower development is starting to progress in this country the basic hydropower knowledge would be advantageous. There is a need to transfer European-top-level experience, knowledge, available state-of-the-art hydro technology to Ugandan researchers.

8 Environment

The Ministry of Water and Environment (MWE), is a cabinet-level government ministry of Uganda. It is responsible for the "sound management and sustainable utilisation of water and environment resources for the betterment of the population of Uganda". The MWE has recently issued a 'Strategic Programme for Climate Change'.

The National Environmental Management Authority (NEMA) is the government body responsible for environmental and social impact assessments for projects being developed.

The Directorate of Water Resources Management (DWRM) is responsible for: developing and maintaining national water laws, policies and regulations; managing, monitoring and regulating water resources through issuing water use, abstraction and wastewater discharge permits; integrating water resources management activities; coordinating Uganda's participation in joint management of transboundary water resources; and peaceful cooperation with the Nile Basin riparian countries.

The Water Sources Protection Guidelines for Hydroelectric power plants describe steps to follow to prepare a Water Source Protection Plan (MWE, 2013). It outlines actions and considerations that are particularly relevant to protecting a water source for a small to medium sized hydroelectric scheme. It is also is a standalone document for ease of its application by those concerned with hydroelectric power plants.

9 Barriers to SHP development

The main challenges to consider for developing small hydropower projects in Uganda are, but not limited to (WSHPDR, 2019):

There is an infrastructure gap in the generation, transmission and distribution of electricity, such that the growing demand is not being met by the existing infrastructure. Distribution losses also remain quite high and there is need for further investment to extend the grid.

There is a gap in financing of the power sector, which will not be bridged by the public sector financing alone, and need for more private sector investment;
High upfront costs and limited access to early-stage support and equity investment present another limitation, as interest rates from commercial lenders are quite high due to the perceived high risks of the investment;
There is a perception of high risk of default on payment by the single off-taker;
The land acquisition process is bureaucratic, complex and slow and affects the overall project costs and the construction of transmission line infrastructure required for the evacuation of power from power plants;
There is a need for capacity building within the government institutions, particularly as relates to planning, design and construction of hydropower plants.

The barriers from a potential investor to SHP:

- Limited local manufacturing capability for equipment related to hydropower technology, which makes it difficult to purchase hydropower related components for replacements, such as bearings, alternators, electronic switch gear
- Political, macro-economic instability and other governance related risks, including taxation regime, mixed signals regarding risks suffered by established developers,
- Project specific characteristics, related to site location, project promoters with their financial and technical strength and experience combined with other external factors related to availability of cost-effective technically competent contractors and consultants, fluctuations of the currency as well as commodity prices.

10 Future prospects

Uganda Vision 2040 identifies electricity generation as one of the key strategic interventions for social-economic transformation of the country. This includes increasing access to 30 % in 2020 and 80 % in 2040 (a 6 % annual increase), with off-grid electricity playing only a minor role. While this is expected to be mainly low-carbon due to large hydropower resources, there is a potential to achieve 100 % access cost-effectively by 2040 with a greater emphasis on small-scale off-grid renewable solutions (IHA, 2019).

There should be also pointed out, that hydropower is sensitive to the climate driven hydrological cycle thus necessitating proper management of the river catchment areas. The prolonged drought experienced in Uganda between 2003 and 2007 led to a decline in hydropower generation of over 60 %, thus necessitating the deployment of expensive thermal power to reduce load shedding which had negatively impacted the economic growth.

The key challenges for hydropower development in Uganda, and most countries in Africa, include the need for substantial up-front investment capital which cannot easily be raised by the sector, as well as environmental and social concerns such as the resettlement and compensations of persons affected mainly by the large hydro projects, and inadequate local implementation experience and technical capacity.

There is a document outlaying steps, actions and considerations that are particularly relevant to protecting a water source for a small to medium sized hydroelectric scheme and aiming to ease hydropower applications (MWE, 2013).

10.1 Large Hydro

To ensure development of hydropower resources in a sustainable manner, in 2010 the government undertook a hydropower development master plan study (JICA, 2011). The study targeted sites above 50 MW mainly along the River Nile. The objective of the study was to prepare a master plan that is in line with the long-term power and transmission development plan. The hydropower master plan prioritised potential hydropower sites based on technical, environmental, economic and financial aspects, to prepare preliminary designs thereof, and to build government capacity in this field.

