The increasing importance of hydropower in Bolivia's electricity sector

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The authors reflect on the huge potential for further hydropower development in Bolivia, but also point out capacity building needs which are tending to limit the full exploitation of this valuable resource. Some key recommendations are made in this respect. The study forming the basis of this article is part of the EU-supported HYPOSO initiative (see Box on p61).

As a result of its topography and abundant water resources, Bolivia has great potential for generating sufficient electricity to cover its national demand. However, a lack of information, studies, projects and investment has led to only partial national coverage of electricity. The Bolivian grid is formed of the National Interconnected System (SIN) and isolated systems. Together they provide national coverage of 93 per cent; in the urban regions it is 99 per cent, and in rural area it is 80 per cent. The installed capacity comprises non-renewable thermal energy (67 per cent) and renewable energy (42 per cent). Renewable energy is produced from various sources: hydropower contributes 24.9 per cent, solar 2.6 per cent, wind 27.10 per cent and thermal sources 4.6 per cent.

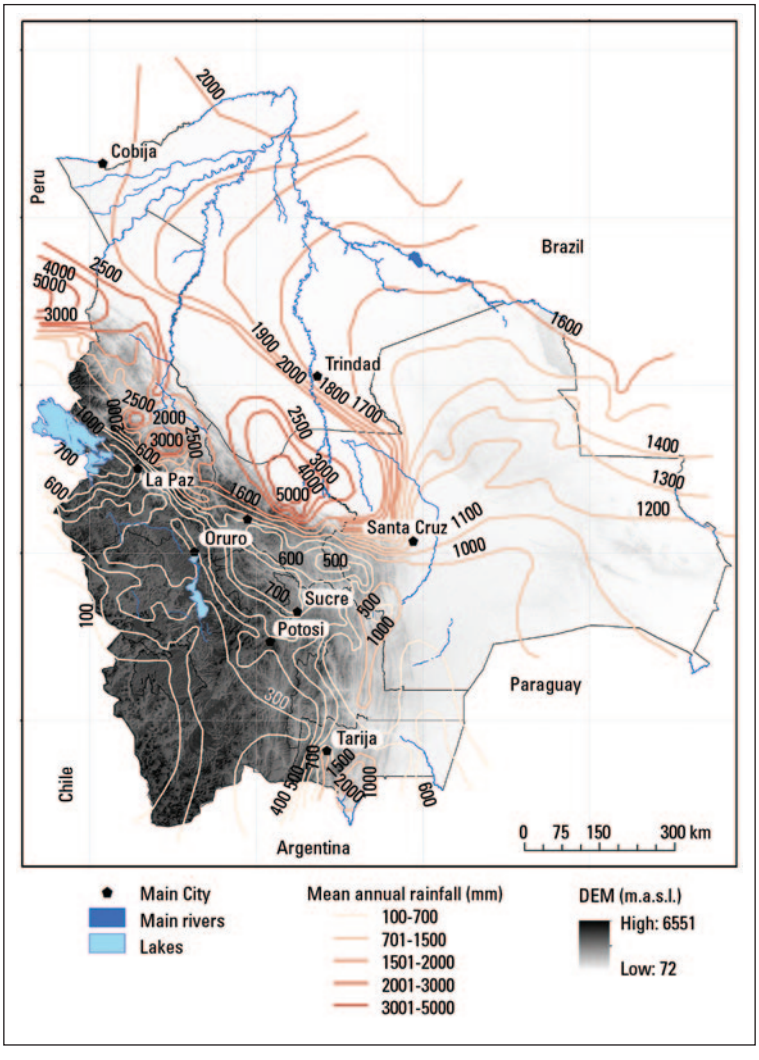

Fig. 1. The mean annual rainfall and main rivers Bolivia. It can be seen that the elevation of the terrain in the country varies significantly from els.72 to 6551.

