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Research article

Itaipu royalties: The role of the hydroelectric sector in water resource management

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ABSTRACT

For countries dependent on hydroelectricity, water scarcity poses a real risk. Hydroelectric plants are among the most vulnerable enterprises to climate change. Investing in the conservation of the hydrographic basin is a solution found by the hydropower sector. Given the importance of the Itaipu plant to the energy matrix of Brazil and Paraguay, the aim of this study is to review the current distribution of royalties from Itaipu, using the hydrographic basin as a of criterion of analysis. Approximately 98.73% of the Itaipu basin is in Brazil. The flow contributes 99% of the total electricity generated there, while the drop height of the water contributes only 1%. Under the current policy, royalties are shared equally between Brazil and Paraguay. In the proposed approach, each country would receive a percentage for their participation in the drop height and water flow in the output of the turbines, which are intrinsic factors for electricity generation. Thus, Brazil would receive 98.35% of the royalties and Paraguay, 1.65%. The inclusion of the hydrographic basin as a criterion for the distribution of royalties will promote more efficient water resource management, since the payment will be distributed throughout the basin of the plant. The methodology can be applied to hydroelectric projects worldwide.

1. Introduction

Latin America's extensive river systems and their hydraulic potential have resulted in this region having a significant share of hydroelectricity in its energy matrix with large binational hydroelectric projects such as Itaipu, Salto Grande, and Yacyretá (WWAP, 2015). Hence, hydroelectricity accounts for about 68% of the electricity generated in Brazil (ANEEL, 2015) and 99.99%, in Paraguay (ANDE, 2015).

Although hydroelectric plants are highlighted as a source of sustainable, renewable energy (Azofra et al., 2015; Fu et al., 2014; Stickler et al., 2013), the supply of water for various uses has become a critical issue in most nations owing to water scarcity and increasing conflicts between users of water resources (Habersack et al., 2016; Kadigi et al., 2008; Maran et al., 2014; WWAP, 2015). These conflicts are particularly common in areas with hydroelectric plants, since these enterprises depend on a minimum flow rate upstream of the plant to meet a certain demand for energy (Fanaian

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et al., 2015; Kadigi et al., 2008; Premalatha et al., 2014).

It is estimated that climate change will affect the future of global hydroelectricity (Gaudard and Romerio, 2014; Hamududu and Killimgtveit, 2012; Maran et al., 2014; Volpi et al., 2006). Aronica and Bonaccorso (2013) note that hydroelectric plants are among the enterprises most vulnerable to climate change. However, change in rainfall, higher temperatures, and increases in extreme weather, are only part of the story (Gaudard and Romerio, 2014; Hamududu and Killimgtveit, 2012; Mereu et al., 2016). According to Côrtes et al. (2015) and Mereu et al. (2016) the reduced availability of water is also a reflection of population and urban growth, land use, and the lack of planning and management of water resources.

Because of human impacts and impacts from climate change on water resources, there is increasing global concern about the need to conserve water (Kadigi et al., 2008). In Latin America, payment for environmental services (PES) is a tool increasingly used by governments and private agencies in the management of water resources (Rodríguez-de-Francisco and Budds, 2015). Regularizing the flow, erosion control, and water infiltration into the soil and improving water quality are just a few services resulting from good management of a watershed (Blackman and Woodward, 2010; Fanaian et al., 2015; Lu and He, 2014; Stickler et al., 2013; Tuinstra and Wensem, 2014).

Therefore, many power companies have sought solutions to the water crisis by investing in the conservation of the hydrographic basin upstream of their plants to ensure the flow of water on which they depend (Blackman and Woodward, 2010; Rodríguez-de-Francisco and Budds, 2015). Monetary investments are made in many ways, such as royalties, environmental management funds or special taxes (Skinner, 2015). In Colombia, for example, a legal instrument addresses part of energy sales to municipalities that are part of the catchment area of the reservoir. Other countries like China (Fu et al., 2014), Mexico (Pagiola et al., 2005), Nepal (Upadhyaya, 2005) and Norway (Skinner, 2015) also have financial mechanisms for preserve the hydrographic basin of its hydroelectric plants. Engel et al. (2008) argue that electricity sector PES programs are likely to be effective, because the recipients of the environmental service benefits are directly involved, and thus, there is a clear incentive to ensure that the mechanism functions well.