In line with this hydropower master plan, the government is fast-tracking the development of the identified hydropower sites. It is currently implementing two key flagship hydropower projects namely, Isimba (183.2 MW) and Karuma (600 MW). Other large hydropower plants being packaged for development include Ayago (840 MW), Orianga (392 MW), Uhuru (350 MW) and Kiba (290 MW). (IHA, 2019)

Other hydropower projects currently under development are the 83 MW Achwa project, the 44.7 MW Muzizi project and the 5.4 MW Nyagak project. On top of that, the GET-FiT portfolio is supporting 17 renewable power generation projects to generate about 156.5 MW, where a total of 69.2 MW is expected by 2019 from nine hydropower projects.

To address the challenge of financing, the Government of Uganda put in place the Energy Investment Fund which enabled to commence the construction of Bujagali hydropower plant. The 250 MW Bujagali hydropower plant was developed under a public private partnership arrangement with Bujagali Energy Limited (BEL). Additional investment capital has been attracted through bilateral financing with our development partners. The challenge of inadequate technical capacity has been addressed by putting in place a local content policy to ensure the participation of Ugandans during construction of the projects.

10.2 Small hydro

A total of 59 mini hydropower sites with a potential of about 210 MW have been identified through different studies. This gives a fair picture of the small and mini hydro potential in the country. Some of the sites can be developed for isolated grids and others as energy supply to the grid (Fashina 2019).

Regarding small hydropower projects, the current policy is that their development is undertaken by the private sector. The Renewable Energy Feed-in Tariffs (REFiT) are in place to promote investment in small hydropower and other renewable power projects (IHA, 2019).

There are many unexploited potential SHP sites in Uganda, which could potentially supply electricity to areas not covered by the national grid. Their data are available at ERA and some of these sites are listed in WSHDR (2019).

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12 Annexes

Questionnaire WP3: D3.2.1. Framework analysis: Market, Policy, Financing, Education, Research

METHODOLOGICAL NOTES

How to fill the HYPOSO QUESTIONNAIRE WP3:D3.2.1

(Framework analysis: Market, Policy, Financing, Education, Research)

Part I. MARKET DATA

INDUSTRIAL DATA (average for last 2 years)

a) Number of companies (any company producing something for or working with hydropower) in hydro sector.
b) Employment: Direct and Indirect people employed (full time equivalent & percentage of SHP) in the sector for the different branches and works during the reporting period.

The following branches should be considered and specified when possible:

- Equipment suppliers: it includes Manufactures (Turbines, Generators, Gearboxes, Valves and gates, Trash-rack cleaners, Penstocks, Cranes, Electric panels, Automation facilities, Transformers) and Companies for Electromechanical equipment erection.
- Engineering activities: it includes Companies for technical assistance, plant and structures design, on site supervision, hydrology, geological and geotechnical survey, topographic survey, biologic survey and training.
- Maintenance services: it includes plant managing companies, post-selling services companies.
- Others: Legal assistance, economical and environmental consultants, promoters, administrators, researchers etc.
- Civil works (estimation): it includes Civil works companies; Special foundation works companies and Penstock erection.

ECONOMICS (all the figures reported in these sections are an average value of the last five year)

- Average Investment cost: The investment cost is the capital costs in terms of design cost, electromechanical equipment, civil works, grid connection and land purchase or rent and administration for investment cost.
- Average Cost per kWh produced: The total cost per kWh produced (specific cost) is calculated by discounting and levelling investment and O&M costs over the lifetime of the power plant, and then dividing them by the annual electricity production.
- Average Operation and maintenance (O&M) costs: O&M costs are related to water right costs, labour cost, insurance, maintenance, repair, spare parts, leases, rents, administration for O&M costs etc measured as a percentage of the total cost.

- Average Lifetime of the mechanical equipment: The technical lifetime of the mechanical equipment represents the period during which it operates in technical sense without replacement of its major parts of investing more than 50 % in refurbishing the equipment measured as an average.
- Cost of civil works: Average cost of all civil works including foundation works, construction of powerhouse, intake, tunnel, penstock entrenchment, conduit channel, etc measured as a percentage of the total cost.
- IRR: The internal rate of return (IRR) is a rate of return used in capital budgeting to measure and compare the profitability of investments. It is also called the discounted cash flow rate of return (DCFROR) or simply the rate of return (ROR).

Low head and High head: The distinction between different heads can be measured as follows:

- High head: 100 m and above
- Medium head: 20 to 100 m
- Low head: up to 20 to 30 m

PART II: POLICY DATA

2.1. LEGISLATION

This includes all kind of regulation/law at local and national level which is implemented and valid during the reporting period and its application affects the development of hydropower. Some examples include the Water Law, all national laws which are concerned with the environment field, such as Environmental Impact Assessment (EIA), designated areas, fish protection law, flood protection and other legislation coming from energy, development, economic and other areas.