In the last two decades, production from hydropower plants has increased by 48 per cent. In 2009, hydro capacity stood at 496 MW with production of 2264 GWh. Ten years on, in 2019, the National Committee of Energy Distribution reported a capacity of 735 MW generated by the Taquesi, Kanata, Corani, Yura, Miguilla, Zongo, Quehata, San Jacinto and Misicuni hydro plants, which are operated by eight companies, some national entities and others private companies. The theoretical hydropower potential in Bolivia is estimated to be around 178 000 GWh/year. However, to the date the hydropower plants in Bolivia generate about 2546 GWh, which means that less than 2 per cent of the theoretical potential has been developed so far. Most of this theoretical potential can be generated in the northeast of Bolivia.

Small-scale hydro plants have been successfully developed in Bolivia, especially in isolated rural areas in the northern part of La Paz. However, the lack of clear national policies and rules, as well as low energy prices, have limited the full development of hydro projects in the country. Applied research is also limited, as there are only two universities that have research departments dealing with hydropower (the hydraulic laboratory at UMSS, and the Institute of Hydraulics and Hydrology at UMSA). It is important for the future to improve the involvement of international companies in Bolivia which can offer training, equipment and materials for further development of hydropower projects.

1. Background

Bolivia is a developing country that still needs to develop strategic economic and industrial activities to strengthen its national economy. The main activity contributing to the economy is the export of oil and gas. However, in the recent years, globally, the oil and gas industry suffered a number of problems (such as a decrease in prices), which directly caused a shrinking of the economy in Bolivia. In addition, the gas reserves in Bolivia are close to being depleted, and the outcomes of exploration for the future were not encouraging. As a result, the Government wants to strength the exploitation of natural resources in Bolivia, including by the construction and development of several medium and large hydropower plants. These new schemes will be a key aspect in allowing Bolivia to becoming an exporter of renewable electric-

ity in the near future. The geographic and climatic conditions in the country are idea for this.

Bolivia has three main physiographic areas:

- to the west, the dominating feature is the Andes range, which is characterized by arid climate;
- to the east, the Amazon basin extends across about 70 per cent of Bolivian territory; and,
- in between are the sub-Andean valleys, forming a transition zone between the Andes and the Amazon.

Most of the available surface water is towards the northeast (see Fig. 1), however the majority of the main cities of Bolivia are in the sub-Andean and Andean regions where rivers are less abundant. However, most of the sub-Andean region are located in steep terrain, and therefore this region could be of interest for the development of small hydropower plants. On the other hand, the Amazon basin in Bolivia has several rivers with average flows greater than 5000 m^3/s. Hence the development of medium to large hydro schemes are of great interest in this region. The average elevation along the Andean region is between 3750 and 4000. Within the sub-Andean zone, the average elevation is 2500. In the Amazon, region the elevations range between 400 and 90.

The overall aim of this paper is to summarize various aspects and activities related to the hydropower sector in Bolivia associated with the HYPOSO (Hydropower solutions for developing and emerging countries) project.

2. Hydrological overview

It is quite common in Bolivia to find basins with poor monitoring or gauging systems, but the Ministry of Environment and Water of Bolivia, together with the Stockholm Environment Institute (Sweden) and Hydraulics Lab (Universidad Mayor de San Simon in Bolivia) together elaborated a National Water Balance. The results of this study have been very significant because it is now possible to access to data, such as precipitation, evaporation (actual and potential), runoff, specific discharge, and the various climate change scenarios. The availability of this information is very significant for conducting evaluations of potential hydropower sites in Bolivia.

The average national precipitation is 640 mm, but there are some regions with precipitation rates greater than 5000 mm, and other regions with rates lower than 100 mm (see Fig. 3a). In general, the precipitation pattern is not uniform either in time or in space, and as a result there are many urban centres with a water deficit, especially in the western part of the country. The runoff is more uniform. To the west and south, the runoff rates are lower, while in the eastern regions they are greater. In the western regions, although there is less rainfall, the varying and steep topography offers good conditions for constructing small and micro hydropower plants.