Brazil and Paraguay are highly dependent on hydroelectricity. Itaipu provides 17% and 75% of the energy consumed in Brazil and Paraguay respectively (ANEEL, 2015). This leaves their energy sector vulnerable to blackouts, as occurred in Brazil in earlier years. Originally, the hydrographic basin from Itaipu was all covered by Atlantic Forest and Cerrado biomes. However, the growth of urban centers and deforestation for agricultural and livestock areas, generated a lot of pressure on the environment (Watanabe et al., 2012; Itaipu Binacional, 2015). Today the basin has only some fragments of its original biomes.

According to a survey conducted by Stickler et al. (2013), deforestation on a regional scale can dramatically reduce precipitation and prolong the dry season locally and forest loss also reduces the water flow of the rivers, which restricts the generation of electricity and affects the expansion of hydroelectric power. Evidence of the relationship between precipitation and forest cover was also found by other authors (Hasler et al., 2009; Knox et al., 2011; Malhi et al., 2008; Werth and Avissar, 2005).

Global demand for energy is expected to grow by more than a third by 2035 (WWAP, 2015). This will generate more pressure on water resources, thus increasing conflicts over use. Resource management policies are fundamental for the allocation of multiple uses of water and the conservation of water resources. Given the importance of the Itaipu hydroelectric plant to the energy matrix of Brazil and Paraguay, this study proposes a methodology for the sharing of royalties from Itaipu, using the hydrographic basin as a unit of spatial analysis.

2. Materials and methods

2.1. Study area

The Itaipu hydroelectric plant is located in the Parana river basin on the border of Brazil and Paraguay (Fig. 1). With 20 generating units and 14,000 MW of installed capacity, it provides about 17% of the energy consumed in Brazil and 75% of the energy consumed in Paraguay (ANEEL, 2015). The Itaipu hydroelectric plant has a drop height of 118.4 m (difference between standard maximum level of the reservoir and the level of the tailrace). The mean annual precipitation in the hydrographic basin is 1400 mm. The maximum, minimum and average flow recorded in Itaipu are, respectively, 39,790 m^3 s^{-1}, 6082 m^3 s^{-1} and 11,663 m^3 s^{-1}. Although the reservoir of Itaipu flood an area of 1350 km^2, with 770 km^2 in Brazil and 580 km^2 in Paraguayan territory, Itaipu is a run-of-the-river hydroelectric plant, which means, the reservoir does not store water in order to generate electricity. (Itaipu Binacional, 2015).

On April 26, 1973, it was signed the Itaipu Treaty between Brazil and Paraguay. In the Treaty, it was decided that each country would receive 50% of the total energy produced, with recognized priority purchase in case of not utilized energy by any part. The plant's construction was funded entirely by Brazil, thus, it was agreed the reduction of debt Paraguay on payments made by Brazil in buying of surplus energy not used by Paraguay (Arce, 2010; Itaipu Binacional, 2008).

Through the generation of electricity, Itaipu paid royalties to Brazil and Paraguay for the exploitation of water resources of the Paraná river. The payment of royalties is laid down in Annex C of the Itaipu Treaty, in which it was established that the royalties would be paid equally to the participating countries. Brazil and Paraguay have already received more than US$ 4.5 billion (Itaipu Binacional, 2015) since Itaipu started trading energy in March 1985. The value of the royalties is calculated according to Eq. (1).

$$Roy_i = EG_i \times VE \times K \times TC \quad (1)$$

where Roy_i corresponds to royalties for the month i; EG_i is the energy generated (GWh) in Itaipu in the month i; VE is the value of gigawatt-hour, defined at US$ 650 by the Itaipu Treaty; K is the adjustment factor of the megawatt-hour value; and TC is the current exchange rate on the day of the royalties payment.

2.2. Data processing

In this study, we used the following information layers: Digital elevation model Shuttle Radar Topography Mission (SRTM) version 3.0, with cell size of 30 m; a mean monthly precipitation data file, made available by the international organization Worldclim (obtained to a period of at least 10 years) and Xavier et al. (2015) (obtained for the period 1980–2013), with approximate cell size of 1000 m and 28,000 m, respectively; annual evapotranspiration data (MODIS), provided by the National Aeronautics and Space Administration (NASA); a vector file with the political divide in South America; and a vector file with the geographic location of the Itaipu dam.

The boundary of the hydrographic basin of the Itaipu plant was derived from the SRTM database. To ensure proper delimitation of the basin, a set of 244 grid cells from SRTM were selected, with intervals 15° S 1° S and 40° W to 60° W. The 244 grid cells from the SRTM were combined into a single set of data, resulting in a