Hydropower Solutions

HYPOSO

Hydropower solutions for developing and emerging countries

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

by Mauricio Villazón and Andres Gonzales, UMSS, Bolivia

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

# Table of Contents

Figures ..... 3
Tables ..... 3
Bolivia ..... 4
1 Key facts ..... 4
1.1 Climate ..... 4
1.2 Topography ..... 4
1.3 Water resources ..... 5
1.4 Power sector overview ..... 5
2 Renewable electricity policy ..... 6
3 Hydropower sector and potential ..... 7
4 SHP policy and market analysis ..... 10
4.1 SHP policy ..... 10
4.2 Industrial overview ..... 14
4.3 SHP economics overview ..... 15
5 Educational framework ..... 16
6 Research situation and needs ..... 19
6.1 R&D projects ..... 19
6.2 Research needs ..... 20
7 SHP financing opportunities ..... 20
8 Environment ..... 22
9 Barriers to SHP development ..... 22
10 Future prospects ..... 23
10.1 Large Hydro ..... 23
10.2 Small hydro ..... 23
11 References ..... 24

## Figures

*Figure 1: Annual electricity generation by source in Bolivia (MW) in December 2019 (CNDC, 2020)* ..... 6
*Figure 2: Hydropower potential in GWh/year in Bolivia (HP&D, 2019)* ..... 7
*Figure 3: Operational hydropower plants in Bolivia as sorted by their installed capacity* ..... 8

## Tables

*Table 1:Bolivia - Small hydro (< 10 MW) characteristics according to different sources* ..... 9
*Table 2: Bolivia - Key legal documents regulating RES and hydropower* ..... 11
*Table 3: Regimes for granting rights (concessions or authorisations) to use hydropower in Bolivia* ..... 14
*Table 4:Bolivia - Overview of companies acting in small hydro sector* ..... 15
*Table 5: Bolivia - Key economic estimates for hydropower* ..... 15
*Table 6: Bolivia - Support schemes for hydropower* ..... 16
*Table 7: Bolivia - List of universities* ..... 17
*Table 8: Bolivia - Identified needs for improving knowledge level at hydropower sector* ..... 18
*Table 9: Bolivia - List of R&D topics, their number and key words (based on the conducted survey)* ..... 19
*Table 10: Local financing institution acting in Bolivia* ..... 21

# 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 km², covering 66 % of Bolivia's territory;
- the endorheic basin or Titicaca Lake basin, which with surface area of 145,081 km² or 13 % of the territory; and
- the South or Río Plata Basin, which covers 229,500 km² 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$^2$).

## 1.4 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.

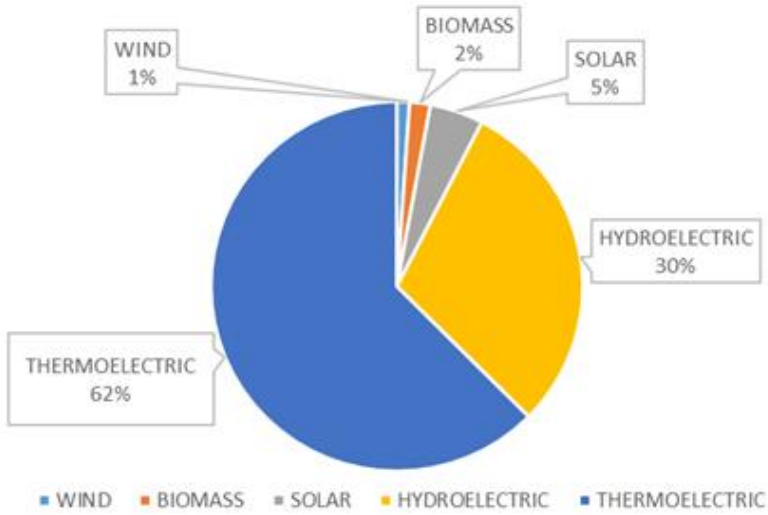


*Figure 1: Annual electricity generation by source in Bolivia (MW) in December 2019 (CNDC, 2020)*

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.

## 2 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.

# 3 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.

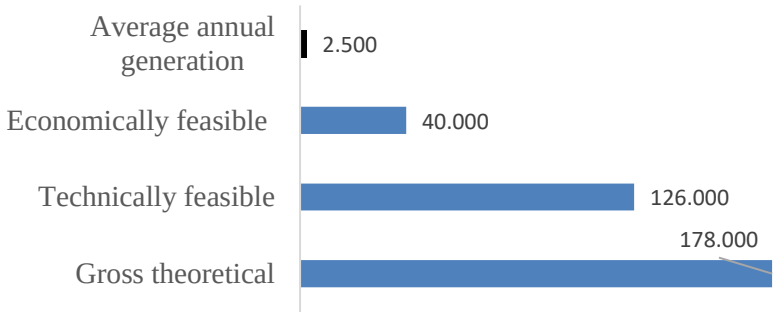


*Figure 2: Hydropower potential in GWh/year in Bolivia (HP&D, 2019)*

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).