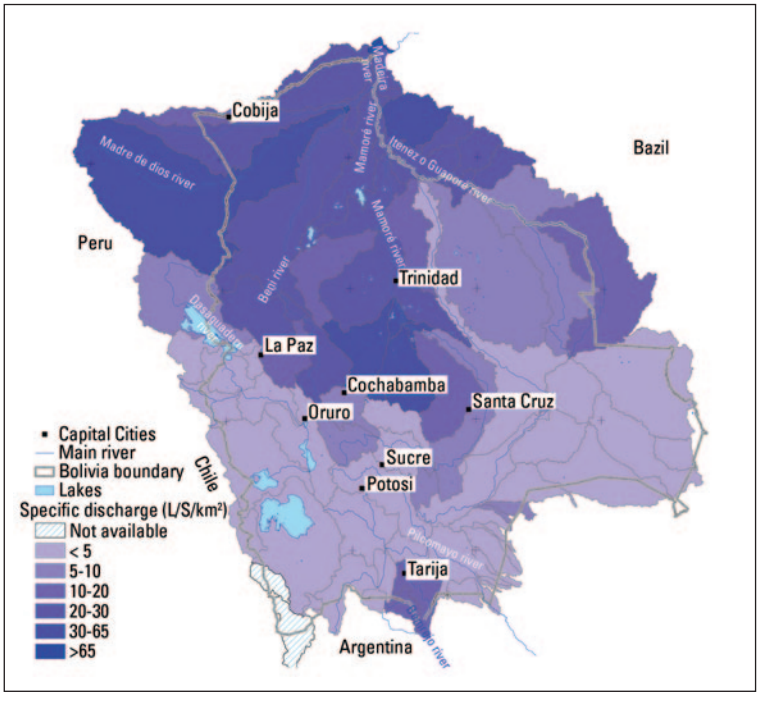

Fig. 2. The specific discharge of Bolivia, Modified from MMAyA [2018[3]].

3. Hydropower and industry overview

Despite the great hydropower potential of Bolivia, the major share of electricity is contributed by non-renewable resources such as natural gas combustion turbines. Now-renewable covers about 62 per cent of the national production, with a capacity of around 1538 MW. The hydropower sector covers about 30 per cent of the national production, from an installed capacity

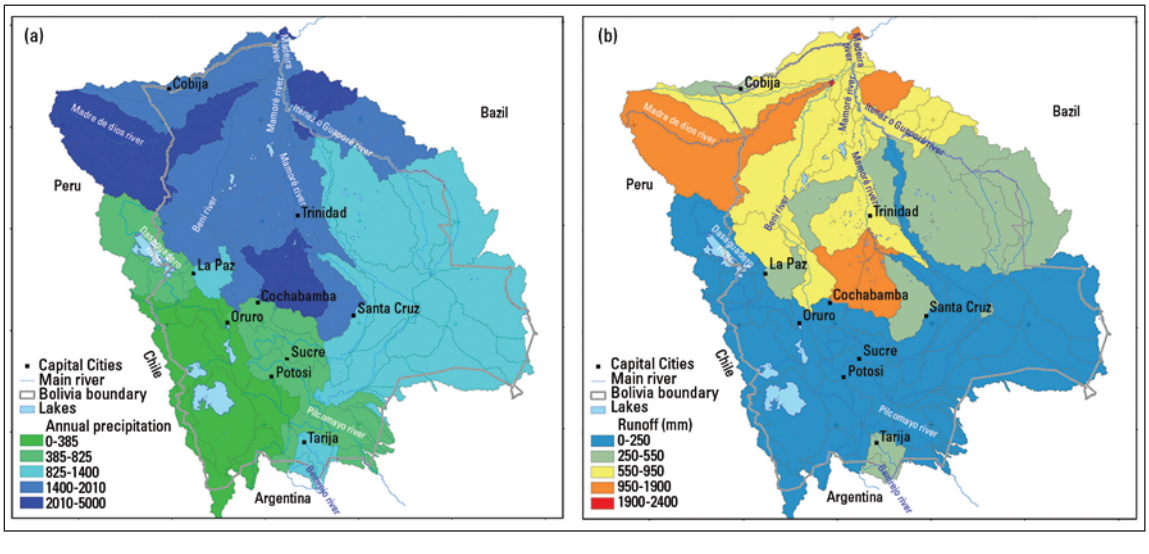

Fig. 3(a). The mean runoff; and, (b) annual precipitation of Bolivia, respectively. Modified from MMAyA [2018[3]].

