Hydropower Solutions

HYPOSO

Hydropower solutions for developing and emerging countries

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

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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 1.

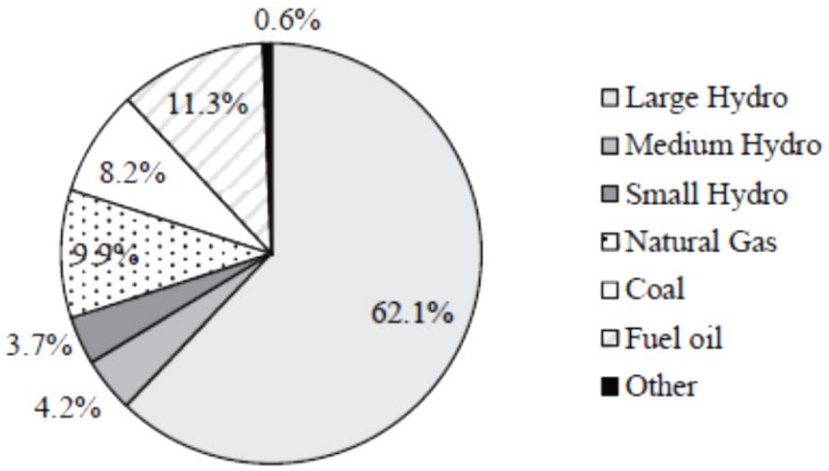

Figure 1: Composition of installed power generation capacity in Colombia in 2015 (Arias-Gaviria et al., 2017)

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) as can be seen in Figure 2.

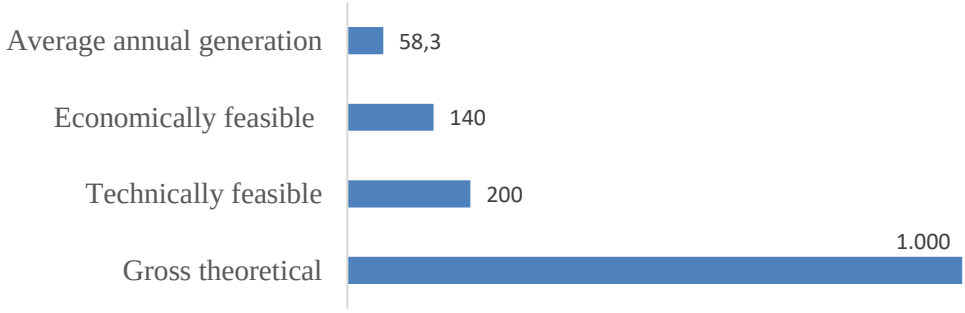

Figure 2: Hydropower potential in TWh/year in Colombia (H&D, 2019)

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 3.

Figure 3: 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 4 (Arias-Gaviria et al. 2017).

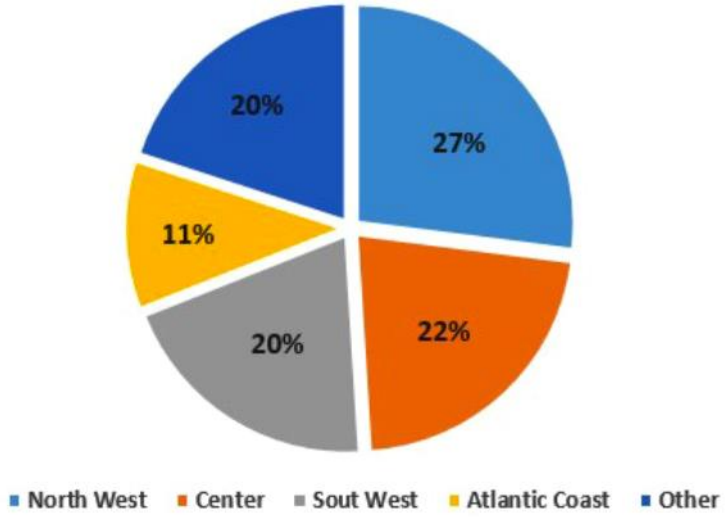

Figure 4: Breakdown of distribution of potential for small hydropower plants by geographic regions in Colombia (based on data of UPME)

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 1).

Table 1: 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 2.

Table 2: 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 3.

Table 3: 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 interconnected network, exploitation of construction materials, use of water, water concessions, dumping permits.
Number 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 4.

Table 4: Main companies in the generation of electricity in Colombia (UPME, 2018a)

Company	Installed capacity [MW]	Share
Emgesa S.A. E.S.P.	3,526.0	19.90 %
Empresas Públicas de Medellín E.S.P.	3,468.2	19.57 %
Isagen S.A. E.S.P.	2,988.9	16.87 %
Empresa De Energía Del Pacífico 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 Energía del Caribe S.A. E.S.P.	723.0	4.08 %
Zona Franca Celsia S.A. E.S.P.	610.0	3.44 %
Empresa Urrá S.A. E.S.P.	338.0	1.91 %
Gestion Energética 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.	233.8	1.32 %
Other	1,718.5	9.70 %
TOTAL	17,720.5	100 %

Electric power companies are classified and registered according to four major fields of the power sector, as shown in Table 5 for the period of 2016 to 2018. A single company can be involved in several major fields and registered accordingly.

Table 5: 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 6).

Table 6: 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 7.

Table 7: 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 energy sales)	10		6

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 8. They do not differ a lot from a common small hydropower practice.

Table 8: 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 in Interconnected Rural Areas (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 self-producers (in Colombia referred to as autogeneradores) 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, self-producers may deliver electricity to the national network in accordance with the regulation established by the Energy and Gas Regulation Commission (CREG). Large-scale self-producers 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-producers 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 9.

Table 9: 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 insensitive 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.

Hydropower subject is included in many universities study programs (Table 10). However, there is an urgent need for practical operation and training in SHP.

Table 10: 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 Mining and Energy 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 Science Direct 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:

- Legal, environmental and regulatory frameworks, focused on traditional expansion model based on large power stations and high voltage interconnection lines, imposing complex, expensive and unnecessary requirements on SHP projects;
- Lack of financial resources and credit opportunities;
- Lack of manufacturing capacity for SHP components;
- Lack of SHP specific expertise;
- Poor capacity building facilities and programs for design and construction of SHP plants and associated works.

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).

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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