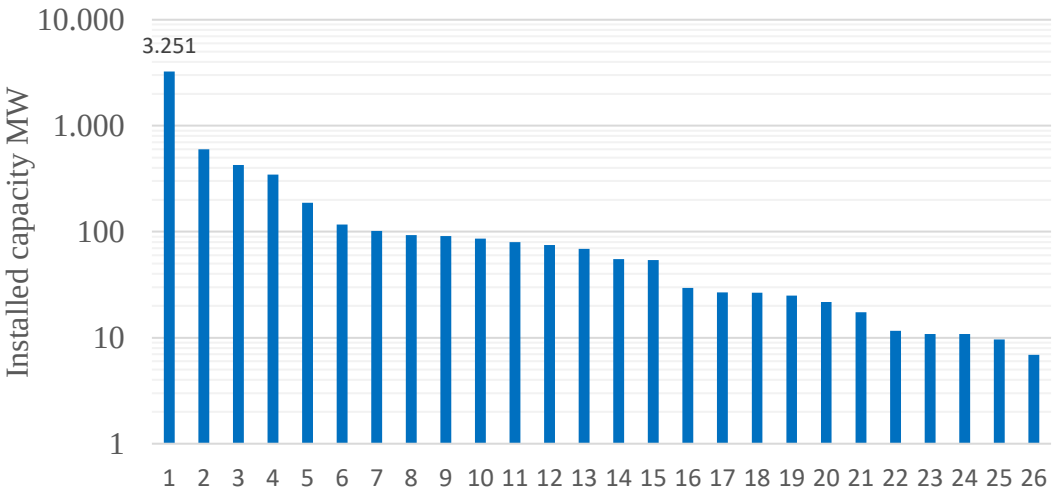


*Figure 3: Operational hydropower plants in Bolivia as sorted by their installed capacity*

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.

# 4 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).

## 4.1 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.<br>- Concessions, licenses and provisional licenses<br>- 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) | Environmental | http://www.silep.gob.bo/ | Prevents hydropower development, especially large one.<br>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)<br><br>3 plants (from 201 to 400 MW) |

## 4.2 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 (< 10 MW) |
|---|---|---|
| 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.

## 4.3 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.<br>• Exemption of taxes for importing equipment and construction<br>• Subsides form the government<br>• Guaranteed electricity purchase<br>• 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. |

# 5 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<br>2 Transportation and energy distribution | 1 Energy and environment<br>2 Planning energy<br>3 Energy and sustainable development |
| | | Undergraduate: Civil engineering | | 1 Hydraulics<br>2 Hydrology<br>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<br>2 Fluid mechanics |
| | | Undergraduate: Civil engineering | | 1 Hydrology<br>2 Hydraulics<br>3 Hydraulic works<br>4 Environmental Engineering |
| 3 | Universidad Privada Boliviana (UPB) | Undergraduate: Civil engineering | Fundamentals of Electrical Engineering | 1 Hydrology<br>2 Hydraulics<br>3 Hydraulic works<br>4 Environmental Engineering |
| | | Undergraduate: Electromechanical engineering | | |
| 4 | Universidad Mayor de San Simón (UMSS) | Undergraduate: Electro mechanic Engineering | | 1 Hydraulic and Pneumatic Machines<br>2 Fluid mechanics |
| | | Undergraduate: Civil engineering | | 1 Hydrology<br>2 Hydraulics<br>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<br>2 Hydraulics<br>3 Hydraulic works<br>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<br>2 Applied Technologies in Conventional Energies and their Industrialization |
| | | Undergraduate: Electromechanical engineering | Hydropower plants | 1 Hydraulic machines<br>2 Fluid mechanics |
| | | Undergraduate: Civil engineering | Micro power plants | 1 Hydrology<br>2 Hydraulics<br>3 Hydraulic works<br>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 |

# 6 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.

## 6.1 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 |

### 6.2 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.

## 7 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).

# 8 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.

# 9 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

# 10 Future prospects

## 10.1 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)

## 10.2 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.

# 11 References

CNDC (2020) Capacidad Efectiva a Diciembre 2019 (Effective Capacity of Bolivia December 2019). Comité Nacional de Despacho de Carga. https://www.cndc.bo/. (Accessed 28 February 2020).

Drinkwaard W., Kirkels A., Romijn H. (2010). A learning-based approach to understanding success in rural electrification: Insights from Micro Hydro projects in Bolivia. Energy for Sustainable Development 14, 232-237.

Drinkwaard, W.S. (2009). The diffusion of micro-hydro power for rural electrification in Bolivia. A learning approach. Master thesis. 2009. Eindhoven University of Technology

HYPOSO D3.1. (2019). Contact list of hydropower stakeholders and multipliers in five targets countries.

IHA (The International Hydropower Association). 2019 Hydropower Status Report. Sector trends and insights.

Ministerio de Energias. Memoria Anual 2016. Comité Nacional de Despacho de Carga (CNDC). https://www.cndc.bo/home/index.php (Accessed 28 February 2020)

HP&D (The International Journal on Hydropower & Dams). (2019). World Atlas & Industry Guide. Aqua-Media Int. UK.

IRENA (The International Renewable Energy Agency).(2015). Renewable Energy Policy Brief. BOLIVIA: http://online.anyflip.com/ilfg/wyhi/mobile/index.html (Accessed 28 February 2020).

Universities in Bolivia: https://www.scholaro.com/u/Countries/bolivia/Universities (Accessed 28 February 2020).

Vargas, L., Jimenez-Estevez, G., Diaz, M., Calfucoy, P., Barrera, M., Barría, F., Kindermann, J.P., (2018). Comparative Analysis of Institutional and Technical Conditions Relevant for the Integration of Renewable Energy in South America.

Velpuri NM, Pervez Md., S., Cushing W., M. (2016). Hydropower Assessment of Bolivia—A Multisource Satellite Data and Hydrologic Modeling Approach. Prepared in cooperation with the CAF – Development Bank of Latin America. Open-File Report 2016–1156 U.S.

WSHDR (World Small Hydropower Development Report) (2019). Liu, D., Kiu, H., Wang, X., Kremere, E., eds. United Nations Industrial Development Organization; International Center on Small Hydro Power. www. smallhydroworld.org (Accessed 28 February 2020).