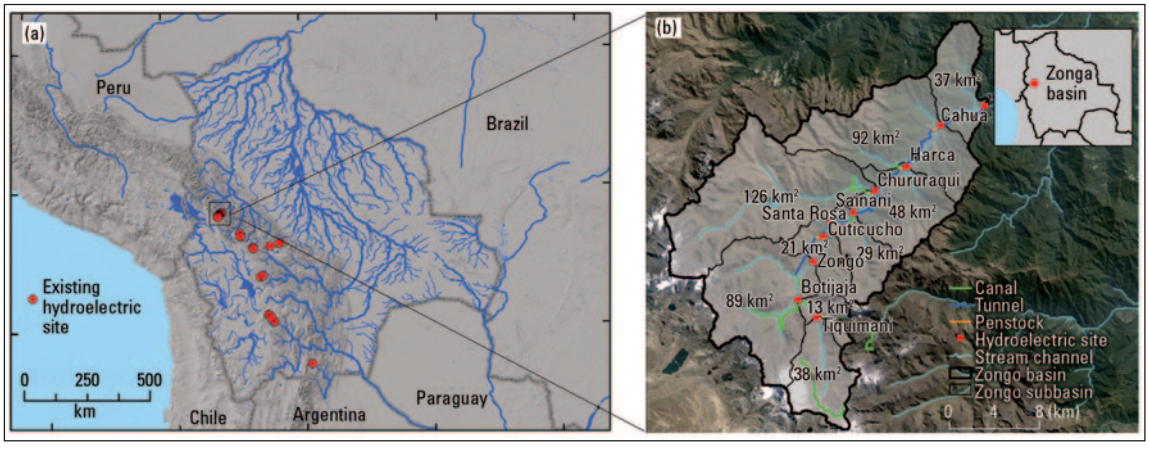

Fig. 4(a). The existing hydropower plants in Bolivia; and, (b) the Zongo cascade system, composed of small hydropower plants (located towards the north of La Paz city). Modified from Velpuri et al, [2016[4]].

of around 734 MW. Smalls contributions are made from geothermal and wind sources, which covers about 8 per cent of national production [Punys *et al*, 2020[1]].

The theoretical hydropower potential in Bolivia is estimated to be around 178 000 GWh/year. However, to the date the hydropower plants in Bolivia only generate about 2500 GWh, which means that less than 2 per cent of the theoretical potential has been developed so far.

The hydropower sector in Bolivia is mainly represented by medium and large plants. In 2019 about 26 hydropower plants were in operation (Fig. 4a), with a total generation of 5289 MW. It is estimated that the investment cost for electricity generation is US$2800/kW, categorizing it as high investment compared with conventional technologies (natural gas and diesel), but with lower operating costs [ESMAP, 2012[2]].

Small and micro hydropower plants are mainly built in isolated and dispersed rural areas. Most of the isolated rural areas are far from the national grid, so electricity generation from small/micro hydropower plants is the most efficient energy solution for these areas. Bolivian small hydropower plants are up to 5 MW, however within the HYPOSO project, the standard definition is up to 10 MW. The classification of hydro plants sizes is as follows:

- Micro: < 500 kW
- Small: 500 kW to 5 MW
- Medium: 5 to 30 MW

Although most hydro plants throughout the country are classified as medium or large, there are some regions with predominantly small and/or micro plants. The mining industry was the first sector to use micro hydro, to supply energy for their camps and associated activities. In the middle of the last century, larger systems of small hydropower plants were built in the sub-Andean regions of La Paz (for example the Zongo and Miguillas systems), see Fig. 4b.

As mentioned earlier, the national government plans to develop and boost the hydroelectric sector; the strategic plan includes hydropower projects of approximately 30 MW which will be connected to the national grid. Hydropower plants with capacities of less than 20 MW will be planned for isolated networks. Identification of new small and micro hydropower plants is currently in progress.