2.2. CONCESSIONS

Concession: Regulation on the national law which regulates concession (= all needed permits and authorizations completed) of water use for new plants and the re-licensing of old ones and other permits needed.

a. Type of permits needed & average time: List of the main type of permits needed to use the water and produce hydropower energy and average time needed to obtain all the permits.

b. Number of plants granted during the reporting period: Number of licenses granted. New permits: Number of licenses for new plants. Refurbishment + relicensing: Number of plants who got a renewal of the old license or a license for a refurbishment.

2.3. SUPPORT (Use national divisions between small and large hydro in this section)

Current support mechanism: This includes, but is not restricted to, investment aid, tax exemptions or reductions, tax refunds, renewable energy (RES) obligation support schemes including those using green certificates, and direct price support schemes including feed-in tariffs and premium. All that promotes the use of energy from renewable sources by reducing the cost of that energy, increasing the price at which it can be sold, or increasing, by means of a renewable energy obligation or otherwise, the volume of such energy purchased.

Type Support and Measurement: This includes two categories:

a) **Regulatory price-driven strategies**: producers of RES-E receive financial support in terms of:

- a subsidy per kW of capacity installed: financial support is given by investment subsidies, soft loans or tax credits usually per unit of generating capacity;

- a payment per kWh produced and sold: financial support is a fixed regulated feed-in tariff (FIT) or a fixed premium (in addition to the electricity price) that a governmental institution, utility or supplier is legally obligated to pay for renewable electricity from eligible generators.

b) **Regulatory quantity-driven strategies**: The desired level of RES generation or market penetration – a quota or a Renewable Portfolio Standard – is defined by governments by tradable certificate systems: Green Certificate (GC) systems. In such systems, the generators (producers), wholesalers, distribution companies or retailers (depending on who is involved in the electricity supply chain) are obliged to supply or purchase a certain percentage of electricity from RES.

PART III. FINANCING

Describe current trends in small hydropower financing. E. g., private funding, international financing, public–private finance, donor-backed finance, green bonds, any innovative mixed finance.

Part IV. EDUCATION

4.1 GENERAL

Scoping the situation in the country about hydropower knowledge and knowledge needs. Specifying the universities and the other organizations working in the knowledge transfer in hydropower and disciplines related to hydropower.

4.2. UNIVERSITIES

Which universities have hydropower as a topic of interest; as an independent study course or as part of renewable or general energy studies? Which topics/courses are lectured in such a study? Syllabus of courses available? How is with education in basic knowledge as engineering hydrology, hydraulics, hydraulic structures, hydraulic machines, electrical grids, environmental sciences, Which universities could be interested in cooperation in the project? What could be their function/role in the project?

Which other educational organizations could be of interest?

4.3 OTHER ORGANIZATIONS

International organizations:

- ICOLD members (All target countries are members except Ecuador) Contact with the Local ICOLD representative (could be found on the ICOLD web-page)
- Other international organization connected with hydropower as IAHR or IC-SHP

Local hydropower organizations if any?

Hydropower education level and activities in power supply companies and governmental organizations

Any local initiatives by independent suppliers/owners

Knowledge about operation and refurbishment of hydropower plants and situation in the country on dam surveillance and safety.

4.4 Scoping the needs in hydropower education

Where are the needs for hydropower education? Governmental organizations working on licensing, owners or power supply organizations, consultants, equipment suppliers, NGOs,

Part V. RESEARCH

The input for the research needs of the target countries should come from the countries itself. Possible global research directions: improvement of the country hydrology, influence on climate change on existing and new projects, improvement of the grid services, multipurpose projects as a chance, improvement in operation and maintenance, production optimization, sediment and erosion control, water-energy-food-ecosystem nexus, definition of ecological flows (local adaptation),

Questionnaire WP3:D3.2.2. Inventory of R&D projects

The following topics were considered:

1. Administrative and marketing aspects
2. Maps, potential assessment, hydrology
3. Know-how and information dissemination
4. Multipurpose projects and rehabilitation

5. General design, civil work & engineering
6. Weirs and water storage/reservoirs
7. Penstocks
8. Methods and equipment for construction, O&M
9. Desilting basins, water intakes & trash racks
10. Electromechanical equipment, control & monitoring
11. Turbines
12. Electrical equipment, Control & monitoring
13. Environmental issues, Environment integration, Residual flow, Environmental impact assessment
14. Bioengineering, Fish passes
15. Waterways
16. Key words
17. Objective
18. Web site
19. Type of project (research / demonstration)
20. Regional / National / International funding
21. Project period
22. Comments on the success/ unsuccess
23. Readiness for the market (already on the market, at short, mid or long term)
24. Results access (public, confidential, free, royalties)
25. Any openings to other projects?