To the authors' knowledge there are about 10 active companies in the medium/small hydropower sector in Bolivia [Punys *et al*, 2020[1]]. This small number of companies limits the development of projects in the hydropower sector. There needs to be a wider range of companies (for example in the equipment manufacturing sector) which can offer not only products but also training for example relating to small turbines, penstocks, electrical components and other equipment required for hydro projects.

4. Research needs in the hydropower sector

As mentioned, there are relatively few companies specializing in hydropower. For example, the Bolivian company Ingelec operated for many years specializing in construction, equipment, and the installation of transmission/distribution lines for hydro and thermal plants. However, this company ceased operating, mainly because there were not enough specialized personnel in the country. This example reflects the current situation in Bolivia in the hydropower sector, where there are needs for research, the training of personnel and investment of resources.

Concerning training and research, there are only two academic institutions which are involved to some extent in the hydropower sector:

- Laboratorio de Hidraulica (Hydraulics Laboratory) is a research unit at the Universidad Mayor de San Simon (Cochabamba). They have wide experience in numerical modelling of river flow and hydropower operation gained over more than 30 years. They also have experience in constructing scale models of hydropower plants to study operational aspects.
- Instituto de Hidraulica e Hidrologia (Institute for Hydraulics and Hydrology) is a research unit at the Universidad Mayor de San Andres (La Paz). They have experience in micro hydro technology and have been conducting research in this field for more than 30 years.

The report of HYPOSO [Punys *et al*, 2020[1]] identified about 19 research and development projects relating to the hydropower sector. These were conducted between 2011 and 2019. Five of them relate to large hydropower plants. The majority were developed by universities. No new or fundamental research had been developed, so all the identified projects were study cases, with well known methodologies being applied. The HYPOSO project has created a list of possible research topics to be developed as priorities in the near future:

- Studies on hydrology, including the analysis of short- and long-term climate change effects.

• Assessment of (multipurpose) projects for consideration by the hydroelectric industry.
• Evaluation of the current state of micro and small hydropower plants, including an assessment of their operational and efficiency.
• Studies to increase overall efficiency of hydroelectric power.
• Studies of new technologies that allow for the maintenance of the facilities with minimal outages.
• Improvement in home electrical connection systems in the rural areas.
• Hydropower socio-environmental and economic impact studies.

As regards small hydro plants, there are some limitations that constrain studies, and research and development of projects. The most important factor is that the national government prioritizes the development of large hydropower schemes particularly in the Amazon basin, close to the border with Brazil. Also, some policies, rules and conditions (for example, low energy prices) for implementing renewable energy projects are not clear or attractive for investors.

5. Conclusions

Bolivia has great potential for generating electricity through hydropower development (with either micro, small, medium or large schemes). The country's topography and water resources are strategic assets which are ideal for identifying suitable locations for hydropower plants. Despite this potential, there are several issues to be solved or mitigated before full development of this sector can be achieved.

There are restrictions concerning access to data, especially hydrological data, but now the national surface water balance established in 2018 is a good source of data. Another issue is that it is necessary to encourage links between private companies (for example equipment manufacturers and distributors within the hydropower sector) and local institutions (the national government, universities and local companies), since there are very few companies in Bolivia offering services or equipment for hydro projects. Finally, the organizational structures and mechanisms for financing need to be improved, to encourage the development of hydropower projects. ◊

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About HYPOSO

The overall objective of the HYPOSO project is to support the market uptake of European hydropower technologies to foster more clean and reliable energy in selected target countries in Africa (namely in Cameroon and Uganda) and Latin America (namely in Bolivia, Colombia, and Ecuador). It is expected that beside the promotion of the European hydropower industry in the developing and emerging regions the realisation of the HYPOSO objectives will pave the way for better investment conditions (legal, political, financial, social) in target regions and increase the share of renewable energy there, especially small and medium-sized hydropower by helping relevant governments, authorities and local stakeholders to create better framework conditions for renewables (eg, faster permits and shorter planning periods, energy cooperatives and communities, easier and faster funding, etc).
This article summarizes the main findings on the analysis for Bolivia. A report on all five countries can be found at:
www.hyposo.eu

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